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Design, Construction Supervision and Baseline Monitoring of Trial Sections on Low Volume Roads in Zambia

Experimental Design and Research Matrix Report

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Acronyms

AfCAP	Africa Community Access Partnership
AfDB	African Development Bank
CBR	California Bearing Ratio
CMA	Cold mix asphalt
DCP	Dynamic Cone Penetrometer
DESA	Daily Equivalent Standard Axles
DN	DCP Number (mm/blow)
DSD	Double surface dressing
FWD	Falling weight deflectometer
LCCA	Life cycle cost analysis
LWD	Lightweight deflectometer
RDA	Road Development Authority
RMC	Relative Moisture Content
UKAid	United Kingdom Aid (Department for International Development, UK)

Contents

Executive Summary

A project for the "Design, Construction Supervision and Baseline Monitoring of Trial Sections on Low Volume Roads in Zambia" is being carried out under the Africa Community Access Partnership (AfCAP) programme. The traditional approach to providing unpaved surfaces on such roads, particularly those carrying higher traffic levels, is un-sustainable in the long-term and consumes vast quantities of non-renewable natural gravel resources.

The success of Zambia's programme of sealing rural roads will depend on the adoption of pavement design standards, materials specifications and construction techniques that are appropriate to low volume roads (LVRs). Currently, such standards do not exist in Zambia and this AfCAP project, which will draw on the outputs of other AfCAP projects carried out in the region, is expected to provide technical solutions that will reduce the life cycle cost of providing rural roads yet ensure an appropriate level of service.

The main purpose of the project is thus to:

- Design a LVR pavement as a Trial Section(s) based on the DCP-DN method.
- Construct the Trial Sections to a sealed standard using an appropriate seal type.
- Establish a programme of long-term pavement performance monitoring.
- Collect and analyse baseline data.
- Ultimately, provide inputs for the development of a new pavement design manual for low volume roads in Zambia.

During the Project Inception stage, the road T2 – Waitwika – D1 in Nakonde District of Muchinga Province was identified as the most suitable location for construction of two 500 m Trial Sections.

This report describes the "experimental design" and the development of the research matrix based on the sampling and testing of in situ and locally available materials and the construction and monitoring requirements related to the implementation of two Trial sections that have been designed using the DCP DN method and incorporating three types of bituminous surfacing.

A life-cycle cost analysis of these sections compared with the traditional unpaved roads in the area will be carried out. In addition, the performance of the DCP DN designed road, the performance of what would normally be considered unsuitable base course materials and the performance of three different bituminous seals will be assessed.

It is anticipated that the outputs of the project will ultimately be used to improve local design practices for rural access roads and allow the greater provision of appropriately designed paved roads instead of the traditional, unsustainable unpaved roads, which require significant maintenance and provide poor riding quality and dusty conditions.

1 Introduction

1.1 Background

Within the context of enabling provision of more rural roads in an environmentally optimised and sustainable manner, the UK Department for International Development (DFID), through the Africa Community Access Partnership (AfCAP) has provided resources to further the state of knowledge with regard to the provision of low volume sealed roads (LVSRs) in Zambia. This is being achieved through financing of a project for the "Design, Construction Supervision and Baseline Monitoring of Trial Sections on Low Volume Roads in Zambia". The traditional approach to providing unpaved roads in such areas is un-sustainable and consumes vast quantities of non-renewable natural gravel resources – thus, an alternative approach is urgently required.

The success of Zambia's programme of sealing rural roads will depend on the adoption of pavement design standards, materials specifications and construction techniques that are appropriate to LVRs. Although such standards exist for several sub-Saharan African countries, many of them, including those in Zambia, have not yet been updated in line with developments in LVR technology that have led to new standards being developed under AfCAP in other partner countries. This AfCAP project is expected to provide technical solutions that will reduce the life cycle cost of rural road provision yet ensure an appropriate level of service. Moreover, the outputs of the project will also provide information that will allow the Road Development Agency (RDA) to develop a Pavement Design Manual for Low Volume Roads that will supplement existing design standards applied on high volume roads.

The main purpose of the project is thus to:

- Design a LVR pavement as a Trial Section(s) based on the DCP-DN method.
- Construct the Trial Sections to a sealed standard using an appropriate seal type.
- Establish a programme of long-term pavement performance monitoring.
- Collect and analyse baseline data.
- Ultimately, provide inputs for the development of a new pavement design manual for low volume roads in Zambia.

During the Project Inception stage, the road T2 – Waitwika – D1 in Nakonde District of Muchinga Province as shown in Figure 1 below, was identified among 19 candidate roads and agreed with the RDA as the most suitable location for construction of two 500 m Trial Sections.

Figure 1: T2 – Waitwika – D1 road selected for the Trial Sections

1.2 Purpose of the Report

The purpose of this report is to provide information on:

- The proposed Trial sections
- The field sampling and testing programme and results
- The experimental design and Research Matrix developed for monitoring these sections to identify variables that could be investigated
- The Proposed monitoring programme

2 Proposed Trial sections

Based on the initial overview visit to identify possible roads for constructing the Trial Sections and the follow-up detailed investigation of the Kantongo – Waitwika - D001 road, two 500-m long Trial Section locations were identified as shown in Figure 2. The manner of selecting these sections and their structural designs are discussed in the separate "Design Report" to be submitted in November 2017.

Figure 2: Location of Trial sections

3 Research Matrix

The aim of the Trial sections is four-fold:

1. To demonstrate the cost-effectiveness of the DCP DN design method in designing an appropriate rural access road.
2. To demonstrate the adequacy of certain materials that are normally considered unsuitable for base course, when used in appropriately designed rural access roads.
3. To assess the performance of the DCP-designed Trial Sections and three different types of bituminous seals on a lightly trafficked rural road.
4. To compare the life-cycle costs of the paved sections of road with the traditional unpaved road.

To achieve these objectives, it will be necessary to closely and comprehensively monitor and evaluate all the input and operating costs and benefits as well as the variables (rutting, roughness, gravel loss, etc.) related to the performance of each of the Trial Sections as described in this report.

For research purposes, the criteria adopted for the selection of each Trial Section were based on consideration of climate, drainage, traffic and subgrade conditions. It is important that each Trial Section differs from the other by only one variable, so that any differences in performance can be attributed directly to that variable.

The design traffic has been estimated at 100 000 equivalent standard axles and the structural design of the pavement for this required only the importation of a new 150 mm thick base course, except where the vertical alignment requires correction, in which case additional formation material will be required. The overall structural capacity of the first section is slightly lower than that of the second section (slightly weaker lower layers below 300 mm - See Section 4.1.1). The required strength of the imported base is a DN value at the anticipated, long-term in-service moisture content (OMC or below) of 4 mm/blow, which can be achieved from lateritic materials available from two sources close to the two Trial sections.

It is also proposed to construct three different types of surface treatments on the Trial sections, including Double Surface Dressing (DSD), Cold Mix Asphalt (CMA) constructed entirely by labour based methods and a 13mm Cape Seal (13mm open Surface Dressing plus one layer of slurry seal to seal the voids between the aggregates on the single seal).

The research will thus require monitoring of various parameters on the two Trial sections as well as unpaved “control” sections that will be adjacent to each Trial section and constructed according to the Contractor’s design for the remainder of the road. These sections will need to simulate as closely as possible the characteristics of the Trial sections (gradient, drainage, etc.). Ideally, it would be beneficial if a section of unpaved road constructed to full gravel road specification could also be constructed: however, it is not clear yet what the gravel road design for the project will be or which gravel source will be used for regravelling the existing road.

The factorial experimental design matrix will thus be as shown in Table 1 with the individual input parameters and values shown in Table 2. The factors included in the design are surfacing type (3 levels) and grade of the road (2 levels).

Table 1: Experimental design matrix

	Surfacing type 1 **Double Surface Dressing**	**Surfacing type 2** **Cold-mix asphalt**	**Surfacing type 3** **Cape Seal**
Section 1 (Grade < 1.5%)	X	X	X
Section 2 (Grade > 1.5%)	X	X	X

Table 2: Characteristics affecting experimental design matrix

Parameter	Trial Section 1			Trial Section 2		
Chainage (km)	3.5		4.0	7.7		8.2
Surfacing Type	DSD	CMA	CS	DSD	CMA	CS
Base Strength (DN)(mm/blow)	≤4			≤4		
SG Strength (DSN_{450})	163			159		
Design Traffic (MESA)	100,000					
Gradient (%)	0.5 – 1.3			1.6 – 4.0		
Rainfall (Mean annual – mm)	1092					

Notes: DSD = Double Surface Dressing; CMA = Cold Mix Asphalt; CS = Cape Seal

It should be noted that the structural design and the support conditions of the two Trial sections are essentially similar and are thus not considered as a variable factor in the experimental design.

4 Material sampling and testing

4.1.1 Soils/Subgrades

During initial identification of the uniform trial sections, the soil types observed on the road alignment were hardpan laterite gravel (in some areas is close to the surface or outcrops), rocky soils and a silty sand.

A DCP survey was carried out at potential Trial section sites, based on a visual evaluation of the in situ soils and the general environment around the road (drainage, shape, etc.), and the traffic. The DCP survey showed that the in-situ subgrade material on the two Trial Sections is well-compacted silty sand exhibiting high strength at the prevailing moisture condition as shown in Figure 3 and Figure 4 below. Samples were collected from test pits along the two Sections to determine the current moisture content of the pavement for interpretation of the DCP soundings, and to obtain the engineering characteristics of the in-situ materials.

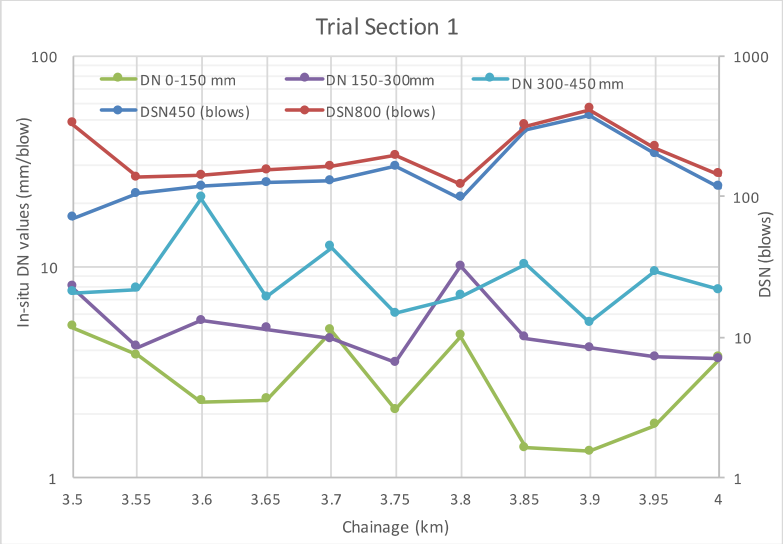


Figure 3: Trial Section 1 – In-situ DN and DSN values

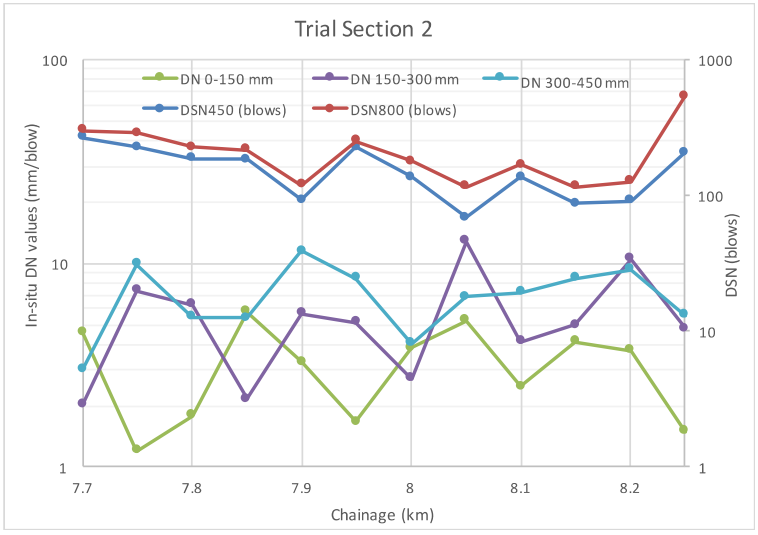


Figure 4: Trial Section 2 –In-situ DN and DSN values

The moisture content and classification test results are summarised in Table 3.

Table 3: Classification test results from samples taken from Trial Sections

Sample	LL (%)	PI (%)	LS (%)	Percentage passing sieve size (mm)					MDD kg/m^3	OMC (%)	FMC/ OMC (%)
				28	5	2	0.425	0.075			
8+000 TP 1 layer 1	22.5	11	5.3	100	99	99	82	32	2139	9.4	31
8+000 TP 1 layer 2	28.0	14.2	5.3	100	99	98	84	35	2139	9.4	84
3+800 TP2 layer 1	23.0	10.2	2	94	73	58	44	16	2195	8.6	34
3+800 TP2 layer 2	25.5	12.5	4	100	99	97	87	41	2015	11	60
3+800 TP2 layer 3	28.2	12	4.7	100	100	99	90	55	1902	13.6	69

4.1.2 Pavement materials

During the Inception phase, various borrow pits were identified along the T2 road from the available information included in the tender for its upgrading. These were located mostly too far from the road eventually selected for the Trial Sections for economic hauling of material for a LVR. However, two borrow pits were identified close to the Trial Sections (haulage less than 2 km) as shown in Table 4 and Figure 5 below. Visual inspection of the materials in these borrow pits indicated that they would probably be suitable as structural layers for the proposed Trial Sections.

The material investigations thus concentrated on these two material sources, which were similar in visual appearance to those observed in existing borrow pits along the T2 road. Sampling was thus limited to the two borrow pits identified.

Table 4: Location of proposed borrow pits

BP number	Road side	BP chainage	Trial Section chainage
1	RHS	2+780	3+500 – 4+000
2	RHS	8+940	7+700 – 8+200

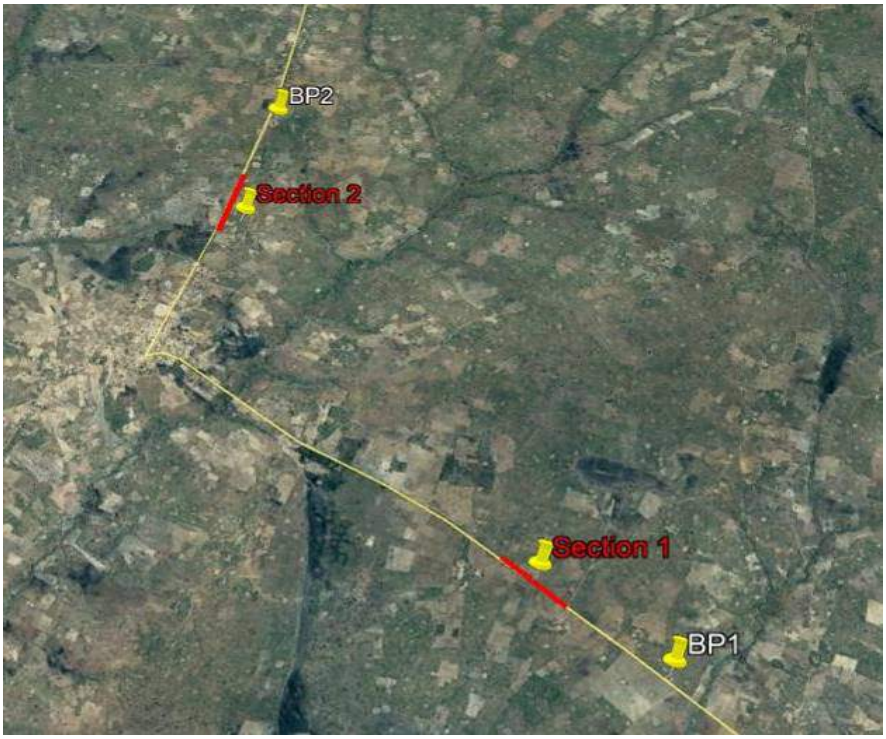


Figure 5: Location of proposed borrow pits

4.1.3 Borrow pit sampling

The following samples were collected from the proposed borrow pits and Trial Sections:

Borrow pit 1 (GPS 9° 28.315' and 032° 37.159'):

The borrow pit is located about 2.78 km from the junction of the road with the T2 road on the right side of the road. The borrow pit consists of a layer of dense hardpan laterite about 2 m thick overlain by about 0.5 m of overburden/topsoil. Beneath the hardpan, a light grey clayey sand (residual granite?) had been exposed by deeper excavation in one area.

Two bulk samples (BP1-1 and BP1-2) of the hardpan laterite, each of about 150 kg in mass, were collected from recently excavated small stockpiles at the locations shown in Figure 6.

Figure 6: Location of samples in Borrow Pit 1

The materials are typical brown, mottled black, orange, white, grey and red hardpan laterite (ferricrete) and contain some quartz pebbles and cobbles and appear to be quite widespread over the area. This, however, would need to be checked before opening the borrow pit by excavating some test pits outside its existing perimeter to determine the extent and depths of usable materials, bearing in mind that about 500 m^3 of material will be required for each pavement layer. Although hard in outcrop, the materials can be easily ripped and worked. The overburden should be moved away using the most appropriate construction plant, and preserved for restoration of the borrow area.

The hardpan area should be ripped and stockpiled and tested for compliance prior to use.

Borrow pit 2

Borrow pit 2 is located about 2 km from the village of Waitwika (Figure 5) and also consists of a dense hardpan laterite, about 2 m thick overlain by 0.4 to 1 m of overburden. The two samples (BP2-3 and BP2-4) collected here were from stockpiles about 6 m apart, currently being worked by the local Council for regravelling of parts of the road.

Environmental and other requirements

For the use of the existing borrow pits, it is not expected that an Environmental Project Brief will be required. It will, however, be up to the Contractor appointed by RDA to identify any environmental, expropriation or compensation requirements related to use of the material from the identified borrow pits and to carry out the necessary administrative requirements for use of the material.

Borrow pit operation

Laterites are notorious for their variability in properties but have also proved to be exceptionally good pavement materials, even when not complying with conventional material specifications (Paige-Green et al, 2015). To overcome this variability, it is essential that all materials are excavated and stockpiled prior to their use. Each stockpile should be tested to ensure relative uniformity and compliance with the proposed specification requirements.

4.1.4 Sample testing

Testing of the borrow pit samples concentrated on the strength and moisture/density relationships, particularly related to the DCP test methods. A summary of all the test results is given in Table 5 and the actual laboratory test sheets are provided in Appendix A.

