Use of the DCP Pavement Design Method for Low Volume Sealed Roads in Malawi

Design Review and Training Report

AFCAP2/ASCAP Project Activity Number MAL2007A

AUTHORS: M I Pinard J Hongve

October 2014

Table of Contents

List of Abbreviations

AFCAP	African Community Access Programme
ASWAP-SP	Agriculture Sector -Wide Approach – Support Project
CBR	California Bearing Ratio
CUSUM	Cumulative Sum
DCP	Dynamic Cone Penetrometer
DFID	Department for International Development
DN	DCP Number - Rate of DCP penetration in mm/blow
EOD	Environmentally Optimized design
EDD	Extended Design Domain
EMC	Equilibrium Moisture Content
FMC	Field Moisture Content
Km	Kilometre
LVR	Low Volume Road
LVSR	Low Volume Sealed Road
MDD	Maximum Dry Density
MESA	Million Equivalent Standard Axles
OMC	Optimum Moisture Content
SID	Spot Improvement Design
ToR	Terms of Reference

List of Tables

Page

List of Figures

Page

ASWAP PROJECT LOCATION MAP

EXECUTIVE SUMMARY

As part of its capacity building programme in Malawi, AFCAP provided technical support, in the form of Low Volume Sealed Roads (LVSR) specialists, to assist the Roads Authority with the implementation of the roads component of the World Bank funded ASWAP-SP project. The main objective of this assistance, which took place over the period 29th September to 10th October, 2014, was to:

- Review the Dynamic Cone Penetrometer (DCP) design work undertaken by the ASWAP-SP design consultants;
- Provide further training to the ASWAP-SP design consultants based on any shortcomings identified in the review above;
- Provide further training to the Central Materials Laboratory and other laboratory technicians on various aspects of materials sampling, laboratory testing procedures and sample preparation for determination of laboratory DN values for imported material.

The five ASWAP-SP projects selected for upgrading to a LVSR standard (total length of 40 km) present a wide variety of engineering challenges and require different solutions in terms of pavement design, materials utilisation and surfacing to tailor the design cost-effectively to the natural and operational road environment. In this regard, the key finding from the visit is that the preliminary project designs need to be enhanced in various respects along the lines suggested in this design review report in order to arrive at the most appropriate design for each road.

Some of the key lessons learnt from the project include:

- The design of a LVSR is a specialised civil engineering discipline. Engineers who have only experience with traditional design methods can initially have difficulty in grasping those concepts which are a key aspect of DCP/LVSR design technology such as the principles of Environmentally Optimized Design coupled with a Spot Improvement Design (SID) approach.
- For training purposes, it is not only the DCP design method that needs to be properly understood by designers but, equally importantly, the broader LVSR design issues such as an appreciation of the role of the road environment and the adoption of appropriate specifications for naturally occurring road construction materials.
- Training in DCP/LVSR technology is a multi-staged process which needs to combine classroom training with hands-on detailed design exposure, including all necessary field investigations and laboratory testing, to produce design which can then be subjected to a rigorous review process in close collaboration with the designer.
- A few issues have been identified that need need to be expanded upon and incorporated in a future update of the DCP Design Manual, e.g. a more detailed explanation of materials testing procedures and requirements, borrow pit investigations and logging of test pits, traffic counting procedures and strategic selection of traffic count census points.

In summary, the design review has highlighted various shortcomings in the preliminary designs which need to be addressed by the design consultants before they are included in the tender documents. It is therefore recommended that further vetting of the final designs should be undertaken by the AFCAP consultants.

1. INTRODUCTION

1.1 Background

The Africa Community Access Programme (AFCAP) is a programme of research and knowledge dissemination funded by the UK government though the Department for International Development (DFID). AFCAP is promoting safe and sustainable rural access in Africa through research and knowledge sharing between participating countries and the wider community.

Previous AFCAP activities in Malawi have included the preparation of a new pavement design manual for low volume sealed roads which is based on the DCP design method. The manual was developed through a highly collaborative approach in-country and an international peer review process. The manual has now been published as an official Malawi government document and is being used for the design of 40km of low volume sealed roads that have been funded by the World Bank under the ASWAP-SP programme. A contract has been signed by the Road Authority with a locally-based consulting firm to undertake the design of these roads, which are located in different parts of the country. The firm has no previous experience with the use of the DCP design method.

As part of the dissemination of the manual and to help ensure its incorporation into the local road construction industry, a one-week training course was conducted in April 2014. The training event was attended by 16 participants from the private sector and government road agencies in Malawi. This initial training raised the capacity of the participants to an intermediate level in respect of the use of the DCP design approach. The consultants who were trained previously are now preparing designs for 40km of Low Volume Sealed Roads (LVSRs) in 5 districts as part of the WB financed ASWAP-SP project (see project location map). Since this is the first time that the DCP design method is being applied in Malawi, there was a need to undertake a thorough design review of the ASWAP-SP roads component in order to:

- Consolidate and build upon the knowledge gained by the design consultants from the previous training carried out.
- Ensure that the DCP pavement design method was applied correctly in all aspects of the process.
- Importantly, ensure that the overall LVSR design philosophy, of which the DCP design is but one aspect, was fully complied with in the Malawi environment.

In view of the above, and as part of its capacity building programme, AFCAP provided technical support, in the form of LVSR specialists, to assist the Roads Authority with the implementation of the roads component of the ASWAP-SP project. Their visit schedule is presented in Annex 1.

1.2 Objectives of Assignment

Against the above background, the main objectives of the AFCAP consultant's assignment were as follows:

1. To review the DCP design work undertaken by the ASWAP-SP design consultants to date;
2. To provide further training to the ASWAP-SP design consultants based on any shortcomings identified in the review above;

3. To provide further training to the CML and other laboratory technicians, particularly on materials sampling, lab procedures and sample preparation for determination of laboratory DN values for imported material.

1.3 Purpose and Scope of Report

The main purpose of this report is to provide detailed feedback for the benefit of all parties concerned on the key findings, conclusions and recommendations arising from the various activities undertaken by the AFCAP consultants in Malawi over the period Monday 29th September to Friday 17th October, 2014. This purpose is considered particularly important since this is the first time that the DCP design method is being applied in Malawi on a donor funded project. Thus, it is crucial that all aspects of the design are carefully scrutinized and, moreover, that all stakeholders are quite clear as to the reasons for the various observations made and the resulting conclusions and recommendations.

In addition to the Introduction given in Section 1 above, the report covers the following topics:

- **Section 2 - The guiding principles for evaluating the LVSR designs**. This section provides a yardstick against which all important aspects of the design were assessed, taking account, particularly, of the adoption of an *Environmentally Optimized Design* approach which is the key to the optimum design of LVSRs in a given environment.

- **Section 3 - Evaluation of Project Roads**. This section provides a detailed account of all aspects of the design of the roads which go beyond the DCP design aspects. This includes related issues such as estimation of design traffic, alignment investigations (soils and geometry), borrow pit investigations, drainage design, social and environmental considerations, construction issues, etc.

- **Section 4 - Training aspects:** This section provides the details of the follow-up training that was undertaken with the design consultants in light of the observations made during the field trips, and against the backdrop of the guiding principles for evaluating LVSRs as presented in Section 2. The section also provides the outcome of the DCP-DN laboratory demonstrations undertaken with technicians from various laboratories in Malawi including the Central Materials Laboratory.