Table 5: Summarised test results

Lab #	ID #	Depth m	USCS class.	MC %	LS %	Sieve analysis						PI	SP	PM	GM	Proctor		DN mm/blow 4 days soaked			DN mm/blow at OMC			DN mm/blow at 75% OMC			CBR 4 days soaked		
						0,075	0,425	2,0	5,0	28,0	50,0					MDD kg/m³	OMC %	93 %	95%	98 %	93 %	95%	98 %	93 %	95%	98 %	93 %	95%	98 %
3582	B/P1 sample 1 base	0.5-2.0	SC		6,67	21	38	52	76	100	100	12	251	245	1,9	2172	8	11,2	10,4	8,89	6,19	5,27	4,34	2,75	1,63	1,23	27	37	51
3583	B/P1 sample 2 base	0.5-2.0	SC		6,67	16	32	45	64	95	100	13	211	204	2,1	2200	7,6	17,7	6,56	3,44	4,79	2,05	1,44	3,02	0,94	0,82	32	48	72
3584	B/P2 sample 3 stock pile	0-2.0	SC		6,67	15	34	52	66	95	100	12	223	181	2	2110	9,5	10,2	5,07	3,39	3,37	3,44	3,47	3,54	2,03	1,22	69	79	92
3585	B/P2 sample 4 stock pile	0-2.0	SC		3,33	16	36	55	71	95	100	13	119	220	1,9	2170	8,1	9,64	4,66	3,57	5,31	3,61	3,53	3,22	1,82	0,92	65	74	86
3586	B/P 1 sample 5	-	SC		2,67	43	59	86	93	94	100	19	156	807	1,1														
3587	8+000 TP 1 layer 1	0,2	SC	2,9	5,33	32	82	99	99	100	100	11	435	349	0,9	2139	9,4												
3588	8+000 TP 1 layer 2	0,45	SC	7,9	5,33	35	84	98	99	100	100	14	446	500	0,8	2139	9,4												
3589	3+800 TP2 layer 1	0,1	SC	2,9	2	16	44	58	73	94	100	10	87	165	1,8	2195	8,6												
3590	3+800 TP2 layer 2	0,2	SC	6,6	4	41	87	97	99	100	100	13	348	516	0,7	2015	11												
3591	3+800 TP2 layer 3	0,45	CL	9,5	4,67	55	90	99	100	100	100	12	422	654	0,6	1902	13,6												

DCP tests were undertaken on a range of compacted samples to evaluate moisture/strength/density relationships. The DN values of all moulds compacted for the MDD/OMC determination were determined and are shown in conjunction with the associated compaction curves in Figure 7 and Figure 8.

Figure 8 shows that for TLC 0.1 MESA, the operating moisture content must not exceed the range 7.5 – 9.0% to attain the required DN values. Figure 7 indicates that the OMCs do, in fact, fall within that range.

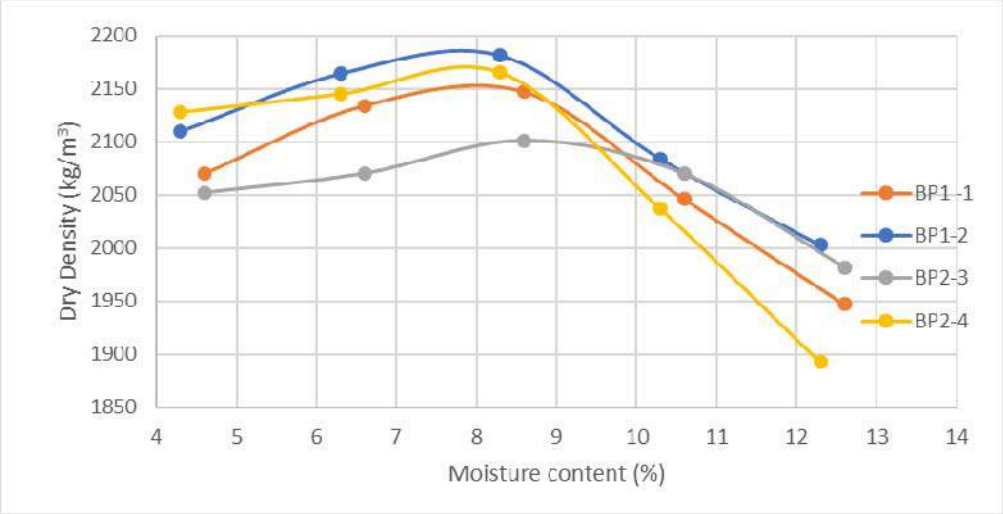


Figure 7: Compaction curves of borrow pit samples

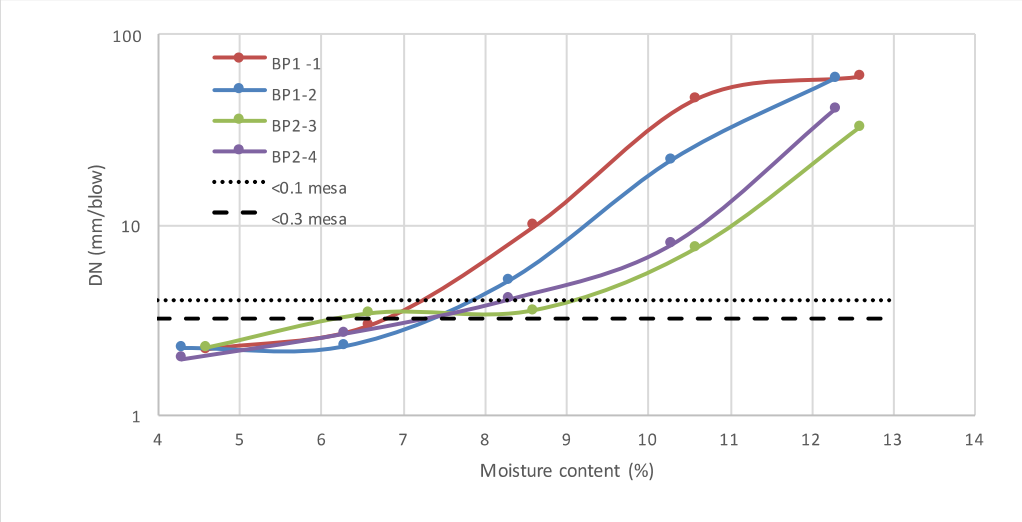


Figure 8: DN results from testing of compaction samples

The borrow pit materials were tested at three compaction efforts and three moisture contents as shown in Figure 9. General classification tests were also routinely carried out to confirm that the grading is acceptable ($1.0 \leq GM \leq 2.3$) and that the materials are not overly plastic.

The classification test results are shown in Table 6 and Figure 9 shows that the materials are all very similar despite the borrow pits being separated by about 5 km.

The DN results at Optimum Moisture Content (OMC) and classification test results indicate that the materials will provide the necessary structural capacity for the design traffic class TLC 0.1 provided that the required compaction is achieved and that the materials do not wet up above OMC.

Improvement of the drainage and sealing the road from shoulder breakpoint to shoulder breakpoint will ensure that the long-term equilibrium moisture regime in the pavement will be below OMC.

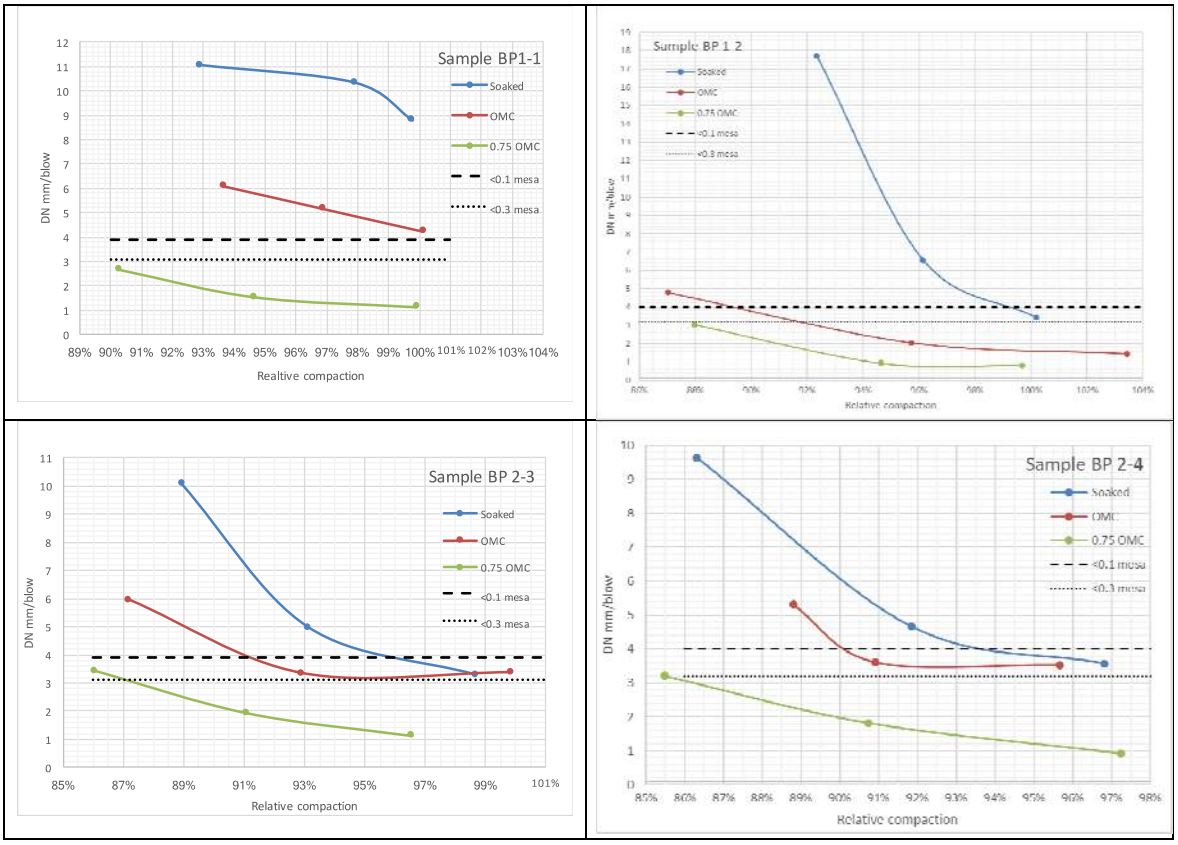


Figure 9: DN values of borrow pit samples at different moisture contents and densities

Table 6: Classification test results for borrow pit samples

Lab #	ID #	Visual Description	LS %	PI	PM	GM	Mod AASHTO	
							MDD kg/m^3	OMC %
3582	B/P1 sample 1	Laterite	6,67	12	245	1,9	2172	8
3583	B/P1 sample 2	Laterite	6,67	13	204	2,1	2200	7,6
3584	B/P2 sample 3 stock pile	Laterite	6,67	12	181	2	2110	9,5
3585	B/P2 sample 4 stock pile	Laterite	3,33	13	220	1,9	2170	8,1

The full laboratory test results are provided in Appendix A.

Based on the preliminary test results, the materials from both borrow pits appear to be suitable for use as a base course for the Trial Sections for the estimated Traffic Load Class TLC 0.1 requiring a DN ≤ 4.0 mm/blow, without modification or stabilisation.

Although the design is based on the measured shear strength of the materials indicated by their DN values, CBR tests were also undertaken for comparison with conventional design methods. The CBR results are summarised in Figure 10.

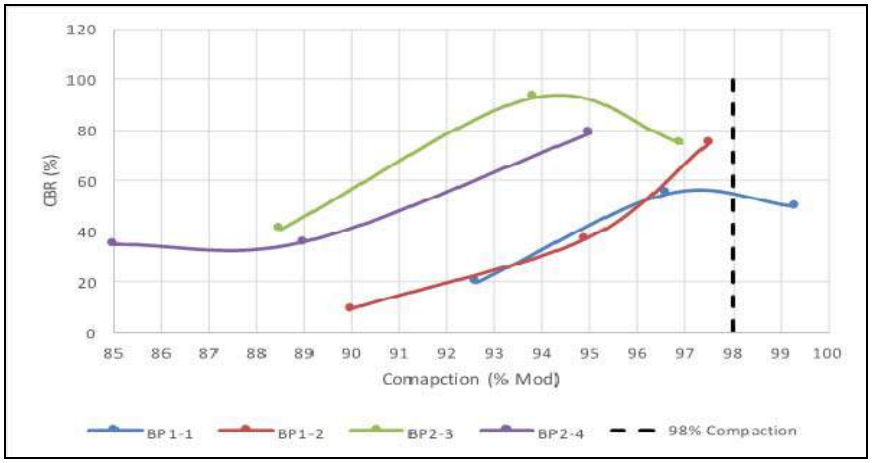


Figure 10: CBR results of borrow pit samples

The CBR results show that the laboratory testing has generally produced lower densities than expected. Although there is some unexplained variation (and possible spurious data) in the results, extrapolation of the strengths to 98% compaction indicates that the CBR will generally be above 60% for all the materials at 98% relative compaction.

4.1.5 Surfacing aggregates

Three sources of surfacing aggregates are known on the Mbala – D1 road. Measured from the Mbala junction, the first is located at Km 143+350 with 3.35 km offset to the left, the second at km 145+050 with 4.64 km offset to the left and the third on at km 153+910 with 0.77 km offset to the right.

The quarry is located at km 145+050, was used for the construction of the TAZARA railway line and was also recently used as a source of aggregate for the upgrading of the D1 road to paved standard with asphalt surfacing. This quarry is proposed as the source of aggregates due both to its proximity with the proposed Trial Sections and the quality of the material.

The quality of the materials is known to be good, with acceptable results for the 10% FACT, Aggregate Crushing Value (ACV) and Flakiness Index (FI) tests being reported during the investigation stage.

The source of surfacing aggregates will be selected by the contractor for the upgrading of the T2 road. Samples of the relevant nominal size aggregates for the construction of the Trial Sections will then be subjected to the standard aggregate tests once the source of the aggregates has been confirmed. An example of a test report on these aggregates is given in Appendix B.

5 Monitoring

5.1 Monitoring requirements and timing

To ensure that sufficient information is obtained for a useful analysis, several parameters as discussed in this section need to be accurately monitored, both during and after construction, as well as during operation of the road sections. Although the use of the data obtained will differ for the different purposes of the project (i.e. life-cycle cost analysis, investigation of the performance of the laterite and the surface seal investigations and assessment of the cost-effectiveness of the DN design method), the proposed data collection items will provide all the required information for the various objectives. For example, the visual condition assessment of the paved sections will allow an interpretation of the structural performance of the Trial sections as well as a comparison of the behaviour of the different surfacing types.

To ensure that useful data is obtained from the Trial sections, it will be essential that they are constructed to the specified quality. Quality and construction control will need to be carefully monitored, using a conventional Quality Management Plan as provided by the Contractor. The Rankin Resident Engineer will also ensure that material quality, as well as compaction and construction tolerances, are strictly adhered to.

Any deficiencies in the construction process may lead to sub-optimal performance and possibly premature failure of the Trial sections that is not related to the materials or design and must be avoided at all cost. A deviation from the conventional quality control (QC) process will be the use of the DCP for compaction control, as shown in Appendix C.

The proposed monitoring requirements and programme are summarised in Table 7 with details regarding the methods and specifics for each section discussed below. In general, the monitoring will follow that outlined in the AfCAP Regional Guidelines for monitoring Long Term Pavement Performance (LTPP) currently being prepared in Mozambique and in Draft form.

It is essential that the monitoring programme shown in Table 7 is rigidly adhered to. The initial and base-line monitoring is to be carried out by the Consultant together with the RDA team on site. However, after completion of the project, intermittent monitoring of the trial sections, will need to be managed by RDA (Research and Development Unit), following the specified monitoring plan.

Table 7: Preliminary monitoring requirements and timing

Timing/ Section type	After stockpiling material	During and after compaction	After construction	Every 3 months	Every 6 months	Ongoing
Unpaved control sections	Classification tests	Daily QC Cost of each activity Videos and photos	Gravel loss survey Riding quality Visual assessments	Gravel loss survey Riding quality Visual assessments	As for every 3 months	Weather Traffic Maintenance activities and costs
Paved trial sections	Classification tests Lab DCP	Daily QC Cost of each activity Videos and photos	Riding quality Rut depths Visual assessment FWD/LWD Skid resistance DCP	Visual assessment	Riding quality Rut depths Visual assessment FWD/LWD	Weather Traffic Maintenance activities and costs
Surfacings		Daily QC Cost of each activity Videos and photos	Visual assessment	Visual assessment	Skid resistance	Weather Traffic Maintenance activities and costs

5.2 Monitoring detail

5.2.1 Weather

Weather information consisting of at least daily rainfall as well as daily maximum and minimum temperatures should be collected for the full duration of the monitoring. Arrangements should be made with a local government organisation (police, agricultural station, school, etc.) for this data collection.

5.2.2 Traffic

Periodic traffic surveys (every two years) must be carried out to monitor the numbers, types, growth and loading of vehicles.

5.2.3 Unpaved road control sections

In order to make performance comparisons, unpaved road control sections are required. The T2-Waitwika-D1 road will be rehabilitated to full gravel standard under an AfDB funded project. The unpaved control sections to be chosen will need to be carefully set up according to the lay-out shown in Figure 11 and be as close to the paved Trial Sections with properties (traffic, subgrade, grade, etc.) as similar as possible to them. The sections should be 300 m long and include a 50-m section for regular gravel loss measurements. The construction cost of this 300-m section should be determined as a pro-rated part of the entire gravel road construction cost, excluding any drainage structures, i.e., the cost of forming, gravelling and constructing the road as well as the cost of the associated side- and mitre-drains. The exact locations of these sections will be chosen during construction based on the Contractor's progress and will be as similar as possible to the paved sections, particularly in terms of gradient.

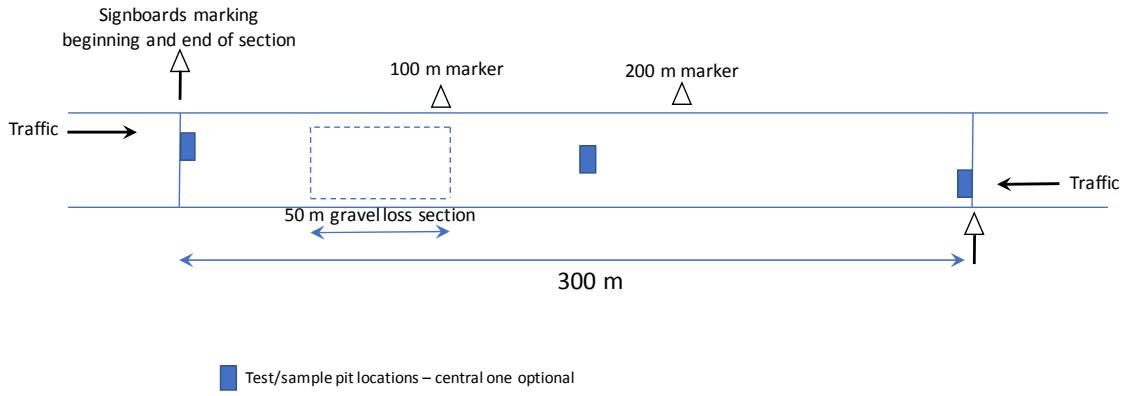


Figure 11: Layout of unpaved road control section

The cost of maintaining the road in an optimum condition through regular grader maintenance would normally be used in the Life Cycle Cost Analysis. However, the typical maintenance practices prevailing in Zambia (often resulting in sub-optimal maintenance and reduced maintenance costs) will be used as well as the optimum maintenance regime in the cost analyses. However, as the road roughness (and thus road user costs) are directly related to the condition of the road (i.e. riding quality) and the maintenance provided, any reduction in maintenance from optimal will result in an increased vehicle operating cost. Despite this, all maintenance costs applied to the unpaved road must be collected and the cost per kilometre of maintenance determined. The visual condition of the road must be recorded at specified intervals (as detailed in Appendix D) and the annual gravel loss determined through precise levelling surveys. The method for this is included in Appendix E.

Riding quality must be measured with an appropriately calibrated response type-measuring device (e.g. bump integrator, Linear displacement integrator or MERLIN) and determined as the average roughness in both directions over the 300-m section length.

Regular visual condition descriptions must be carried out as per Table 7 to support later evaluation of roughness measurements and gravel loss data.

5.2.4 Paved trial sections

As the deterioration of the paved road sections is slower and more predictable than the unpaved sections, the monitoring requirements are less frequent, but require more detailed investigations for the range of issues being investigated. The average riding quality and its change with time need to be monitored to determine the user costs over time. This should be measured using the same equipment as that used for the unpaved road (control) section.

The construction costs of each of the Trial sections must be accurately determined. During construction, the materials used for the base must be sampled and tested for conventional properties (Atterberg limits, grading, CBR and laboratory DN) after compaction of the layer. A reference sample should also be collected and securely stored for any future confirmation or additional testing.

If detailed information regarding the performance of the lateritic material in particular is required, additional testing such as chemical analysis, mineralogy and iron content will be necessary. Cycled CBR testing may also be necessary if there is evidence of self-cementation.

As described above, any maintenance activities will need to be recorded and the costs of these carefully determined. It is essential for a realistic cost-benefit analysis that maintenance is undertaken in accordance with acceptable standards to assess the actual maintenance costs. Poor maintenance practice will likely lead to premature failure of parts of the road, making the life-cycle analysis meaningless.

Performance monitoring of the Paved Trial sections to assess the cost-effectiveness of the DCP DN design method as well as the surfacing performance will require the measurement of rut depths and riding quality, periodic visual assessments, deflection (FWD or minimum of LWD), DCP tests and periodic moisture content determinations, as described above.

Each 500-m Trial Section of paved road should be laid out as 3 sections of 167 m each according to Figure 12, with Panels A and B used for destructive testing and Panels 1 to 7 used for non-destructive testing (e.g. FWD, Rut depths, visual assessment, etc.). The speed humps at the ends of the paved Trial sections will be placed in the respective A or B panels.

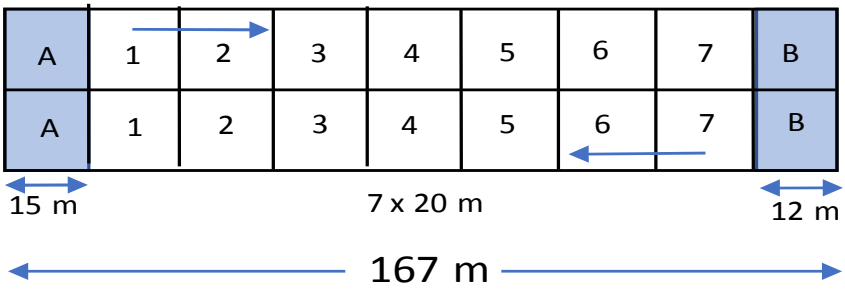


Figure 12: Typical layout of a Trial/experimental Section - not to scale

As different surfacings are proposed for different sections, these will need to be monitored in terms of their comparative performances.

The performance of the laterite base will be of particular interest as it is known that this type of material will generally perform much better than might be inferred from its engineering properties when viewed against traditional compliance criteria. The general monitoring of the pavement required for the assessment of the performance of the Trial sections will provide most of the information necessary for the analysis of the behaviour of the laterite base course materials. The only additional information required will be detailed laboratory data on the mineralogical, chemical and self-cementation properties of the laterites used, which will be carried out after construction.

The routine monitoring of the performance of the pavement will also provide the information required to assess the performance of the bituminous surfacings, specifically the standard visual assessment criteria provided in Appendix D. Additional information on the skid resistance of the different bituminous surfacings will be necessary and information on the properties of the bituminous binders and aggregates used for their construction will also be required. It is recommended that reference samples of the binders and aggregates used be retained for any additional work identified during the monitoring.

5.3 Community surveys

As only short sections of the entire road will be constructed, the impact of the developments on the overall traffic using the road and the lives of the communities will be minimal, and it is unlikely that

any useful information regarding the impact of the trials on the communities will be forthcoming. Community surveys would thus appear to be unnecessary.

5.4 Data processing

All data collected will be verified and processed using Spreadsheets for later analysis. Optimally, the data should be included in one of the AfCAP data bases (Back-analysis or LTPP data base being developed in Mozambique) as well.

For the Life Cycle Cost Analysis (LCCA) analysis, the total cost of the construction and operation (including maintenance) of the Trial sections of paved road will need to be compared with those of the unpaved control sections. As one of the major components of the LCCA is the vehicle operating costs, regular measurement of the road roughness will be necessary. The paved road sections deteriorate gradually over their service life, whereas the deterioration of the unpaved road sections in relation to their roughness will vary in response to changing climatic and traffic conditions. The unpaved roads therefore require more frequent roughness measurement in order to obtain an annual average value of this parameter.

It is essential that the roads are maintained in an appropriate condition as the most common cause of severe road distress is the failure to address minor problems through effective and timeous maintenance. Maintenance of unpaved roads will apply both to grading and regravelling, which is one of the largest costs of maintaining unpaved roads. Crack sealing and pothole repair as well as periodic rejuvenation or resealing of paved road where necessary must be carried out. Maintenance of the side and mitre drains on both the paved and unpaved sections is essential but the unit costs should be similar for all sections. Records of the actual costs of each of all maintenance activities will need to be kept for use in the LCCA.

5.5 Monitoring programme

Additional detail regarding the preliminary monitoring programme summarised in Table 7 is as follows:

5.5.1 During construction:

- Regular daily quality control testing according to the quality control programme – compaction control, materials control, thickness control.
- Retention of appropriate samples of each material used for later “check” or additional testing.
- Costs of each construction activity
- Record of construction processes, procedures and problems (including photographs and videos)

5.5.2 At end of construction

On unpaved control section:

- Gravel loss survey
- Riding quality (average of entire section in both directions)
- Visual assessments (entire section)

On paved Trial sections:

- Riding quality (average of entire section in both directions)
- Rut depths (every 10 m in both wheel tracks in both directions)

- Visual assessment (individual sections)
- FWD/LWD (one in each panel in outer and inner wheel tracks)
- DCP (in outer and inner wheel tracks in Panels A and B of each section)
- Skid resistance (depends on equipment available – representative for each section)

5.5.3 Every 3 months

On unpaved control section:

- Gravel loss survey
- Riding quality (average of entire section in both directions)
- Visual assessments (entire section)

On paved Trial sections:

- Visual assessment (individual sections)

5.5.4 Every 6 months

On paved Trial sections:

- Riding quality (average of entire section in both directions)
- Rut depths (every 10 m in both wheel tracks in both directions)
- Visual assessment (individual sections)
- FWD/LWD (one in each panel in outer and inner wheel tracks)
- Skid resistance (depends on equipment available – representative for each section)

This monitoring should be carried out until sufficient information has been acquired to conduct a proper life cycle cost analysis, probably a minimum of 6 or 7 years but for as long as possible, to determine when maintenance interventions are necessary (rejuvenation or resealing of the bituminous seals and regravelling of the unpaved control section).

In addition:

- An ongoing record of all maintenance activities on each Trial section (and the control) and their costs must be kept.
- Ad hoc checks of moisture content in base, subbase and subgrade in Panels A and B, inner and outer wheel tracks at bi-annual intervals for first two years
- Ongoing collection of weather data (daily rainfall, and temperatures if possible)
- Traffic counts and classifications every two years (preferably to capture seasonal variations in traffic, both in terms of ADT and traffic loading)

6 Conclusions

This report describes the "experimental design", sampling and testing, construction and ongoing monitoring requirements related to the implementation of two Trial sections designed using the DCP DN method and incorporating various bituminous surfacings. It also describes the monitoring of the unpaved "control sections".

A life-cycle cost analysis of these sections compared with the traditional unpaved roads in the area will be carried out. In addition, the performance of the DCP DN designed road compared with the traditional unpaved road, the performance of what would normally be considered unsuitable lateritic base course materials and the performance of three different bituminous surfacings will be assessed.

It is anticipated that the outputs of the project will ultimately be used to improve local design practices for rural access roads and allow the greater provision of appropriately designed paved roads.

APPENDIX A: Laboratory test results

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: **27/09/2017**

OPERATOR: **Enious**

DATE OF SOAKING: **27/09/2017**

DATE OF TESTING: **30/09/2017**

SAMPLE SOURCE: **8+000 TP1 layer 2 (0.45m)**

Soil Description: **Slightly moist strong brown clayey sand**

Lab No. **3588**

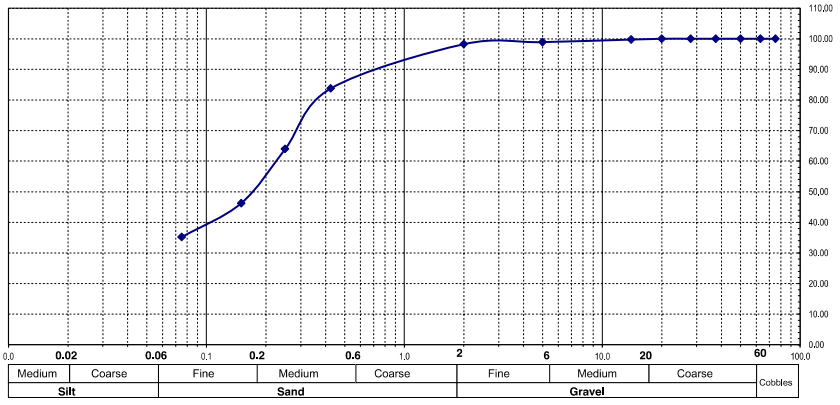
R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

Initial Dry Mass (m_1) **3025** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	100
28.0	0	0.0	0.0	100.0	100
20.0	0	0.0	0.0	100.0	100
Passing 20 mm (m_2)	3025				
total (checked with m_1)	**3025**	1519.0			
riffled (m_3)	1519				
riffled and washed (m_4)	515				
Correction factor $\frac{m3}{m2}$		0.5021			
14.0	4.0	4.0	0.3	99.7	100
5.0	13.0	13.0	0.9	98.9	99
2.0	10.0	10.0	0.7	98.2	98
0.425	220.0	220.0	14.5	83.7	84
<0.425 (+ 1004.0	1272.0				
Passing 0.425 mm (m5)	1272.0				
riffled (m6)	250.0				
riffled and washed (m7)	146.0				
Correction factor $\frac{m6}{m5}$		0.1965			
0.250	59.0	300.2	19.8	64.0	64
0.150	53.0	269.7	17.8	46.2	46
0.075	33.0	167.9	11.1	35.2	35
<0.075 (+ 104.0	105.0	534.2	35.2		
TOTAL		1519.0	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	0.8
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	16.1
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3588 SANS 3001-GR1 2013 (Soil Sieve Analysis)

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

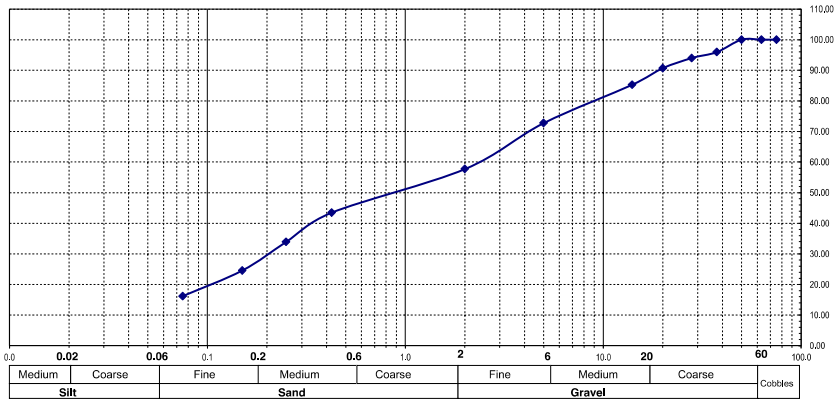
SUPERVISOR:	SN	DATE:	28/09/2017
OPERATOR	Enious	SAMPLE SOURCE:	**3+800 TP2 layer 1 (0.10m)**
DATE OF SOAKING:	28/09/2017	Soil Description	**Dry reddish brown clayey gravelly sand**
DATE OF TESTING:	10/02/2017	Lab No.	**3589**

Initial Dry Mass (m_1) **3098** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	125	60.3	4.0	96.0	96
28.0	62	29.9	2.0	94.0	94
20.0	102	49.2	3.3	90.7	91
Passing 20 mm (m_2)	2809				
total (checked with m_1)	**3098**	1493.3			
riffled (m_3)	1354				
riffled and washed (m_4)	788				
Correction factor m3/m2		0.4820			
14.0	81.0	81.0	5.4	85.2	85
5.0	187.0	187.0	12.5	72.7	73
2.0	224.0	224.0	15.0	57.7	58
0.425	213.0	213.0	14.3	43.5	43
<0.425 (+ 566.0	649.0				
Passing 0.425 mm (m5)	649.0				
riffled (m6)	250.0				
riffled and washed (m7)	158.0				
Correction factor m6/m5		0.3852			
0.250	55.0	142.8	9.6	33.9	34
0.150	54.0	140.2	9.4	24.5	25
0.075	48.0	124.6	8.3	16.2	16
<0.075 (+ 92.0	93.0	241.4	16.2		
TOTAL		1493.3	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	1.8
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	36.7
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3589 SANS 3001-GR1 2013 (Soil Sieve Analysis)

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

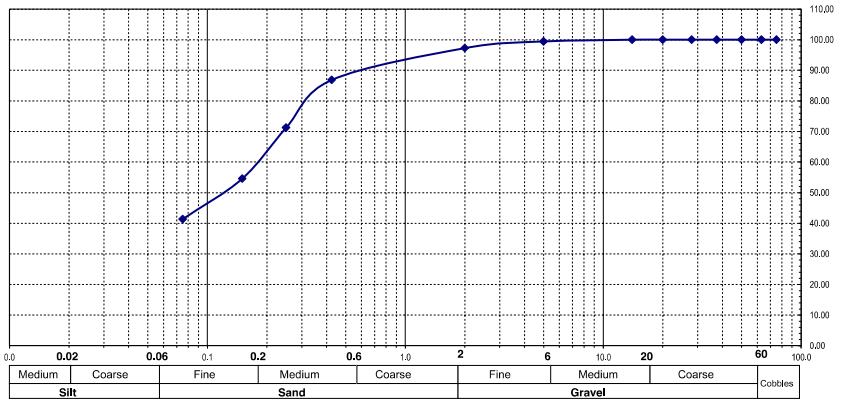
SUPERVISOR:	SN	DATE:	28/09/2017
OPERATOR	Enious	SAMPLE SOURCE:	**3+800 TP2 layer 2 (0.20m)**
DATE OF SOAKING:	28/09/2017	Soil Description	**Slightly moist rediish brown clayey sand**
DATE OF TESTING:	10/02/2017	Lab No.	**3590**

Initial Dry Mass (m_1) **1514** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	100
28.0	0	0.0	0.0	100.0	100
20.0	0	0.0	0.0	100.0	100
Passing 20 mm (m_2)	1514				
total (checked with m_1)	**1514**	693.0			
riffled (m_3)	693				
riffled and washed (m_4)	95				
Correction factor m3/m2		0.4577			
14.0	0.0	0.0	0.0	100.0	100
5.0	4.0	4.0	0.6	99.4	99
2.0	15.0	15.0	2.2	97.3	97
0.425	72.0	72.0	10.4	86.9	87
<0.425 (+ 598.0	602.0				
Passing 0.425 mm (m5)	602.0				
riffled (m6)	250.0				
riffled and washed (m7)	132.0				
Correction factor m6/m5		0.4153			
0.250	45.0	108.4	15.6	71.2	71
0.150	48.0	115.6	16.7	54.6	55
0.075	38.0	91.5	13.2	41.3	41
<0.075 (+ 118.0	119.0	286.6	41.3		
TOTAL		693.0	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	0.7
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	13.1
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3590 SANS 3001-GR1 2013 (Soil Sieve Analysis)