- **Section 5 – Summary:** This section presents the main lessons learnt from the assignment and proposes the next steps in terms of refining the designs and undertaking further investigations and laboratory testing, where required.

2. GUIDING PRINCIPLES FOR EVALUATING ROAD DESIGNS

2.1 Introduction

A common understanding of the basic elements of LVSR technology, and how it has so far developed in the East and Southern African region, is required to provide the necessary background to facilitate the assessment of the design of the ASWAP-SP road projects . This section therefore considers a number of aspects of LVSR technology and the factors affecting its application in the Malawi.

2.2 Design Principles for Low Volume Roads

2.2.1 Definition of a LVR

A common understanding of the definition of a LVR by all stakeholders is crucially important as such an understanding will dictate the approach to undertaking the design of such roads in relation to their characteristics and the related criteria to be used in providing them at an appropriate level of service and minimum life cycle cost.

There is no internationally accepted definition of a LVR. In developed countries such as the USA, roads carrying about 400 vehicles per day (vpd) are defined as very low volume roads. In developing countries, the figure that is currently, typically, used is about 300 vpd PLUS a design traffic loading not exceeding about 1 million equivalent standard axles (MESA). However, neither of these definitions provide a complete picture of the characteristics of a LVR. The unique characteristics of such roads often challenge conventional engineering practice in terms of pavement and materials engineering, geometric design, road safety and maintenance. In this regard, the following attributes are becoming increasingly apparent:

- Almost exclusive reliance on the use of naturally occurring, often non-standard materials, many of which are quite moisture sensitive.
- The adoption of an “Environmentally Optimized Design” (EOD) approach in which the road is designed to suit a variety of task and environmental factors such as rainfall, available materials, construction capacity, terrain, flood risk, etc., in the most cost-effective and sustainable manner.
- The “relaxation” of geometric design standards within an “Extended Design Domain Design” context without undue increase in the risk of road users, including a significant amount of non-motorized traffic in urban/peri-urban areas, coupled with a focus on traffic safety measures in built up areas.
- An alignment which is not necessarily fully “engineered”, especially at very low traffic levels, in the sense that some sections may follow the existing alignment and the full length may offer variable travelling speeds that will seldom exceed about 80 km/h, as dictated by the local topography.
- A recognition that pavement deterioration is driven primarily by environmental factors (particularly moisture), with traffic loading being a lesser influential factor in deterioration, and drainage being of paramount importance;

- An appreciation that conventional economic analysis often cannot justify the investment of public funds in the construction and maintenance of these roads in which relatively difficult to quantify benefits of a broad socio-economic nature are likely to occur.

In view of the above, a holistic appreciation of the attributes that characterize LVRs will guide designers in producing more appropriate designs with an emphasis on using a fit-for-purpose, context sensitive, environmentally optimized approach to design and construction. This will place an onus on the design engineer to provide a road that meets the expected level of service at least life-cycle cost based on a full understanding of the local environment and its demands, and to turn these to a design advantage.

2.2.2 General approach to LVR design

The general approach to the design of a LVR will be guided by the client and will build on information and data collected during the project pre-feasibility and feasibility stages. The client will have a budget in mind for the works, the location and route will be known in outline, and the preferred approach to the works will also be known, for example labour or equipment based. The client may also have views and guidance on apportioning works and contract size, technical issues, social, environmental and time constraints. The job of the road design engineer will then be to develop the project within and around these boundaries and limitations, whilst at the same time alerting the client to issues and problems that may limit or require adjustment of expectations.

The approach to the design of LVRs roads follows the general principles of any good road design practice. There are, however, important differences from the traditional road design practice which the designer must be fully cognizant of if he is to provide the client with an optimised design based on the financial, technical and other constraints that define the project.

Optimising a design requires a multi-dimensional understanding of all of the project elements and in this respect all design elements become context specific. The design team therefore needs to be able to work outside their normal areas of expertise and to understand implications of their recommendations or decisions on all other elements of the design.

The successful design of low volume roads relies on:

- A full understanding by the design engineer of the local environment (natural and social).
- An ability to work within the demands of the local environment and to turn these to a design advantage.
- Recognition and management of risk.
- Innovative and flexible thinking through the application of appropriate engineering solutions rather than following traditional thinking related to road design.
- A client who is open and responsive to innovation.
- Guaranteed routine and periodic maintenance.

There is an onus on the design engineer to provide a road that meets the expected level of service. Design engineers are traditionally conservative and build in factors of safety that cater for their perceptions of risk and extremes of caution. This approach prevents the application of innovation, uses scarce or inappropriate resources and results in high financial costs for the client and the country. There is also often a temptation to provide or upgrade roads to a future level of service not justified by the economic or other project projections; or road user requirements. This type of approach absorbs available resources and prevents extension of access. It is the role of the design engineer to properly represent the clients and country's interests.

The level of attention and engineering judgement required for optimal provision of LVRs is no different and in most cases is higher than that required for the provision of other roads. The design engineer needs to draw on all of his engineering skills, judgement and local experience if appropriate designs are to be developed without incurring unacceptable levels of risk.

2.2.3 Road environment factors

The term "road environment" is an all encompassing one that includes both the natural or bio-physical environment and the human environment. It includes the interaction between the different environmental factors and the road structure. Some of these factors are uncontrollable, such as those attributable to the natural environment, including the interacting influence of climate (e.g. wind, rainfall and intensity), local hydrology and drainage, terrain and gradient. Collectively, these will influence the performance of the road and the design approach needs to recognise such influence by providing options that minimise the negative effects. Others factors, such as the construction and maintenance regime; safety and environmental demands; and the extent and type of traffic are largely controllable and can be more readily built into the design approach.

Typical road environment factors are presented in Figure 2-1 and must all be carefully considered by the design engineer at the design stage of the project.