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 28/09/2017

OPERATOR: Enious

DATE OF SOAKING: 28/09/2017

DATE OF TESTING: 10/02/2017

SAMPLE SOURCE: **3+800 TP2 layer 3 (0.45m)**

Soil Description: **Slightly moist rediish brown sandy clay**

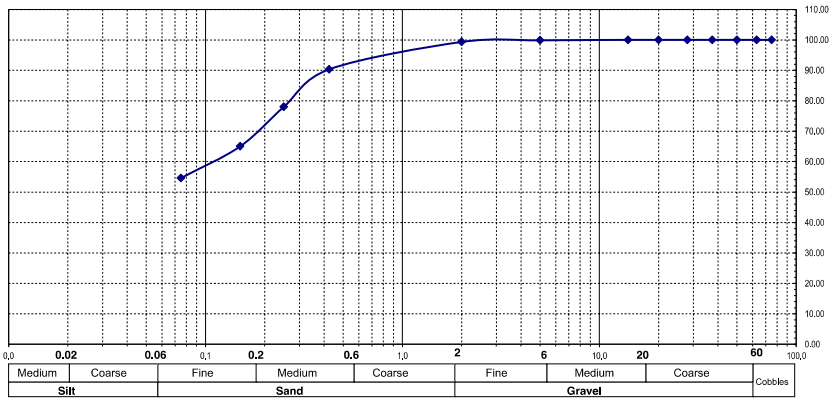
Lab No. **3591**

Initial Dry Mass (m_1) **3656** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75,0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	100
28.0	0	0.0	0.0	100.0	100
20.0	0	0.0	0.0	100.0	100
Passing 20 mm (m_2)	3656				
total (checked with m_1)	**3656**	1909,0			
riffled (m_3)	1909				
riffled and washed (m_4)	237				
Correction factor m3/m2		0.5222			
14.0	0.0	0.0	0.0	100.0	100
5.0	3.0	3.0	0,2	99,8	100
2.0	10.0	10.0	0.5	99.3	99
0.425	172.0	172.0	9.0	90.3	90
<0.425 (+ 1672.0	1724.0				
Passing 0,425 mm (m5)	1724.0				
riffled (m6)	250.0				
riffled and washed (m7)	99.0				
Correction factor m6/m5		0.1450			
0.250	34.0	234.5	12,3	78,0	78
0.150	36.0	248.3	13.0	65.0	65
0.075	29,0	200,0	10.5	54.5	55
<0.075 (+ 151.0	151.0	1041.3	54.5		
TOTAL		1909.0	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	0,6
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	9.7
USCS classification	CL

SIEVE SIZE BY LOG SCALE



Lab # 3591 SANS 3001-GR1 2013 (Soil Sieve Analysis)

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

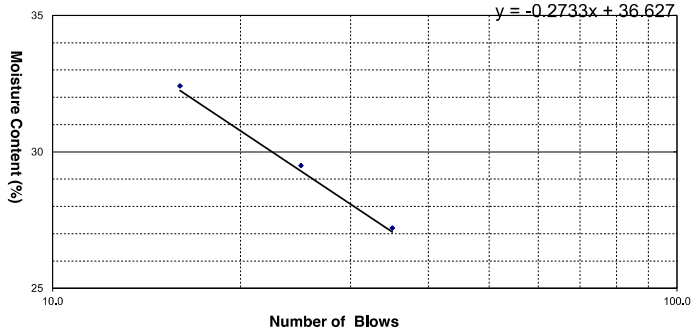
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	B/P 1 sample 1	DESCRIPTION :	Slightly moist yellowish red clayey gravelly sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3582	DATE OF TEST:	26/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	16.0			
Container Number		RNK33	LUS1	16	RK10	RNK35	
Mass of wet soil & contai	g	20.94	20.48	20.95	20.52	20.93	
Mass of dry soil & contai	g	19.52	19.07	19.31	19.51	19.88	
Mass of container	g	14.30	14.29	14.25	14.04	14.04	
Mass of dry soil	g	5.22	4.78	5.06	5.47	5.84	
Mass of moisture	g	1.42	1.41	1.64	1.01	1.05	
Moisture content	%	27.2	29.5	32.4	18.5	18.0	18.2



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known

Proportion passing on 425 µm sieve : 38

LIQUID LIMIT
LL = 29.8 %

PLASTIC LIMIT
PL = 18.2 %

PLASTICITY INDEX
PI = 11.6 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	140			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	6.67			
Shrinkage Product, SP = LS* % <425um			250.7			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 21/09/2017

OPERATOR: Enious SAMPLE SOURCE: **B/P 1 sample 1 (0.5-2.0m) Base layer**

DATE OF SOAKING: 21/09/2017 Soil Description: **Slightly moist yellowish red clayey gravelly sand**

DATE OF TESTING: 22/09/2017 Lab No. **3582**

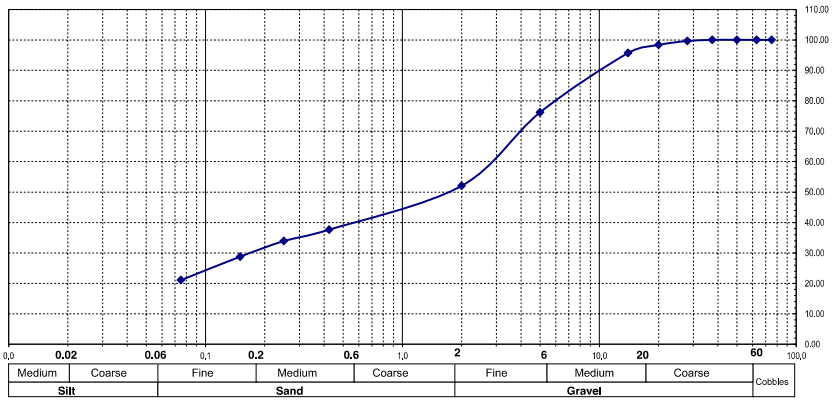
R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

Initial Dry Mass (m_1) **15501** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	100
28.0	57	4.7	0.4	99.6	100
20.0	200	16.6	1.3	98.3	98
Passing 20 mm (m_2)	15244				
total (checked with m_1)	**15501**	1283.3			
riffled (m_3)	1262				
riffled and washed (m_4)	767				
Correction factor m3/m2		0.0828			
14.0	34.0	34.0	2.6	95.7	96
5.0	250.0	250.0	19.5	76.2	76
2.0	310.0	310.0	24.2	52.1	52
0.425	185.0	185.0	14.4	37.6	38
<0.425 (+ 495.0	483.0				
Passing 0.425 mm (m5)	483.0				
riffled (m6)	250.0				
riffled and washed (m7)	112.0				
Correction factor m6/m5		0.5176			
0.250	25.0	48.3	3.8	33.9	34
0.150	34.0	65.7	5.1	28.8	29
0.075	51.0	98.5	7.7	21.1	21
<0.075 (+ 138.0	140.0	270.5	21.1		
TOTAL		1283.3	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	1.9
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	47.2
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3582 SANS 3001-GR1 2013 (Soil Sieve Analysis)

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

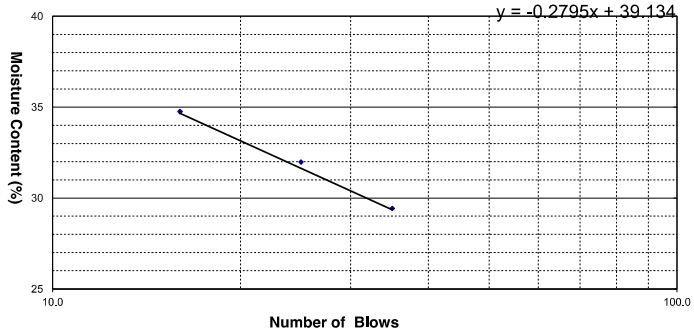
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	B/P 1 sample 2	DESCRIPTION :	Slightly moist yellowish red clayey gravelly sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3583	DATE OF TEST:	27/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	16.0			
Container Number		RNK33	CH12	LUS1	D02	YX	
Mass of wet soil & conta	g	18.18	18.12	18.08	11.13	11.06	
Mass of dry soil & conta	g	17.30	17.18	17.10	10.49	10.42	
Mass of container	g	14.31	14.24	14.28	7.21	7.18	
Mass of dry soil	g	2.99	2.94	2.82	3.28	3.24	
Mass of moisture	g	0.88	0.94	0.98	0.64	0.64	
Moisture content	%	29.4	32.0	34.8	19.5	19.8	19.6



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known
Proportion passing on 425 µm sieve :
32
LIQUID LIMIT
LL = 32.1 %
PLASTIC LIMIT
PL = 19.6 %
PLASTICITY INDEX
PI = 12.5 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	140			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	6.67			
Shrinkage Product, SP = LS* % <425um			211.3			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 21/09/2017

OPERATOR: Enious

DATE OF SOAKING: 21/09/2017

DATE OF TESTING: 22/09/2017

SAMPLE SOURCE: **B/P 1 sample 2 (0.5-2.0m) Base layer**

Soil Description: **Slightly moist yellowish red clayey gravelly sand**

Lab No. **3583**

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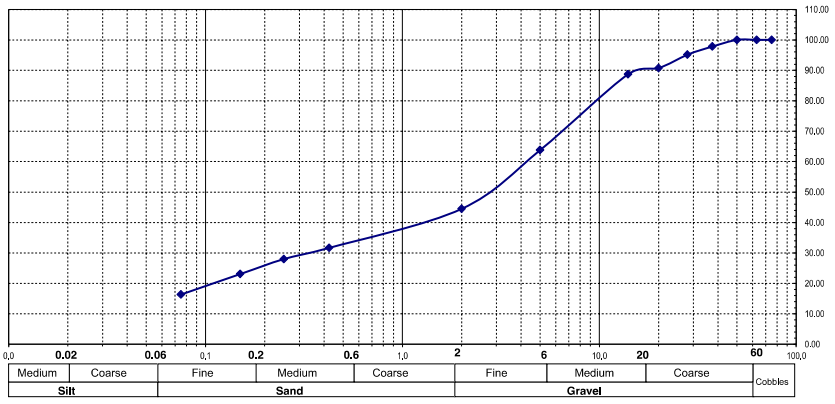
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

Initial Dry Mass (m_1) **15998** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	347	50.6	2.2	97.8	98
28.0	433	63.1	2.7	95.1	95
20.0	704	102.6	4.4	90.7	91
Passing 20 mm (m_2)	14514				
total (checked with m_1)	**15998**	2331.3			
riffled (m_3)	2115				
riffled and washed (m_4)	1435				
Correction factor m3/m2		0.1457			
14.0	47.0	47.0	2.0	88.7	89
5.0	581.0	581.0	24.9	63.8	64
2.0	450.0	450.0	19.3	44.5	44
0.425	299.0	299.0	12.8	31.7	32
<0.425 (+ 680.0	738.0				
Passing 0.425 mm (m5)	738.0				
riffled (m6)	250.0				
riffled and washed (m7)	123.0				
Correction factor m6/m5		0.3388			
0.250	29.0	85.6	3.7	28.0	28
0.150	39.0	115.1	4.9	23.0	23
0.075	53.0	156.5	6.7	16.3	16
<0.075 (+ 127.0	129.0	380.8	16.3		
TOTAL		2331.3	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	2.1
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	40.5
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3583 SANS 3001-GR1 2013 (Soil Sieve Analysis)

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FORM S4

CASAGRANDE

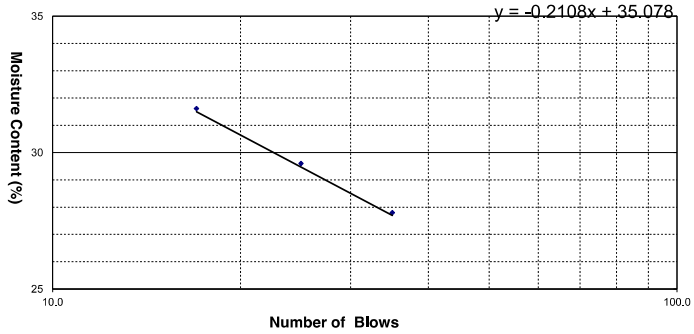
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	B/P 2 sample 3	DESCRIPTION :	Slightly moist yellowish red clayey gravelly sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3584	DATE OF TEST:	27/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	17.0			
Container Number		RK10	RNK35	RNK23	DM09	J8	
Mass of wet soil & conta	g	18.27	18.20	18.16	11.58	11.47	
Mass of dry soil & conta	g	17.35	17.25	17.18	10.95	10.84	
Mass of container	g	14.04	14.04	14.08	7.36	7.40	
Mass of dry soil	g	3.31	3.21	3.10	3.59	3.44	
Mass of moisture	g	0.92	0.95	0.98	0.63	0.63	
Moisture content	%	27.79	29.60	31.61	17.5	18.3	17.9



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known
Proportion passing on 425 µm sieve :
34
LIQUID LIMIT
LL = 29.8 %
PLASTIC LIMIT
PL = 17.9 %
PLASTICITY INDEX
PI = 11.9 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	140			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	6.67			
Shrinkage Product, SP = LS* % <425um			223.3			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 21/09/2017

OPERATOR: Enious

DATE OF SOAKING: 21/09/2017

DATE OF TESTING: 22/09/2017

SAMPLE SOURCE: **B/P 2 sample 3 (0-2.0m) Stockpile layer**

Soil Description: **Slightly moist yellowish red clayey gravelly sand**

Lab No. **3584**

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Rankin House
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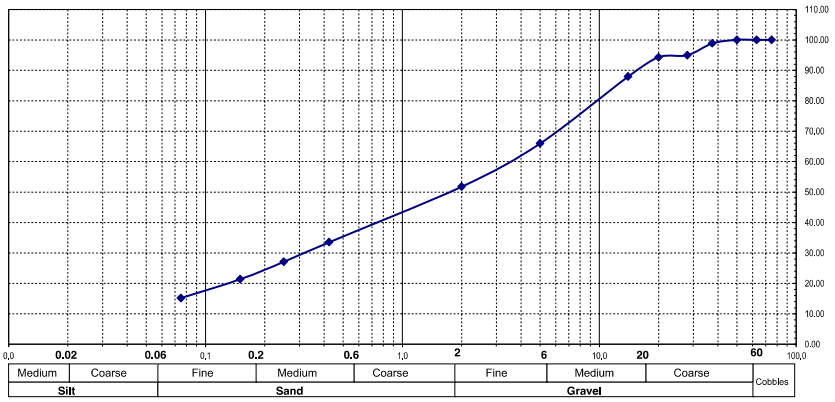
Tel/Fax: 260-1-291195

Initial Dry Mass (m_1) **15448** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	181	22.1	1.2	98.8	99
28.0	599	73.2	3.9	95.0	95
20.0	100	12.2	0.6	94.3	94
Passing 20 mm (m_2)	14568				
total (checked with m_1)	**15448**	1887.5			
riffled (m_3)	1780				
riffled and washed (m_4)	1214				
Correction factor m3/m2		0.1222			
14.0	120.0	120.0	6.4	87.9	88
5.0	415.0	415.0	22.0	66.0	66
2.0	268.0	268.0	14.2	51.8	52
0.425	344.0	344.0	18.2	33.5	34
<0.425 (+ 566.0	633.0				
Passing 0.425 mm (m5)	633.0				
riffled (m6)	250.0				
riffled and washed (m7)	138.0				
Correction factor m6/m5		0.3949			
0.250	48.0	121.5	6.4	27.1	27
0.150	43.0	108.9	5.8	21.3	21
0.075	46.0	116.5	6.2	15.2	15
<0.075 (+ 112.0	113.0	286.1	15.2		
TOTAL		1887.5	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	2.0
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	40.5
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3584 SANS 3001-GR1 2013 (Soil Sieve Analysis)

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FORM S4

CASAGRANDE

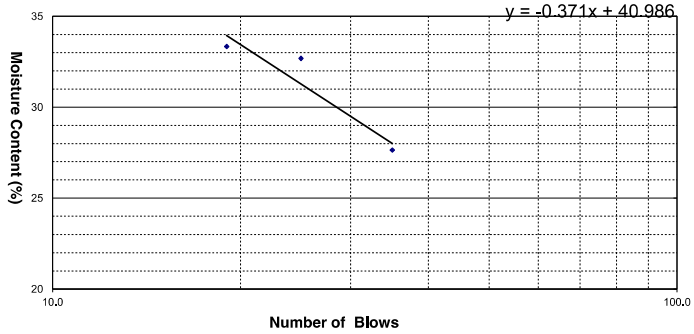
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	B/P 2 sample 4	DESCRIPTION :	Slightly moist yellowish red clayey gravelly sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3585	DATE OF TEST:	28/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	19.0			
Container Number		RNK 33	LUS 1	CH12	D02	XY	
Mass of wet soil & contai	g	18.40	18.34	18.26	11.29	11.18	
Mass of dry soil & contai	g	17.51	17.34	17.25	10.66	10.56	
Mass of container	g	14.29	14.28	14.22	7.20	7.18	
Mass of dry soil	g	3.22	3.06	3.03	3.46	3.38	
Mass of moisture	g	0.89	1.00	1.01	0.63	0.62	
Moisture content	%	27.6	32.7	33.3	18.2	18.3	18.3



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known

Proportion passing on 425 µm sieve : 36

LIQUID LIMIT
LL = 31.7 %

PLASTIC LIMIT
PL = 18.3 %

PLASTICITY INDEX
PI = 13.4 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	145			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	3.33			
Shrinkage Product, SP = LS* % <425um			119.0			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

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Lusaka, Zambia
Tel/Fax: 260-1-291195

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 25/09/2017

OPERATOR: Enious

DATE OF SOAKING: 25/09/2017

DATE OF TESTING: 27/09/2017

SAMPLE SOURCE: **B/P 2 sample 4 (0-2.0m) Stockpile**

Soil Description: **Slightly moist yellowish red clayey gravelly sand**

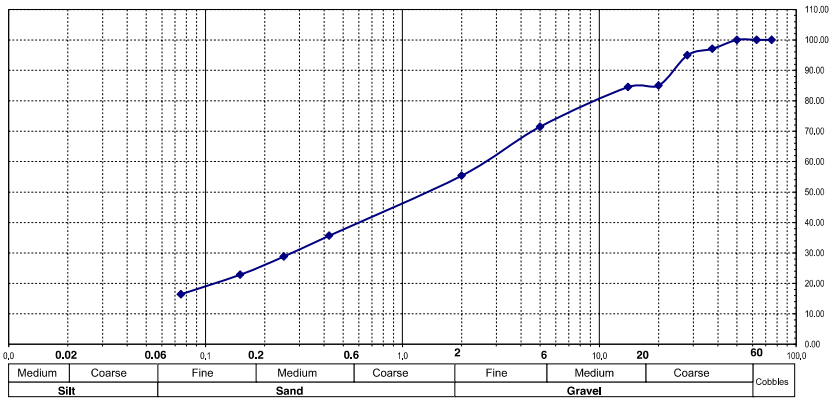
Lab No. **3585**

Initial Dry Mass (m_1) **15282** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75,0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	447	48.8	2.9	97.1	97
28.0	327	35.7	2.1	94.9	95
20.0	1521	166.1	10.0	85.0	85
Passing 20 mm (m_2)	12987				
total (checked with m_1)	**15282**	1668.6			
riffled (m_3)	1418				
riffled and washed (m_4)	909				
Correction factor m3/m2		0.1092			
14.0	8.0	8.0	0.5	84.5	85
5.0	218.0	218.0	13.1	71.4	71
2.0	268.0	268.0	16.1	55.4	55
0.425	329.0	329.0	19.7	35.7	36
<0.425 (+ 509.0	595.0				
Passing 0,425 mm (m5)	595.0				
riffled (m6)	250.0				
riffled and washed (m7)	136.0				
Correction factor m6/m5		0.4202			
0.250	48.0	114.2	6.8	28.8	29
0.150	42.0	100.0	6.0	22.8	23
0.075	45.0	107.1	6.4	16.4	16
<0.075 (+ 114.0	115.0	273.7	16.4		
TOTAL		1668.6	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	1.9
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	42.3
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3585 SANS 3001-GR1 2013 (Soil Sieve Analysis)