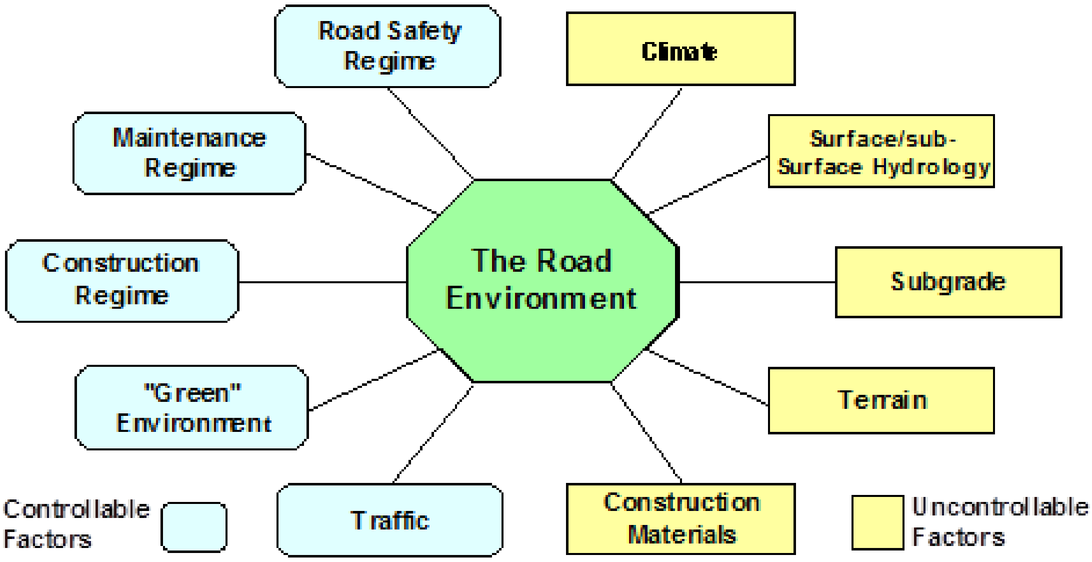


Figure 2-1: Road environment factors

2.2.4 Environmentally optimised design

In order to obtain optimal results from investments in road infrastructure in any country, it is important to adopt an approach that is guided by appropriate local standards and conditions, in order to achieve a sustainable outcome. In this regard, international and regional research has highlighted the benefits of applying the principles of Environmentally Optimised Design (EOD) to the design and construction of low volume rural roads (Cook et al, 2008). The various factors that influence the implementation of LVSR technology and that need to be considered in the context of EOD are illustrated in Figure 2-2.

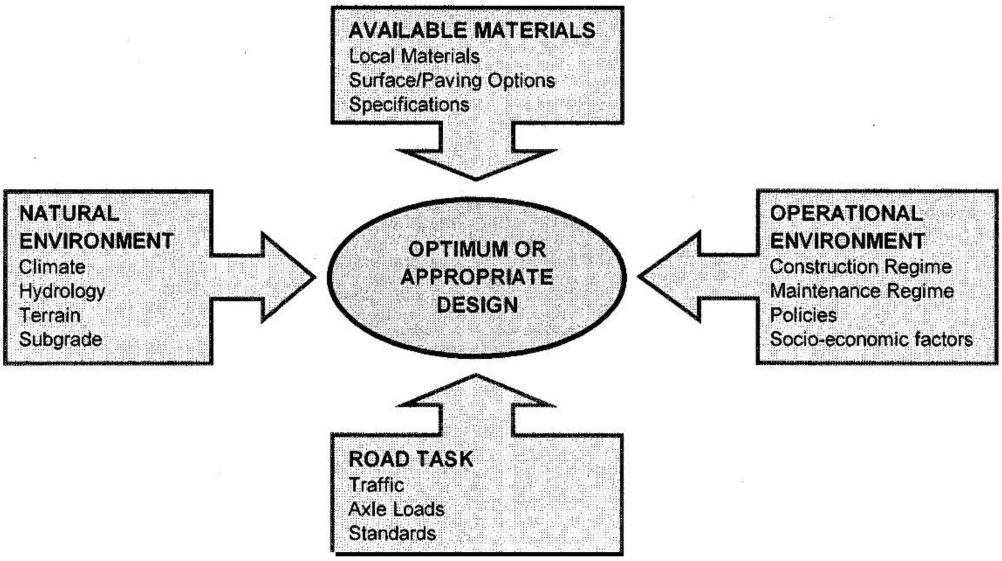


Figure 2-2: LVR implementation within an EOD context

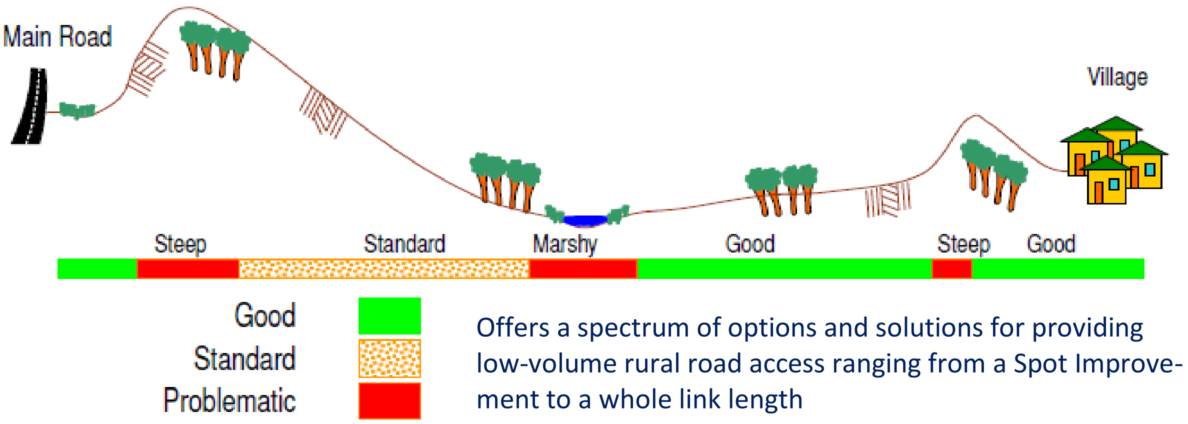
In essence, EOD can be described as a strategy for utilising the available resources of budget and materials in the most cost-effective manner to counter the variable factors of traffic, terrain, materials and subgrade that may exist along an alignment. To be successful and sustainable, LVR technology needs to be implemented within the framework of an EOD strategy. Moreover, if the LVR project is to be sustainable in the long run a number of strategic objectives should be satisfied, including:

- Maximum use of local labour and skills
- Maximum use of locally available or produced materials
- Use of appropriate design standards and materials specifications
- Low capital investment (relatively simple equipment requirements)
- Socially and environmentally acceptable use of materials and construction practices

The appropriate application of an EOD approach requires careful consideration of the variation of different road environments along the length of the road, such as steep gradients, wet and marshy areas as well as passage over easy terrain. This approach also requires consideration of a range of options for improving or creating LVR access – from dealing with individual critical areas on a road link (Spot Improvement Design (SID)), to providing a total whole link design, which in the latter case, could comprise different design options along its length.

The SID principle can be applied within the context of an EOD strategy with the overall aim of ensuring that each section of a road is provided with the most suitable pavement type for the specific circumstances to provide sustainable access along the road. This requires analysis of a broad spectrum of solutions to improve different road sections, depending on their individual requirements, ranging from engineered natural surfaces to bituminous pavements. The chosen solution must be achievable with materials, plant and contractors available locally.

The EOD/SID approach ensures that specifications and designs support the functions of different road sections - assessing local environment and limited available resources. EOD assesses whether the standard design is sufficient for problematic areas and whether it is necessary for the good areas. An under-design of poor sections can lead to premature failure and an over-design will often be a waste of resources which would be better applied on the problematic sections. The EOD/SID principle is illustrated in Figure 2-3.



Offers a spectrum of options and solutions for providing low-volume rural road access ranging from a Spot Improvement to a whole link length

Figure 2-3: Environmentally optimized design approach

It is worth emphasising that EOD/SID applies to the appropriate design of **both the surfacing and pavement structure of a low volume road**. Thus, in order to derive the full benefits of an EOD/SID approach, **LVR technology must consider carefully the surface improvement technology options available to the design engineer, as discussed below.**

2.2.5 Surface improvement technology

Gravel and earth roads are particularly vulnerable to the effects of the road environment. A range of more durable surfacing options, other than gravel or earth are available for low volume roads which provide environmentally friendly pavement preservation treatments. These include various types of both thin bituminous and non-bituminous surfacings such as cobble stone, hand packed stone, concrete slabs, concrete strips and concrete blocks.