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FORM S4

CASAGRANDE

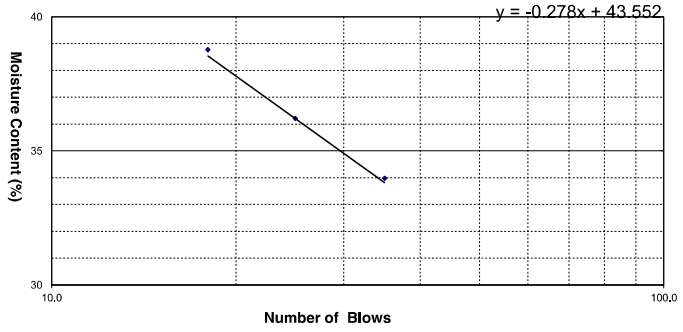
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	B/P 1 sample 5	DESCRIPTION :	Slightly moist light grey gravelly sand-clay mixture
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3586	DATE OF TEST:	28/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	18.0			
Container Number		RNK 23	RNK35	RK10	J8	DM09	
Mass of wet soil & conta	g	18.21	18.14	18.12	11.37	11.26	
Mass of dry soil & contai	g	17.16	17.05	16.98	10.76	10.67	
Mass of container	g	14.07	14.04	14.04	7.39	7.36	
Mass of dry soil	g	3.09	3.01	2.94	3.37	3.31	
Mass of moisture	g	1.05	1.09	1.14	0.61	0.59	
Moisture content	%	34.0	36.2	38.8	18.1	17.8	18.0



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known
Proportion passing on 425 µm sieve :
59
LIQUID LIMIT
LL = 36.6 %
PLASTIC LIMIT
PL = 18.0 %
PLASTICITY INDEX
PI = 18.6 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	146			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	2.67			
Shrinkage Product, SP = LS* % <425um			156.3			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

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Lusaka, Zambia
Tel/Fax: 260-1-291195

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 25/09/2017

OPERATOR: Enious SAMPLE SOURCE: **B/P 1 sample5**

DATE OF SOAKING: 25/09/2017 Soil Description: **Slightly moist light grey gravelly sand-clay mixture**

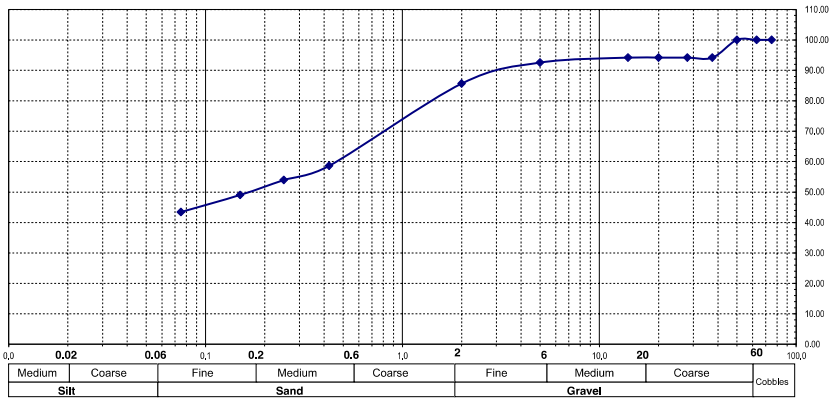
DATE OF TESTING: 27/09/2017 Lab No. **3586**

Initial Dry Mass (m_1) **1587** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	93	36.5	5.9	94.1	94
28.0	0	0.0	0.0	94.1	94
20.0	0	0.0	0.0	94.1	94
Passing 20 mm (m_2)	1494				
total (checked with m_1)	**1587**	622.5			
riffled (m_3)	586				
riffled and washed (m_4)	255				
Correction factor m3/m2		0.3922			
14.0	0.0	0.0	0.0	94.1	94
5.0	10.0	10.0	1.6	92.5	93
2.0	43.0	43.0	6.9	85.6	86
0.425	168.0	168.0	27.0	58.6	59
<0.425 (+ 331.0	365.0				
Passing 0.425 mm (m5)	365.0				
riffled (m6)	250.0				
riffled and washed (m7)	66.0				
Correction factor m6/m5		0.6849			
0.250	20.0	29.2	4.7	53.9	54
0.150	21.0	30.7	4.9	49.0	49
0.075	24.0	35.0	5.6	43.4	43
<0.075 (+ 184.0	185.0	270.1	43.4		
TOTAL		622.5	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	1.1
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	32.9
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3586 SANS 3001-GR1 2013 (Soil Sieve Analysis)

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FORM S4

CASAGRANDE

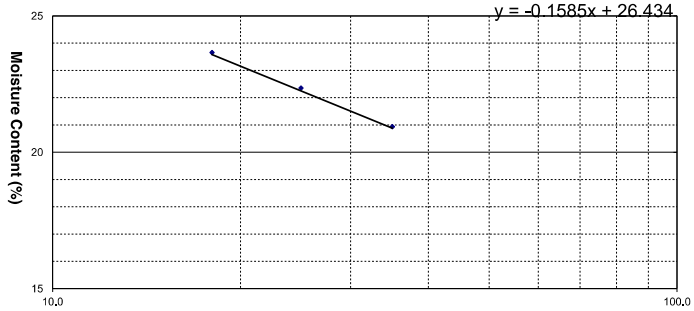
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	8+000 TP 1 layer 1 2.0m	DESCRIPTION :	Dry strong brown clayey sand
CLIENT :	Rankin	CONDITION:	Dry	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3587	DATE OF TEST:	30/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	18.0			
Container Number		RNK 23	RNK35	RK10	J8	DM 09	
Mass of wet soil & conta	g	18.46	18.30	18.16	11.23	11.17	
Mass of dry soil & conta	g	17.70	17.52	17.37	10.83	10.78	
Mass of container	g	14.07	14.03	14.03	7.40	7.36	
Mass of dry soil	g	3.63	3.49	3.34	3.43	3.42	
Mass of moisture	g	0.76	0.78	0.79	0.40	0.39	
Moisture content	%	20.9	22.3	23.7	11.7	11.4	11.5



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known

Proportion passing on 425 µm sieve : 82

LIQUID LIMIT
LL = 22.5 %

PLASTIC LIMIT
PL = 11.5 %

PLASTICITY INDEX
PI = 11.0 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	142			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	5.33			
Shrinkage Product, SP = LS* % <425um			435.7			

Comments:

END

Page 1 of 1

WET SIEVE ANALYSIS **FORM: SANS 3001-GR1: 2013**

CLIENT: **Rankin**

PROJECT: **Pave road design - T002 - Waitwika - D001**

SUPERVISOR: **SN** DATE: 27/09/2017

OPERATOR: Enious SAMPLE SOURCE: **8+000 TP1 layer 1 (0.2m)**

DATE OF SOAKING: 27/09/2017 Soil Description **Dry strong brown clayey sand**

DATE OF TESTING: 30/09/2017 Lab No. **3587**

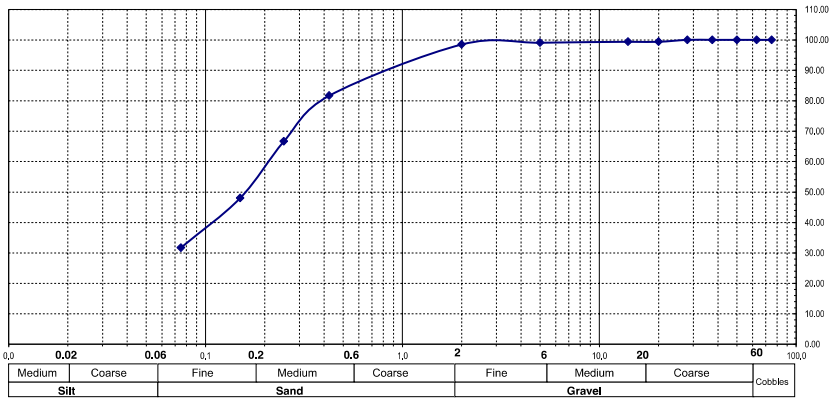
R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

Initial Dry Mass (m_1) **3243** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0			100.0	100
63.0	0	0	0.0	100.0	100
50.0	0	0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	100
28.0	0	0.0	0.0	100.0	100
20.0	21	9.8	0.6	99.4	99
Passing 20 mm (m_2)	3222				
total (checked with m_1)	**3243**	1509.8			
riffled (m_3)	1500				
riffled and washed (m_4)	508				
Correction factor m3/m2		0.4655			
14.0	0.0	0.0	0.0	99.4	99
5.0	4.0	4.0	0.3	99.1	99
2.0	9.0	9.0	0.6	98.5	98
0.425	254.0	254.0	16.8	81.7	82
<0.425 (+ 992.0	1233.0				
Passing 0.425 mm (m5)	1233.0				
riffled (m6)	250.0				
riffled and washed (m7)	155.0				
Correction factor m6/m5		0.2028			
0.250	46.0	226.9	15.0	66.6	67
0.150	57.0	281.1	18.6	48.0	48
0.075	50.0	246.6	16.3	31.7	32
<0.075 (+ 95.0	97.0	478.4	31.7		
TOTAL		1509.8	100.0		

Grading Modulus: GM = (300 -%<2mm-%<0.425mm-%<0.075mm)/100	0.9
Grading Coefficient: GC= (%<28.0-%<0.425) x (%<5.0mm)/100	18.2
USCS classification	SC

SIEVE SIZE BY LOG SCALE



Lab # 3587 SANS 3001-GR1 2013 (Soil Sieve Analysis)

R a n k i n
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Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

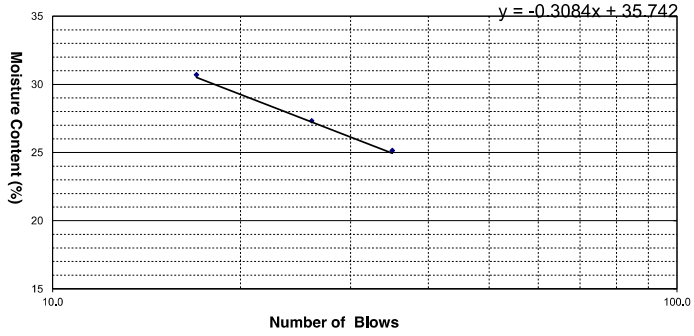
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	8+000 TP 1 layer 2 0.45m	DESCRIPTION :	Slightly moist strong brown clayey sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3588	DATE OF TEST:	29/09/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	26.0	17.0			
Container Number		RNK 23	RNK35	RK10	DM09	J8	
Mass of wet soil & conta	g	18.40	18.27	18.16	11.45	11.31	
Mass of dry soil & conta	g	17.53	17.36	17.19	10.96	10.83	
Mass of container	g	14.07	14.03	14.03	7.36	7.40	
Mass of dry soil	g	3.46	3.33	3.16	3.60	3.43	
Mass of moisture	g	0.87	0.91	0.97	0.49	0.48	
Moisture content	%	25.1	27.3	30.7	13.6	14.0	13.8



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known
Proportion passing on 425 µm sieve :
84
LIQUID LIMIT
LL = 28.0 %
PLASTIC LIMIT
PL = 13.8 %
PLASTICITY INDEX
PI = 14.2 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	142			
Linear Shrinkage, LS = 100* (1-(L_D/L_0))		%	5.33			
Shrinkage Product, SP = LS* % <425um			446.4			

Comments:

END

Page 1 of 1

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

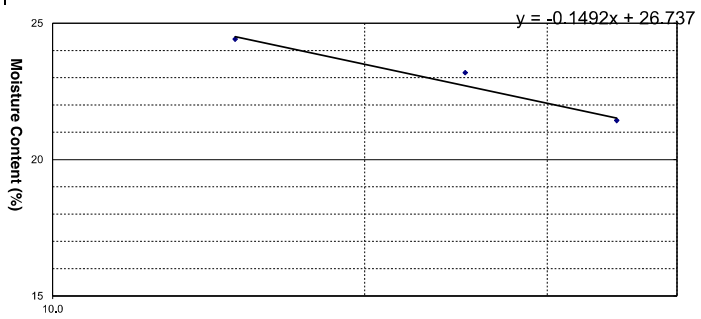
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	3+800 TP 2 layer 1 0.1m	DESCRIPTION :	Dry reddish brown clayey gravelly sand
CLIENT :	Rankin	CONDITION:	Dry	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3589	DATE OF TEST:	10/02/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		35.0	25.0	15.0			
Container Number		RNK 23	RNK35	RK10	J8	DM09	
Mass of wet soil & conta	g	18.65	18.44	18.26	11.45	11.35	
Mass of dry soil & conta	g	17.84	17.61	17.43	10.98	10.91	
Mass of container	g	14.06	14.03	14.03	7.40	7.36	
Mass of dry soil	g	3.78	3.58	3.40	3.58	3.55	
Mass of moisture	g	0.81	0.83	0.83	0.47	0.44	
Moisture content	%	21.4	23.2	24.4	13.1	12.4	12.8



Sample preparation :
a) As received
b) Airdried : ° C
c) Washed on 425 µm
d) Oven dried : ° C
e) Not known
Proportion passing on 425 µm sieve :
43
LIQUID LIMIT
LL = 23.0 %
PLASTIC LIMIT
PL = 12.8 %
PLASTICITY INDEX
PI = 10.2 %

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	147			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	2.00			
Shrinkage Product, SP = LS* % <425um			86.0			

Comments:

END

Page 1 of 1

R a n k i n
Engineering Consultants
Rankin House
Chozi Road
Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

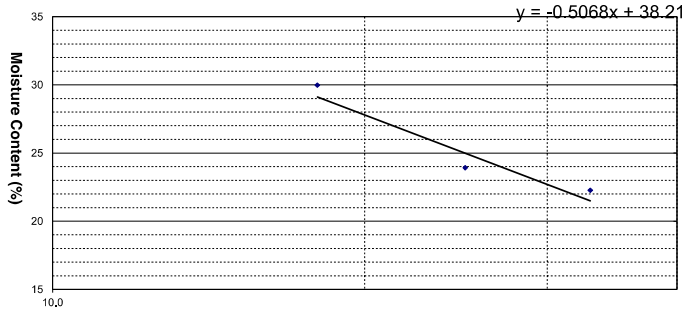
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	3+800 TP 2 layer 2 0.2m	DESCRIPTION :	Slightly moist redlish brown clayey sand
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3590	DATE OF TEST:	10/02/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		33.0	25.0	18.0			
Container Number		RNK 33	LUS1	CH12	D02	YX	
Mass of wet soil & conta	g	18.41	18.27	18.08	11.72	11.50	
Mass of dry soil & conta	g	17.66	17.50	17.19	11.20	11.00	
Mass of container	g	14.29	14.28	14.22	7.20	7.18	
Mass of dry soil	g	3.37	3.22	2.97	4.00	3.82	
Mass of moisture	g	0.75	0.77	0.89	0.52	0.50	
Moisture content	%	22.3	23.9	30.0	13.0	13.1	13.0



Sample preparation :	
a) As received	
b) Airdried :	° C
c) Washed on 425 µm	
d) Oven dried :	° C
e) Not known	
Proportion passing on 425 µm sieve :	
87	
LIQUID LIMIT	
LL = 25.5	%
PLASTIC LIMIT	
PL = 13.0	%
PLASTICITY INDEX	
PI = 12.5	%

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	144			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	4.00			
Shrinkage Product, SP = LS* % <425um			347.6			

Comments:

END

Page 1 of 1

R a n k i n
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Rankin House
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Lusaka, Zambia
Tel/Fax: 260-1-291195

FORM S4

CASAGRANDE

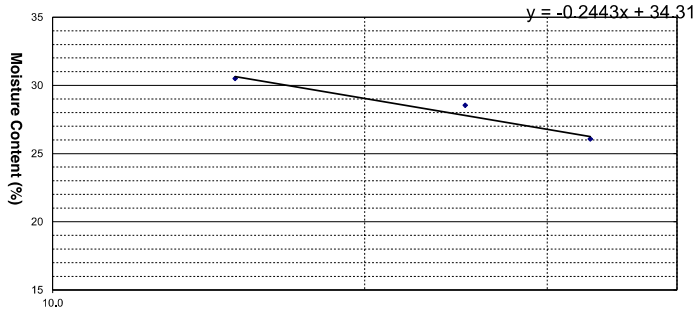
Liquid and Plastic Limits Test Report

Linear Shrinkage and Shrinkage Product

PROJECT :	Pave road design - T002 - Waitwika - D001	LOCATION :	3+800 TP 2 layer 3 0.45m	DESCRIPTION :	Slightly moist rediish brown sandy clay
CLIENT :	Rankin	CONDITION:	Slightly moist	DATE OF RECEIPT :	18/09/2017
ADDRESS :		LAB No :	3591	DATE OF TEST:	10/02/2018
RESPONSIBLE TECHNICIAN :	Enious	CHECKED :	SN	APPROVED :	SR

TEST METHOD ref. SANS 3001-GR10:2013, GR12:2013

		LIQUID LIMIT			PLASTIC LIMIT		
TEST NO.		1	2	3	1	2	Average
Range		28 - 35	22 - 28	15 - 22			
Number of blows		33.0	25.0	15.0			
Container Number		RK 15	A6	K5	S1	1	
Mass of wet soil & contai	g	18.80	18.64	18.45	11.88	11.66	
Mass of dry soil & contai	g	17.82	17.61	17.41	11.25	11.03	
Mass of container	g	14.06	14.00	14.00	7.32	7.17	
Mass of dry soil	g	3.76	3.61	3.41	3.93	3.86	
Mass of moisture	g	0.98	1.03	1.04	0.63	0.63	
Moisture content	%	26.1	28.5	30.5	16.0	16.3	16.2