Improved surfacings may be provided for the entire length of a road, or only on the most vulnerable sections. The approach may include dealing only with individual critical sections (weak or vulnerable sections; roads through villages or settlements) on a road link (spot improvements), or providing a total whole rural link design, which could comprise different design options along its length.

2.2.5.1 Bituminous surfacings

A basic appreciation of the characteristics of the different types of surfacings available for use in Malawi is required so as to ensure that the most appropriate type of surfacing is chosen in an EOD context as discussed below.

Figure 2-4: Common types of bituminous surfacings

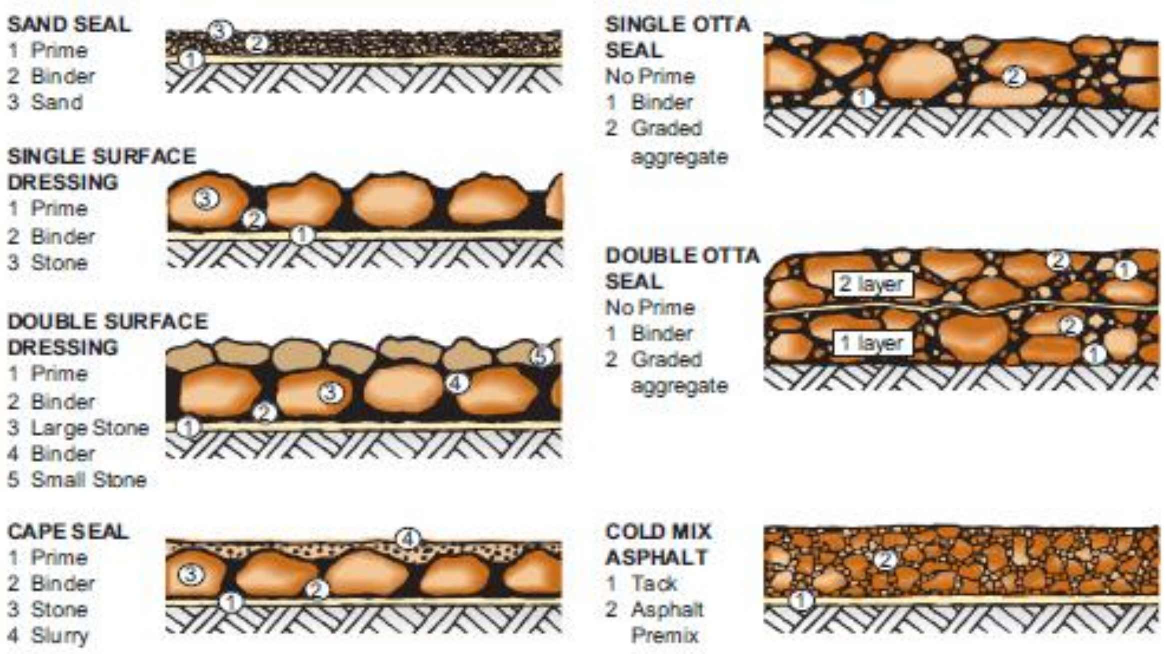


Table 2-1 provides an overview of the characteristics of different types of bituminous surfacings that may be considered for use in Malawi.

Table 2-1: Characteristics of typical bituminous surfacings

LCS	Characteristics
Sand seal	- Empirical design. - Consists of a prime coat, a film of binder (cutback bitumen or emulsion) followed by a graded natural sand or fine sand-sized machine or hand-broken aggregate (max. size typically 6 – 7 mm) which must then be compacted. - Is primarily a temporary surfacing, or for application on top of other seals. - Especially useful if good aggregate is hard to find. - Very suitable for labour-based construction, especially where emulsions are used, and requires simple construction plant. - Single sand seals are not very durable (life of 3-4 years) but performance can be improved with the application of a second seal (life of 6-7 years).
Slurry seal	- Empirical design. - Consists of a mixture of fine aggregates, Portland cement, emulsion binder and additional water to produce a thick creamy consistency which is spread to a thickness of 5-15 mm. - Not normally used on new roads; more typically used for re-texturing surface dressings prior to resealing or for constructing Cape seals. - Very suitable for labour-based construction using relatively simple construction plant (concrete mixer) to mix the slurry. - Thin slurry (5 mm) is not very durable (life 3-4 years) but performance can be improved with the application of a thicker (15 mm) slurry (life span of 6-7 years).

Surface dressing	- Rational design. - Consists of a binder (emulsion or penetration grade) sprayed onto the previously primed surface and then covered with a layer of crushed aggregate chippings (single surface dressing – SSD) or with a second another application of binder and aggregate (double surface dressing – DSD). - DSD usually used to seal an unpaved surface; SSD used as a maintenance treatment for existing bituminous sealed roads or in combination with a sand seal to improve its durability. - Fairly suitable for labour-based construction and, when emulsion is used, requires relatively simple construction plant. - SSD+ sand seal is fairly durable (life 6-7 years) but performance can be improved with the application of a second seal (life span of 8-10 years).
Otta seal	- Empirical design. - Consists of a low viscosity binder (e.g. cutback bitumen, MC 3000 or 150/200 penetration grade bitumen) followed by a layer of graded aggregate (crushed or screened) with a maximum size of up to 19 mm. - Due to the fines in the aggregate, requires extensive rolling to ensure that the binder is flushed to the surface. - May be constructed in a single layer or, for improved durability, with a sand seal over a single layer or in a double layer. - Very suitable for labour-based construction but requires relatively complex construction plant (bitumen distributor + binder heating facilities). - Provides a very durable type of surfacing (life span of 5-6 years for single seal, 8-10 years for single seal + sand seal and 12-15 years for double seal).
Cape Seal	- Partly rational (surface dressing) and partly empirical (slurry seal) design. - Consists of a single 19 mm or 13 mm surface dressing followed by two layers or one layer respectively of slurry. The primary purpose of the slurry is to fill the voids between the chips to produce a tightly bound, dense surfacing. - Fairly suitable for labour-based construction and, when emulsion is used with the surface dressing; can be constructed with relatively simple plant. - Produces a very durable surfacing, particularly with the 19 mm aggregate + two slurry applications (life span of 12 – 15 years).
Penetration macadam	- Empirical design - Constructed by first applying a layer of rolled coarse (e.g. 40/60 mm aggregate) followed by the application of emulsion or penetration grade binder. Next, the surface voids in the coarse aggregate layer are filled with finer aggregate (e.g. 10/20 mm aggregate) to lock in the coarse aggregate followed by an additional application of emulsion binder which is then covered with fine aggregate (e.g. 5/10 mm) and rolled. - Very suitable for labour-based construction as aggregate and emulsion can be laid by hand. - Produces a stable interlocking, robust layer after compaction (life of 8-10 years) but the cost is relatively high due to the high rate of application of bitumen.
Cold mix asphalt	- Empirical design - Consists of an admixture of graded gravel (similar to an Otta seal) and a stable, slow-breaking emulsion which is mixed by hand or in a concrete mixer. After mixing the material is spread on a primed road base and rolled. - Very suitable for labour-based construction; requires very simple construction plant. - Produces a dense surfacing, comparable to an Otta seal (life span of 8-10 years)

The choice of the appropriate surfacing type in a given situation will depend on the relevance or otherwise of a number of factors, including the following:

- Traffic (volume and type).
- Pavement (type – strength and flexural properties).
- Materials (type and quality).
- Environnent (climate – temperature, rainfall, etc.).

- Operational characteristics (geometry – gradient, curvature, etc.).
- Safety (skid resistance - surface texture, etc.).
- Construction (techniques and contractor experience).
- Maintenance (capacity and reliability).
- Economic and financial factors (available funding, life cycle costs, etc.).
- Other external factors.

The suitability of various types of surfacings for use on LVSRs, in terms of their efficiency and effectiveness in relation to the operational factors outlined above is summarized in Table 15-23. Whilst not exhaustive, the factors listed in the table provide a basic format which can be adapted or developed to suit local conditions and subsequently used to assist in making a final choice of surfacing options. These options can then be subjected to a life cycle cost analysis and a final decision made with due regard to prevailing economic factors and be compatible with the overall financial situation.

Table 2-2: Suitability of various surfacings for use on LVSRs

SSS-Single Sand Seal, **DSS**-Double Sand Seal, **SLS**-Slurry Seal, **SSD**-Single Surface Dressing, **SOS**-Single Otta Seal, **DSD**-Double Surface Dressing, **DOS**-Double Otta Seal, **CS**-Cape Seal 13/19mm+Single/Double SLS, **CMA**-Cold Mix Asphalt

Surfacing attributes	**Thin seal/phased strategy**				**Double/Combination seal strategy**							
	SSS	**DSS**	**SLS**	**SSD**	**SSD+SS**	**DSD**	**SOS**	**SOS+SS**	**DOS**	**CS 13mm**	**CS 19mm**	**CMA**
Ease of design	🟩	🟩	🟩	🟧	🟧	🟧	🟥	🟥	🟥	🟧	🟧	🟨
Ease of construction	🟩	🟩	🟩	🟧	🟧	🟧	🟥	🟥	🟥	🟧	🟧	🟩
Service life	🟥	🟥	🟥	🟥	🟧	🟨	🟧	🟩	🟩	🟨	🟩	🟨
Suitability for LBM	🟩	🟩	🟩	🟨	🟨	🟨	🟧	🟧	🟧	🟨	🟨	🟩
Risk of poor mtce capability	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟨
High skid resistance	🟥	🟥	🟥	🟩	🟨	🟩	🟧	🟧	🟧	🟨	🟩	🟧
Early road marking	🟧	🟧	🟩	🟩	🟧	🟩	🟥	🟥	🟥	🟩	🟩	🟩
Suitability for turning actions	🟥	🟥	🟥	🟥	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨
Sensibility to material quality	🟧	🟧	🟧	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟨
Constr. sensitivity to gradient (>8%)*	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟧	🟧	🟨

🟩 Very good 🟨 Good 🟧 Reasonable 🟥 Poor/not suited

2.2.5.2 Non-Bituminous surfacings

There are a number of situations in which bituminous surfacings are unsuitable for use on LVRs, for example, on very steep grades, very flexible subgrades or in marshy areas. In such circumstances, some type of more rigid, structural/semi-structural, surfacing would be more appropriate. There are a number of such surfacings which are potentially suitable for use on LVRs as presented in Figure 2-5 below.

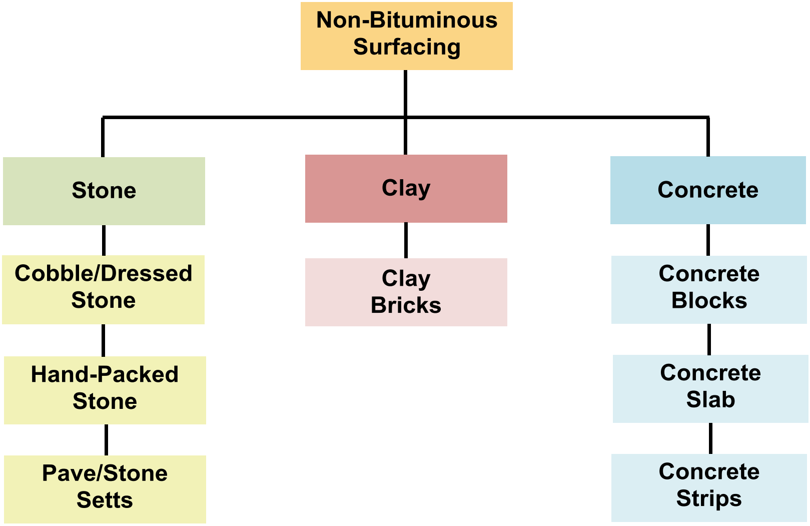


Figure 2-5: Common types of non-bituminous surfacings

The non-bituminous surfacings described above all act simultaneously as a surfacing and base layer and provide a structural component to the pavement because of their thickness and stiffness. They all require the use of a sand bedding layer which also acts as a load transfer layer for the overlying construction. In some cases they act additionally as a drainage medium. All the non-bituminous surfacings are well suited for use on steep grades in situations where the more traditional types of bituminous surfacings would be ill-suited.

The general characteristics of a range of non-bituminous surfacings that may be considered for use in Malawi are summarized in Table 2-3. These surfacings are all particularly suitable for use on LVRs in the following situations:

- Relatively steep gradients where high tyre traction is required
- High rainfall areas where slipperiness may be a problem on steep grades
- Severely stressed areas, such as near market places
- Oil spillage is likely to occur
- Very low maintenance capability is likely
- Very long life is required
- Poor/weak subgrades prevail
- Natural stone is in plentiful supply

Table 2-3: General characteristics of non-bituminous surfacings

Surfacing	Characteristics
Cobble Stone/ Dressed Stone	- Consists of a layer of roughly rectangular dressed stone laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints. Individual stones should have at least one face that is fairly smooth, to be the upper or surface face when placed. - Each stone is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregates is brushed into the spaces between the stones and the layer then compacted with a roller. - Generally 150 mm thick and dressed stones generally 150-200mm thick. - Joints sometimes mortared.