Sample preparation :	
a) As received	
b) Airdried :	° C
c) Washed on 425 µm	
d) Oven dried :	° C
e) Not known	
Proportion passing on 425 µm sieve :	
90	
LIQUID LIMIT	
LL = 28.2	%
PLASTIC LIMIT	
PL = 16.2	%
PLASTICITY INDEX	
PI = 12.0	%

LINEAR SHRINKAGE and SHRINKAGE PRODUCT

Specimen reference			1	3	4	5
Initial Length	L_0	mm	150			
Oven dried length	L_D	mm	143			
Linear Shrinkage, LS = 100* (1-(L_D/L_O))		%	4.67			
Shrinkage Product, SP = LS* % <425um			421.4			

Comments:

END

Page 1 of 1

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN
ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: Rankin

ADDRESS:

PROJECT: Pave road design - T002 - Waitwika - D001

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: Km 3+800 TP2 layer1 (0.1m) Dry reddish brown clayey gravelly sand

SAMPLE CONDITION: Dry

Lab # 3589

Test Standard: SANS 3001-GR20:2010

Container Number	F15	CM1	RK7				
Mass of wet soil & container (g) (m_2)	44.09	44.2	44.22				
Mass of dry soil & container (g) (m_3)	43.26	43.29	43.4				
Mass of container (g) (m_1)	14.07	14.22	14.3				
Mass of dry soil (g) (m_3 - m_1)	29.19	29.07	29.1				
Mass of moisture (g) (m_2 - m_3)	0.83	0.91	0.82				
Moisture content (%)	2.8%	3.1%	2.8%				
AVERAGE	2.9%						

CHECKED BY: DL

DATE:

END

Page 1 of 1

Lab # 3589 SANS 3001-GR20 2010 (Moisture Content)

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN
ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: Rankin

ADDRESS:

PROJECT: Pave road design - T002 - Waitwika - D001

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: Km 3+800 TP2 layer2 (0.2m) Slightly moist rediish brown clayey sand

SAMPLE CONDITION: Slightly moist

Lab # 3590

Test Standard: SANS 3001-GR20:2010

Container Number	100	CR	RK10				
Mass of wet soil & container (g) (m_2)	44.85	44.05	44.33				
Mass of dry soil & container (g) (m_3)	42.88	42.27	42.47				
Mass of container (g) (m_1)	14.19	13.87	14.04				
Mass of dry soil (g) (m_3 - m_1)	28.69	28.4	28.43				
Mass of moisture (g) (m_2 - m_3)	1.97	1.78	1.86				
Moisture content (%)	6.9%	6.3%	6.5%				
AVERAGE		6.6%					

CHECKED BY: DL

DATE:

END

Page 1 of 1

Lab # 3590 SANS 3001-GR20 2010 (Moisture Content)

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN

ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: Rankin

ADDRESS:

PROJECT: Pave road design - T002 - Waitwika - D001

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: Km 3+800 TP2 layer3 (0.45m) Slightly moist rediish brown sandy clay

SAMPLE CONDITION: Slightly moist

Lab # 3591

Test Standard: SANS 3001-GR20:2010

Container Number	RK9	K7	ACM1				
Mass of wet soil & container (g) (m_2)	44.65	44.45	44.28				
Mass of dry soil & container (g) (m_3)	42.1	41.87	41.53				
Mass of container (g) (m_1)	14.36	13.77	14.21				
Mass of dry soil (g) (m_3 - m_1)	27.74	28.1	27.32				
Mass of moisture (g) (m_2 - m_3)	2.55	2.58	2.75				
Moisture content (%)	9.2%	9.2%	10.1%				
AVERAGE	9.5%						

CHECKED BY: DL

DATE:

END

Page 1 of 1

Lab # 3591 SANS 3001-GR20 2010 (Moisture Content)

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN
ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: **Rankin**

ADDRESS:

PROJECT: **Pave road design - T002 - Waitwika - D001**

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: **Section 2 layer 1 (0.2m) Dry strong brown clayey sand**

SAMPLE CONDITION: **Dry**

Lab # 3592

Test Standard: SANS 3001-GR20:2010

Container Number	RK15	RNK17	A6				
Mass of wet soil & container (g) (m_2)	44.3	44.2	44.01				
Mass of dry soil & container (g) (m_3)	43.44	43.37	43.12				
Mass of container (g) (m_1)	14.09	13.97	14.03				
Mass of dry soil (g) (m_3 - m_1)	29.35	29.4	29.09				
Mass of moisture (g) (m_2 - m_3)	0.86	0.83	0.89				
Moisture content (%)	2.9%	2.8%	3.1%				
AVERAGE	**2.9%**						

CHECKED BY: **DL**

DATE:

END

Page 1 of 1

Lab # 3592 SANS 3001-GR20 2010 (Moisture Content)

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN
ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: **Rankin**

ADDRESS:

PROJECT: **Pave road design - T002 - Waitwika - D001**

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: **Section 2 layer2 (0.45m) Slightly moist strong brown clayey sand**

SAMPLE CONDITION: **Slightly moist**

Lab # 3593

Test Standard: SANS 3001-GR20:2010

Container Number	MD8	RNK33	K11				
Mass of wet soil & container (g) (m_2)	44.87	44.51	44.39				
Mass of dry soil & container (g) (m_3)	42.54	42.37	42.2				
Mass of container (g) (m_1)	14.01	14.31	14.03				
Mass of dry soil (g) (m_3 - m_1)	28.53	28.06	28.17				
Mass of moisture (g) (m_2 - m_3)	2.33	2.14	2.19				
Moisture content (%)	8.2%	7.6%	7.8%				
AVERAGE	**7.9%**						

CHECKED BY: **DL**

DATE:

END

Page 1 of 1

Lab # 3593 SANS 3001-GR20 2010 (Moisture Content)

MOISTURE CONTENT TEST REPORT

FORM S1

RANKIN
ENGINEERING CONSULTANTS
RANKIN HOUSE
CHOZI ROAD
LUSAKA, ZAMBIA
Tel/Fax: 260-1-291195

CLIENT: Rankin

ADDRESS:

PROJECT: Pave road design - T002 - Waitwika - D001

DATE OF RECEIPT: 18-09-2017

TECHNICIAN: SN

DATE: 19-09-2017

SAMPLE SOURCE: Layer 2, Dry yellowish red sand

SAMPLE CONDITION: Dry

Lab # 3594

Test Standard: SANS 3001-GR20:2010

Container Number	MD6	AB5	105				
Mass of wet soil & container (g) (m_2)	44.45	44.75	44.48				
Mass of dry soil & container (g) (m_3)	44.01	44.29	44.05				
Mass of container (g) (m_1)	14.31	13.83	14.39				
Mass of dry soil (g) (m_3 - m_1)	29.7	30.46	29.66				
Mass of moisture (g) (m_2 - m_3)	0.44	0.46	0.43				
Moisture content (%)	1.5%	1.5%	1.4%				
AVERAGE	1.5%						

CHECKED BY: DL

DATE:

END

Page 1 of 1

Lab # 3594 SANS 3001-GR20 2010 (Moisture Content)

Rankin Engineering

California Bearing Ratio Test Report

Date 05/10/2017

Checked By DL

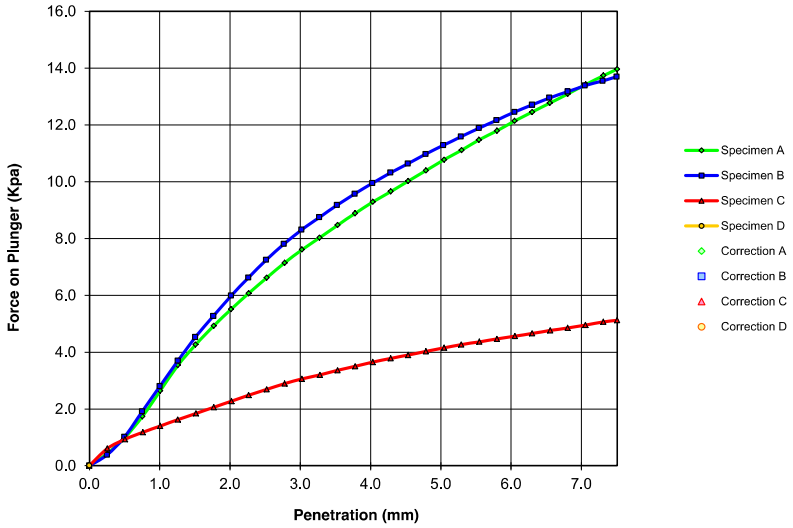
Date

Computed By CM

04/10/2017

Tested By CM

Load Penetration Curve



CBR Results

Results	A	B	C	
2.54 mm Pen.	50.2	54.9	20.4	
5.08 mm Pen.	53.9	56.4	20.7	
Moisture (%)	8.07	7.96	8.09	Swell%0.00
Density (g/cm3)	2.155	2.098	2.009	
%Compaction	99.26	96.62	92.55	

Project Information

Project Num					**Sample Location**	
Project	Pave road design T002 Waitwika				Specimen A	
Date	10/05/2017				Specimen B	B/pit sample 1(0.5 - 2.0m)
Client	Rankin				Specimen C	
					Test Variables	
Job Ref.	607				Liquid Limit:	29.8
Sample Num.	3582				Plastic Limit:	18.2
Remarks	%Compaction	93	95	98		
	%CBR	27	37	51		

Rankin Engineering

California Bearing Ratio Test Report

Date

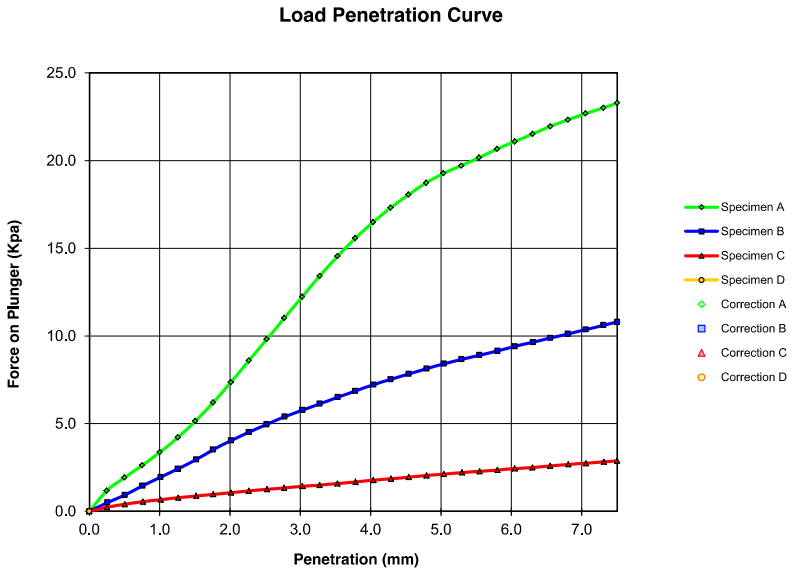
Checked By DL

Date

Computed By CM

04/10/2017

Tested By CM



CBR Results				
Results	**A**	**B**	**C**	
2.54 mm Pen.	74.3	37.5	9.5	
5.08 mm Pen.	96.4	42.1	10.6	
Moisture (%)	7.36	7.36	7.36	Swell% 0.00
Density (g/cm3)	2.145	2.087	1.979	
%Compaction	97.50	94.85	89.97	

Project Information						
Project Num					**Sample Location**	
Project	Pave road design T002 Waitwika				Specimen A	
Date	28/09/2017				Specimen B	B/pit sample 2(0.5 - 2.0m)
Client	Rankin				Specimen C	
					Test Variables	
Job Ref.	607				Liquid Limit:	29.8
Sample Num.	3583				Plastic Limit:	18.2
Remarks	%Compaction	93	95	98		
	%CBR	32	48	72		

Rankin Engineering

California Bearing Ratio Test Report

Date 05/10/2017

Checked By DL

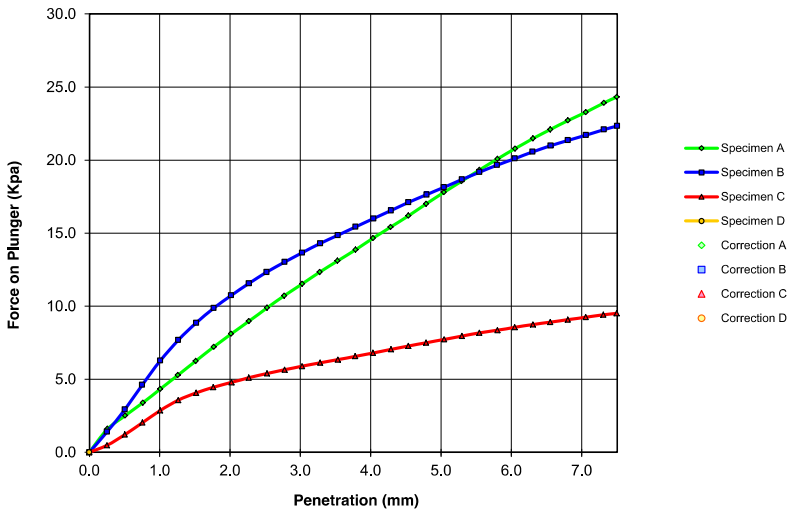
Date 05/10/2017

Computed By CM

04/10/2017

Tested By CM

Load Penetration Curve



CBR Results

Results	A	B	C	D	Average
2.54 mm Pen.	74.9	93.4	40.9		
5.08 mm Pen.	89.0	90.7	38.6		
Moisture (%)	9.56	9.56	9.56	Swell% 0.00	
Density (g/cm3)	2.044	1.979	1.867		
%Compaction	96.86	93.80	88.50		

Project Information

Project Num				**Sample Location**	
Project	Pave Road Design			Specimen A	
Date	04/10/2017			Specimen B	B/P2 Sample 3 - 0.2m
Client	Rankin			Specimen C	
				Test Variables	
Job Ref.	607			Liquid Limit:	29.8
Sample Num.	3584			Plastic Limit:	17.9
Remarks	%Compaction	93	95	98	
	%CBR	69	79	92	

Rankin Engineering

California Bearing Ratio Test Report

Date

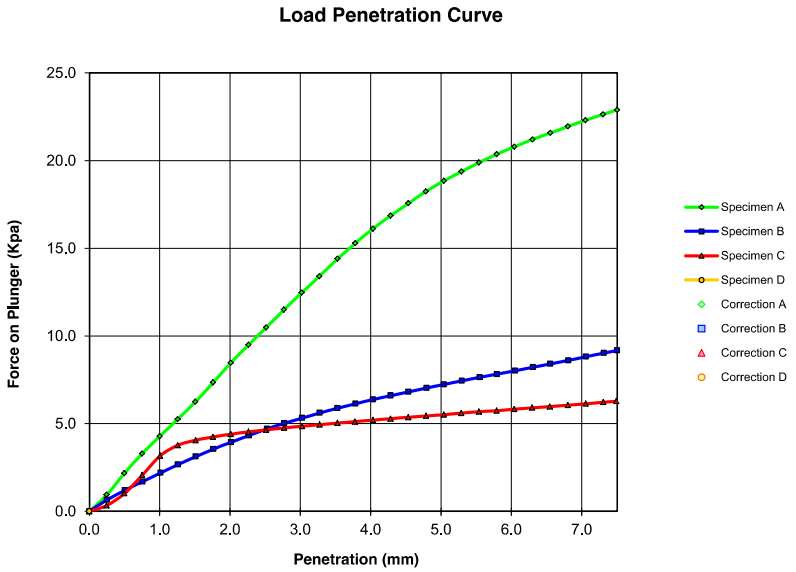
Checked By DL

Date

Computed By CM

Date ########

Tested By CM



CBR Results				
Results	**A**	**B**	**C**	
2.54 mm Pen.	79.4	35.6	35.2	
5.08 mm Pen.	94.3	36.2	27.6	
Moisture (%)	8.19	8.19	8.19	Swell% 0.00
Density (g/cm3)	2.065	1.934	1.843	
%Compaction	95.17	89.13	84.93	

Project Information						
Project Num					**Sample Location**	
Project	Pave Road Design				Specimen A	BP 2 Sample 4 0.2m
Date	04/10/2017				Specimen B	
Client	Rankin				Specimen C	
					Test Variables	
Job Ref.	607				Liquid Limit:	31.7
Sample Num.	3585				Plastic Limit:	18.3
Remarks	%Compaction	93	95	98		
	%CBR	65	74	86		

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3585

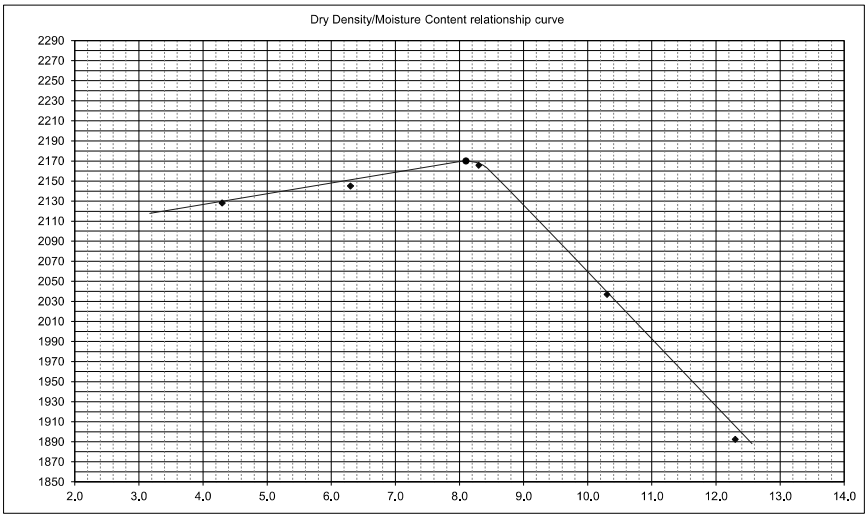
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist yellowish red clayey gravelly sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** B/p 2 sample 4 8+940 RHS 0.0-2.0m

Compaction type:

Mould no. 28		Mass		4828 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9960.0	10100.0	10251.0	10023.0	9742.0				
Weight of sample	g	5132.0	5272.0	5423.0	5195.0	4914.0				
Wet Density	kg/m^3	2226	2287	2353	2254	2132				
Dry Density	kg/m^3	2128	2145	2166	2037	1893				
Factor of mould:										
Moisture Container no.		DM6	DM4	TK4	RL2	OM05				
Weight of wet soil+ container	g	2754	2943	3620	2742	2890				
Weight of dried soil + container	g	2622	2791	3341	2502	2610				
Weight of container	g	648	1045	698	605	677				
Weight of dry soil	g	1974.0	1746.0	2643.0	1897.0	1933.0				
Actual Moisture Content	%	6.7	8.3	10.5	12.6	14.7				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.3	0.3	0.3	0.3	0.3				
Adjusted Moisture Content	%	4.3	6.3	8.3	10.3	12.3				



Optimum Moisture Content:	**OMC**	**8.1** %
Maximum Dry Density:	**MDD**	**2170** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** **3587**

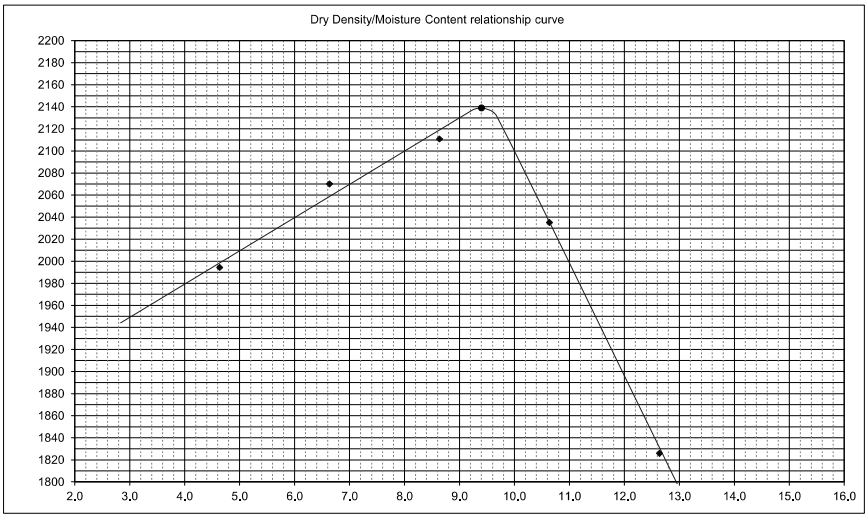
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Dry strong brown clayey sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** 8+000 TP 1 layer 1 0.2m

Compaction type:

Mould no. 33		Mass		4787 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9612.0	9891.0	10089.0	9993.0	9542.0				
Weight of sample	g	4825.0	5104.0	5302.0	5206.0	4755.0				
Wet Density	kg/m^3	2093	2214	2300	2259	2063				
Dry Density	kg/m^3	1994	2070	2111	2035	1826				
Factor of mould:										
Moisture Container no.		OM35	OM41	OM31	OM12	OM5				
Weight of wet soil+ container	g	542	698	732	607	612				
Weight of dried soil + container	g	523	665	687	558	556				
Weight of container	g	116	166	177	101	117				
Weight of dry soil	g	407.0	499.0	510.0	457.0	439.0				
Actual Moisture Content	%	4.7	6.2	8.7	10.6	13.0				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.6	0.6	0.6	0.6	0.6				
Adjusted Moisture Content	%	4.6	6.6	8.6	10.6	12.6				



Optimum Moisture Content: OMC	**9.4** %
Maximum Dry Density: MDD	**2139** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3588

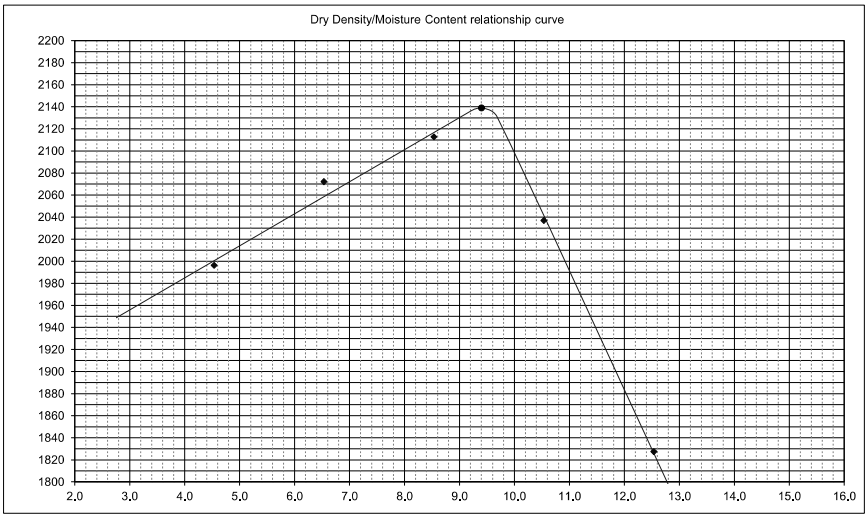
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist strong brown clayey sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** 8+000 TP 1 layer 2 0.45m

Compaction type:

Mould no. 33		Mass		4787 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9612.0	9891.0	10089.0	9993.0	9542.0				
Weight of sample	g	4825.0	5104.0	5302.0	5206.0	4755.0				
Wet Density	kg/m^3	2093	2214	2300	2259	2063				
Dry Density	kg/m^3	1996	2072	2113	2037	1827				
Factor of mould:										
Moisture Container no.		OM45	OM40	OM32	OM16	OM8				
Weight of wet soil+ container	g	541	698	732	608	611				
Weight of dried soil + container	g	524	665	687	558	556				
Weight of container	g	116	166	177	101	117				
Weight of dry soil	g	408.0	499.0	510.0	457.0	439.0				
Actual Moisture Content	%	4.2	6.2	8.7	10.8	12.7				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.5	0.5	0.5	0.5	0.5				
Adjusted Moisture Content	%	4.5	6.5	8.5	10.5	12.5				



Optimum Moisture Content:	**OMC**	**9.4** %
Maximum Dry Density:	**MDD**	**2139** kg/m^3

Remarks:

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3589

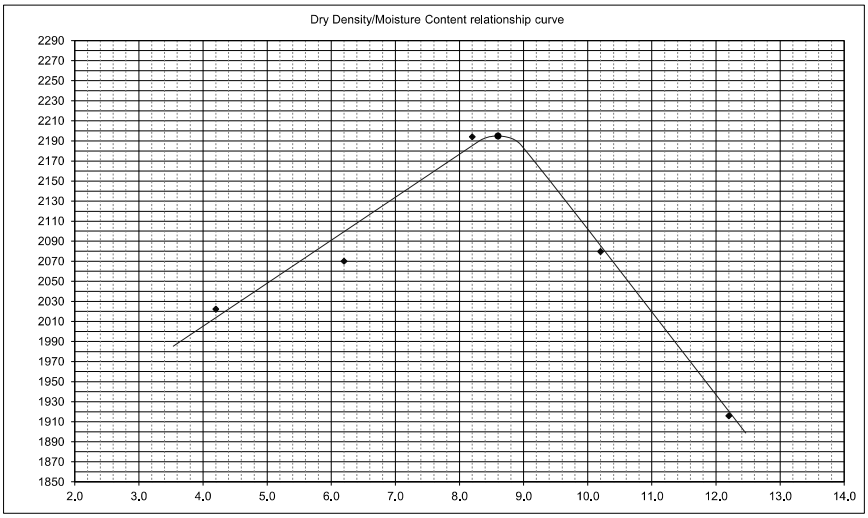
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Dry reddish brown clayey gravelly sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** 3+800 TP 2 layer 1 0.1m

Compaction type:

Mould no. 35		Mass		4842 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9714.0	9925.0	10331.0	10141.0	9812.0				
Weight of sample	g	4872.0	5083.0	5489.0	5299.0	4970.0				
Wet Density	kg/m^3	2114	2205	2381	2299	2156				
Dry Density	kg/m^3	2022	2070	2194	2080	1916				
Factor of mould:										
Moisture Container no.		RL1A	RL2	RL5	RL03	RL6				
Weight of wet soil+ container	g	2868	2977	3135	3037	3015				
Weight of dried soil + container	g	2780	2838	2949	2835	2783				
Weight of container	g	668	605	675	886	884				
Weight of dry soil	g	2112.0	2233.0	2274.0	1949.0	1899.0				
Actual Moisture Content	%	4.2	5.8	8.1	10.3	12.4				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.2	0.2	0.2	0.2	0.2				
Adjusted Moisture Content	%	4.2	6.2	8.2	10.2	12.2				



Optimum Moisture Content:	**OMC**	**8.6** %
Maximum Dry Density:	**MDD**	**2195** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3590

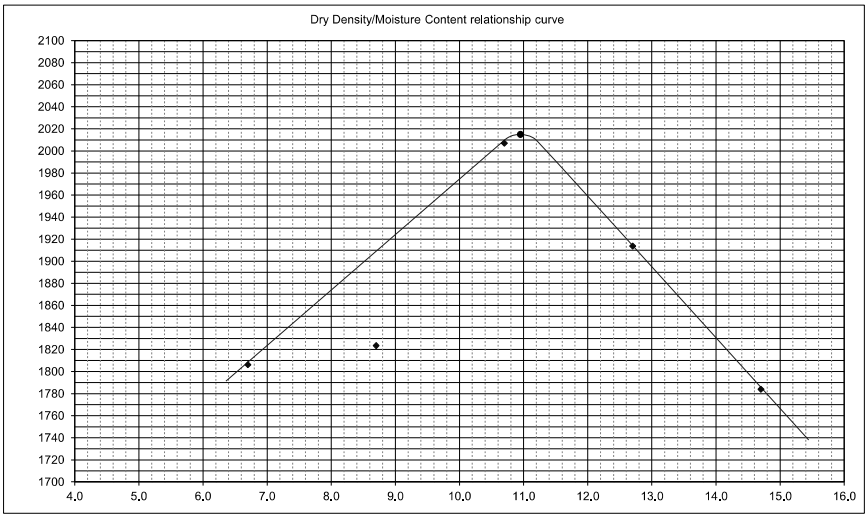
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist rediish brown clayey sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** 3+800 TP 2 layer 2 0.2m

Compaction type:

Mould no. 35		Mass		4842 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		6	8	10	12	14				
Weight of mould + sample	g	9298.0	9425.0	9979.0	9829.0	9573.0				
Weight of sample	g	4456.0	4583.0	5137.0	4987.0	4731.0				
Wet Density	kg/m^3	1933	1988	2229	2164	2052				
Dry Density	kg/m^3	1806	1824	2007	1914	1784				
Factor of mould:										
Moisture Container no.		RL2	TK4A	RL3	RL01	RL6				
Weight of wet soil+ container	g	2977	2886	3004	3007	3020				
Weight of dried soil + container	g	2828	2709	2778	2744	2722				
Weight of container	g	605	698	677	686	684				
Weight of dry soil	g	2223.0	2011.0	2101.0	2058.0	2038.0				
Actual Moisture Content	%	6.7	8.4	10.7	12.7	14.8				
Estimated Moisture Content	%	6.0	8.0	10.0	12.0	14.0				
Average diff. Moisture content	%	0.7	0.7	0.7	0.7	0.7				
Adjusted Moisture Content	%	6.7	8.7	10.7	12.7	14.7				



Optimum Moisture Content:	**OMC**	**11.0** %
Maximum Dry Density:	**MDD**	**2015** kg/m^3

Remarks:

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** **3591**

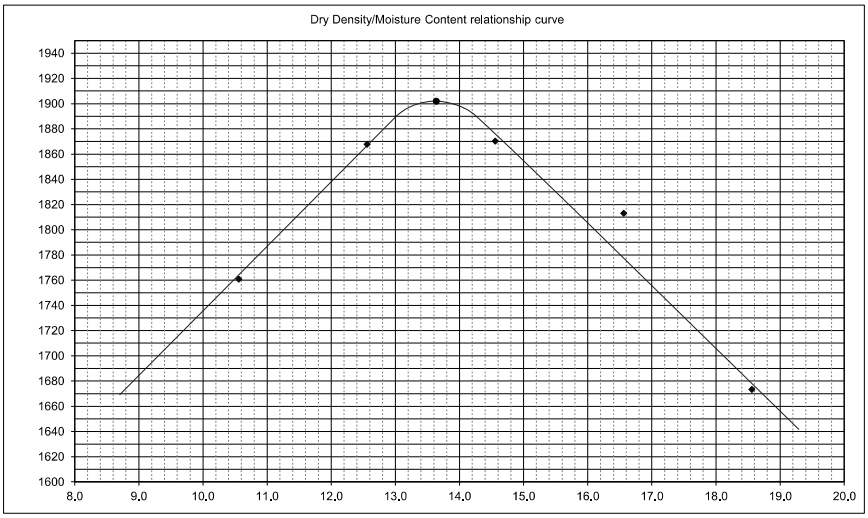
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist rediish brown sandy clay

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** 3+800 TP 2 layer 3 0.45m

Compaction type:

Mould no. 33		Mass		4787 g		Volume	2305	(m^3)	Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9288.0	9648.0	9741.0	9673.0	9374.0				
Weight of sample	g	4501.0	4861.0	4954.0	4886.0	4587.0				
Wet Density	kg/m^3	1953	2109	2149	2120	1990				
Dry Density	kg/m^3	1761	1868	1870	1813	1673				
Factor of mould:										
Moisture Container no.		RL6	RL8	TK	RL5	RL1				
Weight of wet soil+ container	g	3004	3008	3053	3072	3026				
Weight of dried soil + container	g	2778	2744	2773	2770	2655				
Weight of container	g	677	686	885	884	678				
Weight of dry soil	g	2101.0	2058.0	1888.0	1886.0	1977.0				
Actual Moisture Content	%	10.8	12.4	14.7	15.9	19.0				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	6.6	6.6	6.6	6.6	6.6				
Adjusted Moisture Content	%	10.6	12.6	14.6	16.6	18.6				



Optimum Moisture Content:	**OMC**	**13.6** %
Maximum Dry Density:	**MDD**	**1902** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3582

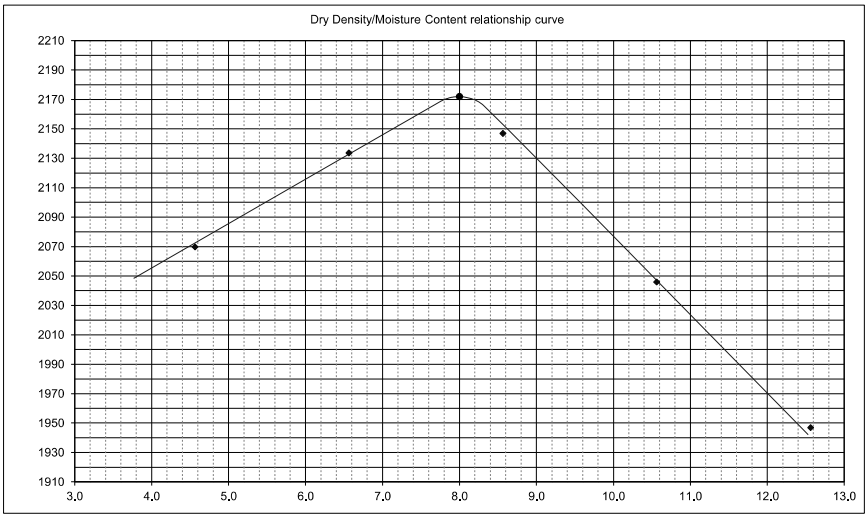
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist yellowish red clayey gravelly sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** B/p 1 sample 1 2+800 RHS 0.5-2.0m

Compaction type:

Mould no. 28		Mass		4828 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9832.0	10085.0	10217.0	10058.0	9895.0				
Weight of sample	g	5004.0	5257.0	5389.0	5230.0	5067.0				
Wet Density	kg/m^3	2171	2281	2338	2269	2198				
Dry Density	kg/m^3	2070	2134	2147	2046	1947				
Factor of mould:										
Moisture Container no.		OM5	RL3	BZ1	RL1	TK10				
Weight of wet soil+ container	g	3701	3592	3650	3746	3698				
Weight of dried soil + container	g	3575	3403	3441	3448	3405				
Weight of container	g	669	677	1049	686	1046				
Weight of dry soil	g	2906.0	2726.0	2392.0	2762.0	2359.0				
Actual Moisture Content	%	4.3	6.5	8.6	10.7	12.6				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.6	0.6	0.6	0.6	0.6				
Adjusted Moisture Content	%	4.6	6.6	8.6	10.6	12.6				



Optimum Moisture Content:	**OMC**	**8.0** %
Maximum Dry Density:	**MDD**	**2172** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3583

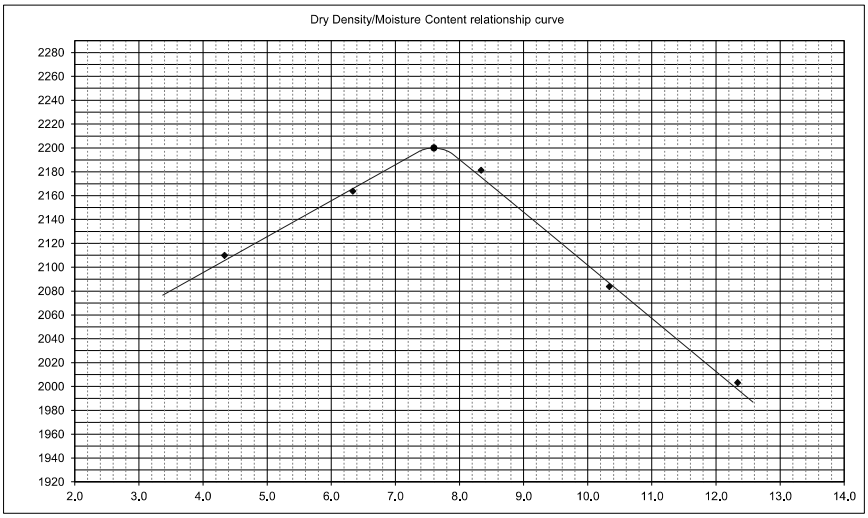
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist yellowish red clayey gravelly sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** B/p 1 sample 2 2+800 RHS 0.5-2.0m

Compaction type:

Mould no. 28		Mass		4828 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9918.0	10148.0	10292.0	10144.0	10031.0				
Weight of sample	g	5090.0	5320.0	5464.0	5316.0	5203.0				
Wet Density	kg/m^3	2208	2308	2370	2306	2257				
Dry Density	kg/m^3	2110	2164	2181	2084	2003				
Factor of mould:										
Moisture Container no.		OM	KK01	RL6	RL7	RL12				
Weight of wet soil+ container	g	3640	4053	3735	3504	3692				
Weight of dried soil + container	g	3514	3861	3494	3259	3352				
Weight of container	g	673	1072	674	678	680				
Weight of dry soil	g	2841.0	2789.0	2820.0	2581.0	2672.0				
Actual Moisture Content	%	4.4	6.5	8.4	9.4	12.9				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.3	0.3	0.3	0.3	0.3				
Adjusted Moisture Content	%	4.3	6.3	8.3	10.3	12.3				