Hand Packed Stone	- Consists of a layer of large broken stone pieces (typically 150 to 300mm thick) tightly packed together and wedged in place with smaller stone chips rammed by hand into the joints using hammers and steel rods. The remaining voids are filled with sand or gravel. - Hand-packing achieves a degree of interlock which should be assumed in the design. - Requires a capping layer when the subgrade is weak and a conventional sub-base of G30 material or stronger. - Normally bedded on a thin layer of sand (SBL) - An edge restraint or kerb constructed, for example, of large or mortared stones improves durability and lateral stability.
Pave/Stone Setts	- Consists of a layer of roughly cubic (100mm) stone setts laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints. - Individual stones should have at least one face that is fairly smooth to be the upper or surface face when placed. - Each stone sett is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. - Sand or fine aggregate is brushed into the spaces between the stones and the layer is then compacted with a roller.
Fired Clay Brick	- Consists of a layer of high quality bricks, typically each 10 cm x 20 cm and 7-10 cm thick, laid by hand on a sand bed with joints also filled with a sand and lightly compacted or bedded and jointed with cement mortar. - Kerbs or edge restraints are necessary and can be provided by sand-cement bedded and mortared fired bricks. - Normally laid in herringbone or other approved pattern to enhance load spreading characteristics - Un-mortared brick paving is compacted with a plate compactor and jointing sand is topped up if necessary. For mortar-bedded and joint-fired clay brick paving, no compaction is required.
Concrete Blocks	- Consists of pre-cast concrete blocks in moulds typically 10 cm x 20 cm x 7 cm. - Laid by hand, side-by-side on a 3-5 cm sand bed with gaps between blocks filled with fine material and lightly compacted to form a strong, semi-pervious layer. - Well suited to labour based construction with modest requirement for skilled workforce.
Non-Reinforced Concrete (NRC)	- Involves casting slabs of 4.0 to 5.0 m in length between formwork with load transfer dowels between them to accommodate thermal expansion. - Provides a strong durable pavement with low maintenance requirements. - More suited to areas with good quality subgrade; in areas of weakness, reinforcement may have to be considered. - Suited to small contractors as concrete can be manufactured using small mixers.
Lightly Reinforced Concrete	- Similar to NRC but with light mesh reinforcement which provides added strength to counteract the wheel loading as traffic moves onto the end slab from the adjacent surfacing. - Well suited in areas of relatively weak subgrade to improvement strength, preventing excessive stress and cracking.
Concrete Strips	- Consists of parallel 1.5 m x 0.5 m unreinforced concrete strips spaced 1 m apart so that both sets of vehicle wheels would run on the strips. The end of the strip on a downward slope should be thickened to act as a dowel - Strips contain transverse concrete strips between the wheel tracks to help stop excessive erosion down the centre of the strips.

Examples of various types of non-bituminous surfacings are illustrated below.

Picture 1

Picture 2

Examples of concrete strips (left) and concrete slabs (right) which are particularly well suited for use on steep/very steep (10/15%) grades, especially in wet/high rainfall environments.

2.2.6 Drainage

Moisture is the single, most important, factor affecting pavement performance and long-term maintenance costs of a LVSR. Thus, one of the significant challenges faced by the designer is to provide a pavement structure in which the weakening and erosive effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction/maintenance provisions and degree of acceptable risk. This challenge is accentuated by the fact that most low volume roads will be constructed from natural, often unprocessed, materials which tend to be moisture sensitive. *This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life.*

There are a number of design considerations which are of critical importance in minimizing the chances of moisture ingress into a road pavement. The main ones are:

- Ensuring adequate external drainage , and
- Sealing of the carriageway and shoulders

2.2.6.1 Drainage factor

To achieve adequate external drainage, the road must also be raised above the level of existing ground such that the crown height of the road (i.e. the vertical distance from the bottom of the side drain to the finished road level at the centre line) is maintained at a minimum height (h_{min}). This height must be sufficiently great to prevent moisture ingress into the potentially vulnerable outer wheel track of the carriageway (Figure 2-6). The recommended minimum crown height of 0.75m applies to unlined drains in relatively flat ground (longitudinal gradient, g, less than 1%). The recommended values for sloping ground (g > 1%) or where lined drains are used, for example, in urban or peri-urban areas, may be reduced slightly. Naturally, the capacity of the drain should meet the requirements for the design storm return period.

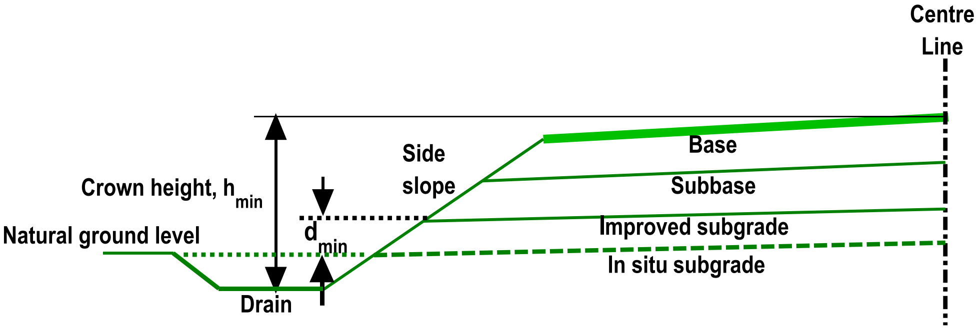


Figure 2-6: Minimum crown height in relation to depth of drainage ditch

2.2.6.2 Sealing of carriageway and shoulders

The most effective means of preventing water from entering the road pavement from above is by the use of a durable, waterproof surfacing that is adequately maintained over the design life of the road. There are many types of bituminous surfacings that can used for this purpose, some being more impermeable than others. These have been addressed above.

It is also critically important to seal the shoulders of LVR pavements. By so doing, lateral moisture infiltration is confined to within the usually un-trafficked shoulder. Thus, even in the rainy season, the moisture content in the outer wheel track of the road is most likely to remain at or below OMC. This is crucially important as the combination of an adequate drainage factor, as discussed above, coupled with the sealing of the carriageway and shoulders, ensures sufficiently favourable moisture conditions to allow the strength (DN) of the imported pavement material to be determined at OMC or below – a factor that widens considerably the possibility of using many natural gravels in the road pavement. Of course, there will always be situations, e.g. in low-lying or marshy areas, where it would be prudent to determine the strength of the pavement material in its soaked condition.

3. EVALUATION OF PROJECT ROADS

3.1 Approach to Undertaking Evaluation

The approach to undertaking the evaluation of the road projects was based on a combination of the following:

1. Visits to each of the five project sites in the company of all the key stakeholders (design consultant, World Bank and Roads Authority representatives) during which all important aspects of the road design were discussed in detail, in light of what was observed on the ground and in relation the prevailing road environment.

2. Classroom discussions in which all the observations arising from the site visits were again discussed in detail and aspects of the DCP design highlighted where refinements were considered necessary in light of what was observed on the ground.

3. Practical demonstration of the laboratory DCP-DN testing of borrow pit materials earmarked for incorporation in the road pavements, including the manner of properly interpreting the results.

4. A wrap-up meeting towards the end of the visit in which a number of additional personnel from the Roads Authority were invited to participate and at which PowerPoint presentations were made to capture all the salient features of the designs and to illustrate examples of both good and poor design practice.

The above approach sought to engender amongst all stakeholders a thorough understanding of the application of LVSR technology involving the use of the DCP design method as well as an appreciation of the importance of providing such roads in the context of an EOD/SID approach.

3.2 General Observations

The design of the five road sections for upgrading to LVSR were at the time of the design review at a preliminary design stage with several key issues needing further investigations and analysis. Based on a review of the Design Reports and observations during the field visits, key issues for improvement of the designs were discussed in some detail on site and elaborated on further during the follow-up training and the joint meeting with the Roads Authority, the World Bank, the ASWAP-SP Project Manager and Royal Associates.

The following issues are identified for further investigations and analysis and incorporation in the Design Reports. Comments are also given related to the quality of the data and test methods and proposals for improvements.

3.2.1 Design reports

The Design Reports in their current form are inadequate and lacking in key, standard information some of which are for placing the projects in context and some which may impact on the final design decisions, such as:

- Climatic zones / rainfall pattern
- Geology / soils
- Demographics / Population served by the road sections
- Road Classification and description / discussion of the current function of the roads

More detailed information should also be given on:

- Economic activity / agricultural output
- Social & administrative services (schools, hospitals/clinics, district administrations etc.).

3.2.2 Project background and road selection

For reference, it would also be useful to incorporate a section in the Project Background on the process / criteria for selection of the projects. As observed and discussed during the field visits, the exact length of 8 km selected for upgrading to LVSR in each of the five districts may not be the most logical decision. Hence a description of the process and discussion of possible deviations from the 8 km target length will help to clarify this issue before the projects go out to tender.

3.2.3 Traffic counting and estimation

Classified 7-day traffic counts have been carried out for all road sections (5 day 16 hour counts and 2 day 24 hour counts), hence the traffic counts seemingly give a good estimation of the traffic volumes and design traffic loading for geometric and pavement design purposes.

However, concern was raised as to the selection of census points. In general counting was done at only one census point at the start or end of each section on the assumption that the traffic counted at this point was all through traffic. From our observations of traffic along the sections one suspects that local traffic at these points may have inflated the traffic figures. Also, no mention was made of seasonality effects on the traffic counts – a feature that may affect the traffic estimates.

Reliable traffic counts are the basis for both the geometric and pavement design and cost little compared to the overall project costs. **It is therefore recommended that new counts are carried out at strategic locations along the routes**. In particular the traffic figures for road S134 Kasinje – Kandeu in Ntcheu District seems out of proportion compared to the observations on the road during the site visit. Distinctions must be made between the local traffic at trading points / villages for and on the inter-settlement sections.

In some areas with high agricultural outputs allowance for seasonal variations should also be made to arrive at average annual daily traffic (AADT).

For the estimation of design traffic loading, the reduced Vehicle Equivalent Factors (VEF) proposed in the report “Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi” (Pinard 2011), have been used. Currently this would be a reasonable assumption. However, as it happens, a country wide axle load survey has just been carried out for the Roads Authority (RA) by the Council for Industrial & Scientific

Research, South Africa (CSIR). It is envisaged that more reliable average VEF based on this study will soon be available for the update of the design traffic loading estimates for the project roads and should, if possible, be used in the determination of the design traffic loading.

In light of the above, it is recommended that he final Design Report should include:

- Rationale for selection of Traffic Census points with location maps;
- Annexes with original traffic counts in standardised formats;
- Summary of Traffic Counts in the main report in standardised formats;
- Rationale for selection of Vehicle Equivalent Factors (VEF);
- Estimates of Design Traffic Loading over 10 and 15 years design periods and a discussion of the most appropriate choice of design period based on where in the traffic class the estimated Traffic Loading falls (e.g. if the 15 year MESA is estimated at 0.11, the most appropriate design period may be 10 years with MESA below 0.1, since the pavement strength will not be effectively utilised within the 15 years design period).

3.2.4 Alignment investigations

3.2.4.1 Determination of in situ FMC/OMC ratio

In accordance with the procedure described in the Design Manual, test pits in the alignment were excavated at 500 m intervals to determine in situ moisture content for the three upper 150 mm layers at the time of the DCP testing and choice of percentile (20th, 50th or 80th) for the DCP data analysis and pavement design.

From the tables presented in the Design Reports it seems that the material from each test pit was blended before determination of MDD, OMC and the FMC/OMC ratio on the assumption that the MDD and OMC were the same for each layer.

This may, however, not be the case and separate MDD and FMC/OMC ratios should be determined for each layer. Absolute FMC values, as presented in the report, will give some indication of potential drainage problems or high water tables, but may lead to incorrect choice of percentiles for the data analysis.

It is recommended that the alignment soil test data are presented in a table as shown below:

Table 3-1: Proposed format for presentation of alignment soil data

Layer depth (mm)	Description of soil	GM	PI	MDD	OMC	FMC	FMC/OMC ratio

3.2.5 Materials investigations

The key to cost effective design of LVSR is to make best possible the use of locally available materials. To this end the consultant had obtained information from staff at Central Materials Laboratory on the location of potential borrow pits in the project areas and dug test pits to determine the extent of the borrow pits and total volumes of materials for imported pavement layers.

The Design Reports do not have any information on the materials in the various borrow pits apart from a very brief description of the borrow pits and the material type, which for some is not correct.

Proper logging with a description of the material, layer depth etc. of each pit had not been done. It was therefore recommended to log and describe the test pits in accordance with the guidelines used in South Africa (Jennings, Brink and Williams, 1973) and tabulate the information with the standard classifications results. This was explained during the follow-up training and the consultant given a copy of the guideline.

The material from all test pits from each borrow pit had also been blended before testing instead of testing each test pit separately before blending in order to identify areas of the borrow pits with different material properties. The test pits observed were also quite shallow. Quite likely the material properties deeper down may be different from those in the top layers, e.g. PI and grading may change substantially with depth in a seam of weathered granite. The preliminary test results may therefore not reflect the best possible use of the material in the various borrow pits.

The preliminary test results for some of the borrow pits indicated very high PI values. Laterites (pedogenic material) with PI of up to around 20 have shown to perform well, but weathered granites and quartzites (non-pedogenic materials) with PI values of up to 30 are not recommended for use as pavement layers without modification in one form or another.

The team put the consultant in contact with a very experienced Malawian Materials Technician from the private sector that has extensive knowledge of materials sources in the entire country. It is hoped that with his assistance, new and possibly better sources of material can be identified nearer to the project sites.

3.2.6 Laboratory testing

3.2.6.1 General testing requirements

The pavement design relies on reliable materials test results. The preliminary designs as presented were based on basically one result from each borrow pit, which may or may not be misleading. As a minimum requirement all materials test should be tested at least in triplicate and averaged (of at least two if one is deemed to be an outlier). Hence, repeated testing of the borrow pits is required to gain more confidence in the results.

As mentioned above, the test pits must also be dug to greater depths to get a better impression of the material properties for the entire seam. This may alter the preliminary conclusions drawn on the basis of the first tests completely, most likely to the better.

Large enough samples must be taken to facilitate testing in ***at least*** triplicate for all tests (Classifications tests, MDD/OMC, Lab DN).

3.2.6.2 Laboratory DN tests

Laboratory DN tests had been carried out for all borrow pits and preliminary design decisions based on one set of 0.75 OMC DN values.

As for all other tests, the Lab DN test must also be done in ***at least*** triplicate. Furthermore the consultant had not executed the test in accordance with the demonstration and guideline issued during the first training.

New Lab DN tests in triplicate must therefore be carried out for all borrow pits following the correct procedures. Once the tests are carried out, the team will be of assistance to interpret the results.

For Malawi which has a fairly moist subtropical climate, the design decision should normally be based on OMC DN values. Basing the design on 0.75 OMC DN values is deemed to be too risky.

On certain sections with potential drainage problems or flood risk, the pavement design should possibly be based on 4-day soaked DN values.

3.2.7 DCP Design

3.2.7.1 DCP equipment

DCP tests in the field and laboratory were carried out with DCP equipment hired from Shire Construction Ltd, Lilongwe. The team was told that the equipment was checked for correct weight of the hammer (8 kg) and dropping distance (575 mm) before carrying out the field tests.