Optimum Moisture Content:	**OMC**	**7.6** %
Maximum Dry Density:	**MDD**	**2200** kg/m^3

Remarks:

For the Engineers

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Compaction Test

Test Standard: SANS 3001-GR30:2013 **LAB No.** 3584

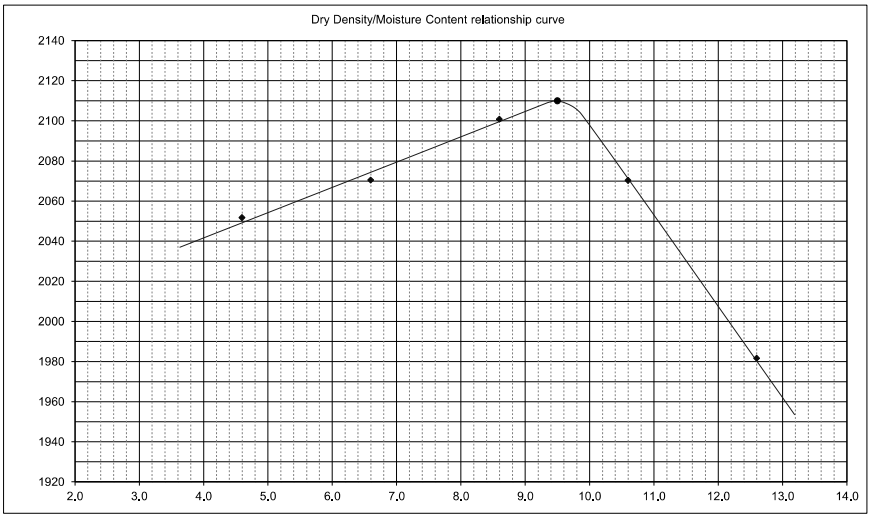
Client Rankin **Project:** Pave road design - T002 - Waitwika - D001

Date Sampled: **Sampled By:** DL **Sample Description:** Slightly moist yellowish red clayey gravelly sand

Sample St.: **Offset from ¢ (m):** **Lane:** **Work Area:** **Source:** B/p 2 sample 3 8+940 RHS 0.0-2.0m

Compaction type:

Mould no. 43		Mass		4828 g		Volume	2305 (m^3)		Factor	43.38
WATER ADDED		4	6	8	10	12				
Weight of mould + sample	g	9790.0	9931.0	10103.0	10122.0	9987.0				
Weight of sample	g	4962.0	5103.0	5275.0	5294.0	5159.0				
Wet Density	kg/m^3	2153	2214	2289	2297	2238				
Dry Density	kg/m^3	2052	2070	2101	2070	1982				
Factor of mould:										
Moisture Container no.		RL10	RL11	RL5	RL6B	RL8				
Weight of wet soil+ container	g	3166	3026	2942	3365	3162				
Weight of dried soil + container	g	3051	2881	2762	3104	2885				
Weight of container	g	640	680	675	699	677				
Weight of dry soil	g	2411.0	2201.0	2087.0	2405.0	2208.0				
Actual Moisture Content	%	4.8	6.2	8.5	10.8	12.7				
Estimated Moisture Content	%	4.0	6.0	8.0	10.0	12.0				
Average diff. Moisture content	%	0.6	0.6	0.6	0.6	0.6				
Adjusted Moisture Content	%	4.6	6.6	8.6	10.6	12.6				



Optimum Moisture Content:	**OMC**	**9.5** %
Maximum Dry Density:	**MDD**	**2110** kg/m^3

Remarks:

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APPENDIX B: Laboratory test results on possible surfacing aggregate

Civilab

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Southdale
2135

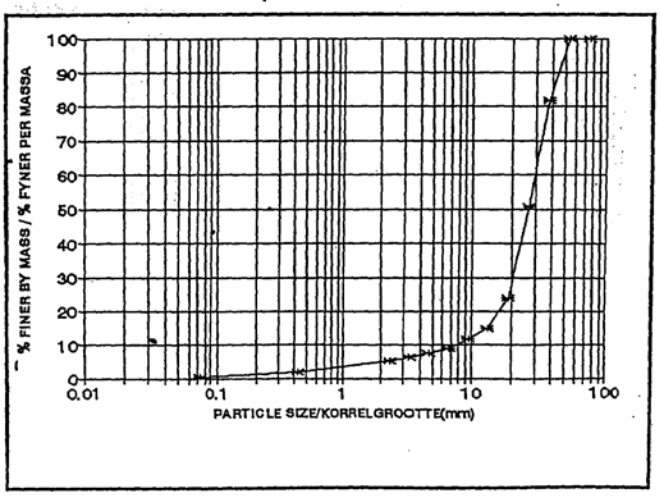
AGGREGAAT TOETSGEGEWENS DATA\AGGREGATE TEST DATA

Projek\Project :	ZAMBIA ROAD PROJECT
Projek\Project.nr\no. :	1039/F71/07/98
Monster\Sample nr\no.:	Z669
Beskryw.\Descript. :	Mbala - Nakonde Road D1/10
Datum\Date :	04/09/98
Veldverw\Field Ref. :	Borehole Number 2

% PASSSING BY MASS (mm)	SIZE (mm)	TEST SAMPLE
	75.0	100
	53.0	100
	37.5	82
	26.5	51
	19.0	24
	13.2	15
	9.5	12
	6.7	9
	4.75	7
	3.35	6
	2.36	5
	0.425	2
(mm)	DUST CONTENT	0.4

AGG.CRUSHING VALUE(%)	20.0	WATER ABSORPTION (%)	0.31
10% FACT (kN)	N/T	R&W STRIPPING	N/T
FLAKINESS INDEX (%)	24.2	BINDER ABSORPTION (%)	N/T
AV.LEAST DIMENSION(mm)	N/T	APPARENT RELATIVE DENSITY	2.665
COMPACTED BULK DENSITY	N/T	BULK RELATIVE DENSITY	2.643

Remarks : (N/T) DENOTE NOT TESTED.



APPENDIX C: Compaction control using DCP

Compaction control using the DCP							Page 1 of 2
Project:				Checked by:			
	Completed date:		Time:		Checked date::		Time:
hainage:	/		Side:		Lab DN:		OMC:

Compaction Trial					
Target DN:	achieved at relative compaction:		% of MDD	FMC:	RMC:

Production					
Achieved compaction - average of		tests:	% of MDD	FMC:	RMC:

Elimination of Outliers

First				
Test no	DN	T_0	Sample values	
1			S_n =	
2			$\bar{x}$ =	
3			T_0 =	
4				
5				
6				
7				
8				
9				
10				
11				
12				

Second				
Test no	DN	T_0	Sample values	
1			S_n =	
2			$\bar{x}$ =	
3			T_0 =	
4				
5				
6				
7				
8				
9				
10				
11				
12				

Third				
Test no	DN	T_0	Sample values	
1			S_n =	
2			$\bar{x}$ =	
3			T_0 =	
4				
5				
6				
7				
8				
9				
10				
11				
12				

No of tests N	Critical T1
4	1.46
5	1.67
6	1.82
7	1.94
8	2.03
9	2.11
10	2.18
11	2.23
12	2.29

$$T_o = \frac{x_o - \bar{x}_n}{s_n}$$

S_n = Standard deviation

$\bar{x}$ = Sample mean

X_0 = DN

Decision: Accept | Conditional acceptance | Reject

Action:

Approved by: Date:

Compaction control using the DCP	Page 2 of 2

Judgement criteria:

1. Check Sample Mean
   a. If $x_n > x_{n\,max}$, reject
   b. If $x_n \leq x_{n\,max}$, proceed to
2. Check Standard Deviation
   a. If $S_n \leq S_{n\,accept}$, accept
   b. If $S_{n\,accept} < S_n \leq S_{n\,conditional}$,
   c. If $S_n > S_{n\,conditional}$, reject

APPENDIX D: Visual assessment field forms

VISUAL ASSESSMENT : FLEXIBLE PAVEMENTS

AfCAP Africa Community Access Partnership

ROAD AUTHORITY :
REGION / SUBURB :
ROAD NO / STREET NAME :
SEGMENT (FROM - TO) :
SEGMENT DIMENSIONS : LENGTH ____ m WIDTH ____ m

ROUTE CLASS : 1 2 3 4 5
TRAFFIC : VL L M H VH
GRADIENT : Flat | Med | Steep
TERRAIN : Flat | Rolling | Mount

ENGINEERING ASSESSMENT

SURFACING

CURRENT SURFACING :

	DEGREE: MINOR 0 1 2	WARNING 3 4	SEVERE 5	EXTENT: ISOLATED 1 2	3 4	EXTENSIVE 5
SURFACING FAILURES						
SURFACING PATCHING						
SURFACING CRACKS						
BINDER CONDITION (DRY / BRITTLE)						
AGGREGATE LOSS (A / N)						
BLEEDING / FLUSHING						
SURFACING DEFORMATION / SHOVING						

TEXTURE: COARSE | MEDIUM | FINE | VARYING
VOIDS: MANY | FEW | NONE | VARYING

STRUCTURAL

	DEGREE: MINOR 0 1 2	WARNING 3 4	SEVERE 5	EXTENT: ISOLATED 1 2	3 4	EXTENSIVE 5
BLOCK CRACKS						
TRANSVERSE CRACKS						
LONGITUDINAL CRACKS						
CROCODILE CRACKS						
PUMPING						
RUTTING						
UNDULATIONS / SETTLEMENT						
PATCHING						
FAILURES / POTHOLES						

FUNCTIONAL ASSESSMENT

ROUGHNESS	Very Good	Good	Moderate	Poor	Very Poor
Problem			ndulations	moles	rrugations
SKID RESISTANCE	Very Good	Good	Moderate	Poor	Very Poor
Problem				bleeding	polished
SURFACE DRAINAGE		Adequate	Inconsistent	Inadequate	
Problem	rutting	shoulders	ndulations	failures	side drains
SHOULDERS (unpaved)	None	Safe	Inconsistent	Unsafe	
Problem	eroded	vergrown	inclined	too high	oo narrow
EDGE DEFECTS	0 1 2 3 4	5	1 2 3	4 5	
Problem			edge break	drop off	dge cracks

SUMMARY

OVERALL PAVEMENT CONDITION	Very Good	Good	Moderate	Poor	Very Poor

(COMMENTS:

OTHER PROBLEMS	service crossings	trees	moles		mechanic al damage

ASSESSOR : ____ DATE : ____

VISUAL ASSESSMENT : UNPAVED ROADS

ROAD AUTHORITY	:		ROUTE CLASS :	1	2	3	4	5
REGION / SUBURB	:		TRAFFIC :	VL	L	M	H	VH
ROAD NO / STREET NAME	:		GRADIENT :	Flat		Med	Steep	
SEGMENT (FROM)	:		TERRAIN :	Flat	Rolling		Mount	
SEGMENT (TO)	:		ROAD TYPE :	Gravel	Earth	Track		
SEGMENT DIMENSIONS	:	LENGTH ____ m	WIDTH ____ m					

MATERIAL INFORMATION / GRAVEL PROPERTIES

MATERIAL TYPE	Ferricrete	Calcrete	Quartzite	Chert	Dolomite
	Sandstone	Granite	Shale	Dolorite	Varies
MATERIAL QUALITY	Very Good	Good	Moderate	Poor	Very Poor
		Problem	oversize	clay/silt	ose gravel / oose sand
MAXIMUM SIZE		< 13 mm	13 - 25 mm	25 - 50 mm	> 50 mm
GRADING		Coarse	Medium	Fine	
ESTIMATED 'PI'		< 6	6 - 12	> 12	
LAYER THICKNESS	0 mm	25 - 50 mm	50 - 100 mm	100 - 125mm	> 125mm
EXPOSURED SUBGRADE		none	isolated	frequent	continious
SUBGRADE QUALITY	Very Good	Good	Moderate	Poor	Very Poor
		Problem		wet	clay/mud / sand

SURFACE DISTRESS / ENGINEERING ASSESSMENT

	DEGREE					EXTENT				
	MINOR		WARNING		SEVERE	ISOLATED				EXTENSIVE
	0	1	2	3	4	5	1	2	3	4	5
POTHOLES											
CORRUGATIONS											
RUTTING											
LOOSE MATERIAL											
STONINESS : FIXED											
: LOOSE											
EROSION : LONGITUDINAL											
: TRANSVERSE											

FUNCTIONAL ASSESSMENT

ROUGHNESS			Very Good	Good	Moderate	Poor	Very Poor
	Problem	formation / potholes	stoniness	ck outcrop	rrugations	loose mat	ut/erosion
TRAFFICIBILITY			Very Good	Good	Moderate	Poor	Very Poor
	Problem	loose mat	clay	rocky	vegetation	steep	drainage
SAFETY			Very Good	Good	Moderate	Poor	Very Poor
		Problem					
DRAINAGE : ON THE ROAD			Very Good	Good	Moderate	Poor	Very Poor
		Problem		windrows	rutting	oad shape	road level
DRAINAGE : SIDE OF THE ROAD			Very Good	Good	Moderate	Poor	Very Poor
		Problem		ulvert inlets	side drains	itre drains	road level

SUMMARY

OVERALL PAVEMENT CONDITION	Very Good	Good	Moderate	Poor	Very Poor

(COMMENTS:

ASSESSOR : _____ DATE : _____

APPENDIX E: Gravel loss measurement procedure

The loss of gravel from unpaved roads is an essential part of investigation of innovative materials or construction techniques. Numerous techniques ranging from the incorporation of metallic sensors, Ground Penetrating Radar (GPR), the excavation of holes, etc. have been used in attempting to quantify gravel loss. However, only precise levelling surveys have been found to be sufficiently accurate for research and monitoring purposes. The process for this is described below and involves comparing the average height of a section of road over time with the height of fixed benchmarks.

These benchmarks must be positioned at the start and end of the monitoring section, preferably in the road and placed so that they are unlikely to be affected by subgrade movements.

The setting of 500 mm steel roads (10 - 15 mm in diameter) in concrete blocks at subgrade level has been found to be satisfactory (Figure A-1).

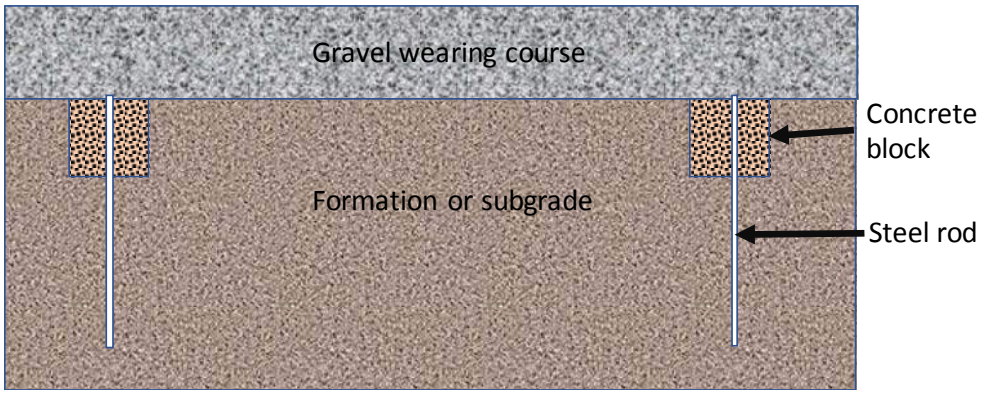


Figure E-1: Placement of stable benchmarks

A gravel loss monitoring section will normally be 50 m long, on a flat and level section of road with no culverts or cross-drainage structures and should fit within the trafficked portion of the carriageway. The bench marks should be placed at each end of the section and at least 3 (preferably 4) should be installed as shown in Figure A-2.

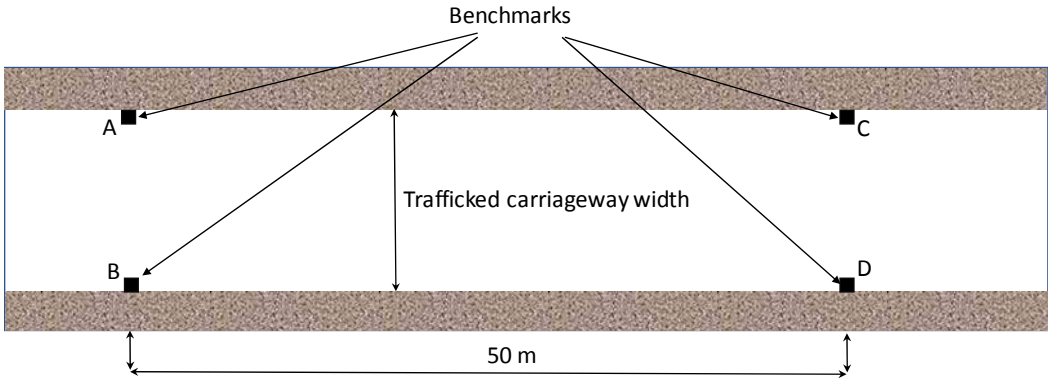


Figure E-2: Location of stable benchmarks

The width of the monitored section (trafficked carriageway width) is usually between 5 and 8 or 9 metres and should be fixed at metre lengths.

During monitoring, the heights of each of the bench marks should be determined and checked against the previous heights to ensure that there has been no movement relative to each other. Two tape measures should then be laid out, one longitudinally along the 50-m length between the bench marks on one side (B and D) and the second transversely between the first two benchmarks (A and B).

A level should be taken at each 1-metre interval along the tape between benchmarks A and B. The transverse tape should then be moved to the point at 5 m along the longitudinal tape and measurements taken across the road again. This will continue at 5 m intervals until the final transverse measurement at 50-m giving 11 sets of readings, each numbering between 6 and 9 or 10 across the road. The objective is to try and take the level readings as close as possible to fixed points during each survey.

If there has been no differential movement between the benchmarks, any one of them can be used as a datum. The average height of all the readings is then calculated and the difference between this and the bench mark height determined. This is done at about 3 month intervals and a progressive change (decrease) in the height of the road relative to the benchmarks will be determined.
This can be plotted as the gravel loss with time.