On inspection in the Shire Laboratory it was observed that the cone that was attached to the DPC instrument was worn out and had the wrong shape. It is therefore suspected that some or all of the DCP tests (both field and laboratory) may have been carried out with a worn cone, thereby giving inaccurate results, possibly on the conservative side (too high DN values). The Materials/Design Engineer from Royal Associates.

During the training for Laboratory Technicians, it was also discovered that the dropping height for the DCP hammer constantly had to be re-adjusted. There is thus also a distinct possibility that the dropping height may not have been correct for some/many of the DCP tests.

New cones with the correct dimensions and shape were borrowed from the Central Materials Laboratory (CML) to be used for the re-testing of the borrow pit material during the training of the laboratory staff.

The problems observed with the DCP equipment and availability of spares highlights the importance of refining and standardizing the DCP equipment design and, if possible, instigating local production of quality DCPs and spares as previously suggested to the AFCAP PMU.

3.2.7.2 DCP data collection and analysis

DCP tests had been taken every 100 m along the sections and input into the WinDCP programme for analysis. From the data analysis presented in the report, the consultant had apparently got a good grasp of the operation of the WinDCP software and the method for analysing the data that were taught during the first training in March/April 2014. However, the data analysis had been done in a mechanical fashion and all data points including outliers with exceptionally high (strong) and low (weak) DSN800 values, had been included in the Cumulative Sum (Cusum) and average analysis, thereby distorting the results.

The DCP data presented in the reports nevertheless give valuable information for further investigations, as pointed out during the field visits and training session with Royal Associates, as to the likely reason for these abnormal values, e.g. water seepage from higher ground and low lying spots with poor drainage.

On the basis of the existing DCP data the consultant should therefore do additional DCP penetrations at and around the spots with abnormal values to determine the extent of such sections and eventually what to do in terms of drainage improvements, pavement design and alignment adjustments.

3.2.7.3 Sensitivity analysis

The consultant was advised and shown how to carry out sensitivity analysis of the pavement design by varying the Traffic Class (DCP DN catalogue values) and anticipated long term moisture condition (wetter, same as or drier than at time of DCP survey) for choice of percentile of DN values to assess whether or not this would influence the pavement design. If such sensitivity analyses result in only minor changes it could be advisable to choose the more conservative option.

In the final instance sound engineering judgement taking all factors into considerations should be the basis for the final decision.

3.2.8 Geometric design

3.2.8.1 Horizontal alignment

The proposed horizontal alignments generally follow the existing alignments. During the field visits only a couple of spots were identified that need to be straightened out and/or widened to improve visibility and road safety. In the team’s opinion fully engineered alignments are not required on these roads based on the low traffic levels and their current function. However, problem spots as mentioned above require fully engineered solutions combined with traffic calming measures.

3.2.8.2 Vertical alignment

Good drainage and keeping the pavement (as) dry (as possible), is key to the construction of LVSR using often moisture sensitive natural materials.

The drainage requirement on most sections can generally be satisfied with the existing vertical alignment with one or two imported pavement layers to achieve the required pavement strength. However, some sections that are low lying and are prone to flooding, most notably the start of road D381 Nsangwe-Dolo in Chikwawa District, will require substantial fills to prevent wetting up of the pavement during the wet season.

3.2.8.3 Cross section

Based on the traffic counts, the 4-wheeled ADT for the five roads including first year 20% generated traffic after upgrading will be as follows:

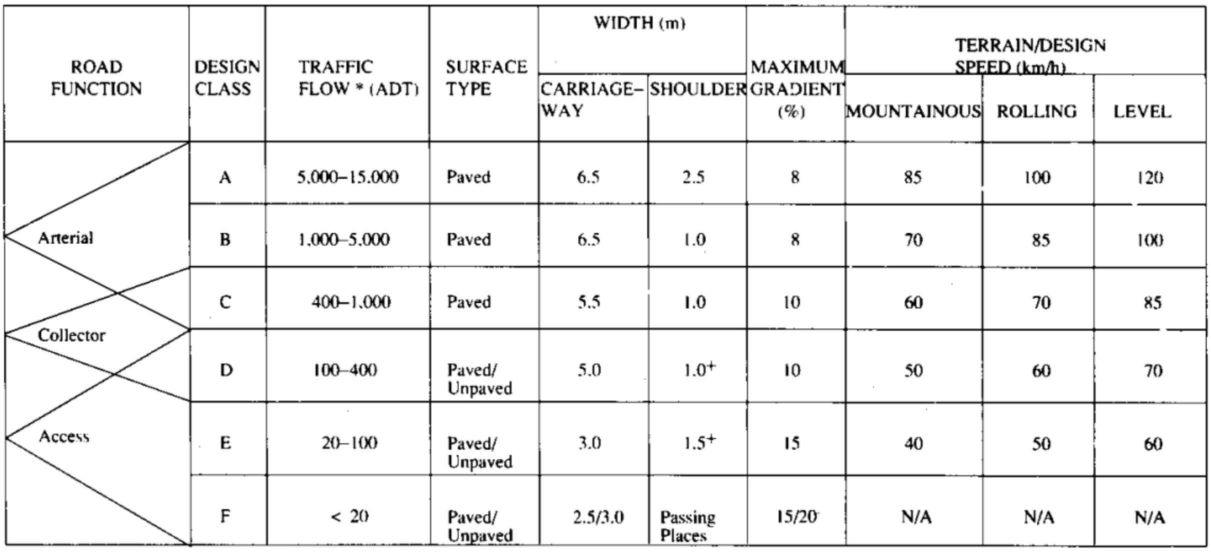
Table 3-2: Four-wheeled ADT on project roads

District	Ntcheu	Salima	Mwanza	Chitipa	Chikwawa
4-wheeled ADT	696*	85	76	46	50

*Figure likely too high and includes local traffic at trading centre near junction with M5

As per the classification in the TRL Overseas Road Note 6 in Table 3-3 below, these roads currently fall in Category E. A total width of 6.0 m is deemed to be appropriate for the inter-settlement sections of all but D11 Kalenge River Bridge – Misuku in Chitipa District. The steep terrain for this road with high and steep cut slopes on one side and steep drops on the other effectively limits the general width to 4.5 m. Local widening in the many curves on D11 is, however, possible and must be done to improve road safety and facilitate safe meeting of vehicles.

Table 3-3: Design Classes as per TRL Overseas Road Note 6



ROAD FUNCTION	DESIGN CLASS	TRAFFIC FLOW * (ADT)	SURFACE TYPE	WIDTH (m)		MAXIMUM GRADIENT (%)	TERRAIN/DESIGN SPEED (km/h)		
				CARRIAGE-WAY	SHOULDER		MOUNTAINOUS	ROLLING	LEVEL
	A	5,000–15,000	Paved	6.5	2.5	8	85	100	120
Arterial	B	1,000–5,000	Paved	6.5	1.0	8	70	85	100
	C	400–1,000	Paved	5.5	1.0	10	60	70	85
Collector	D	100–400	Paved/ Unpaved	5.0	1.0+	10	50	60	70
Access	E	20–100	Paved/ Unpaved	3.0	1.5+	15	40	50	60
	F	< 20	Paved/ Unpaved	2.5/3.0	Passing Places	15/20	N/A	N/A	N/A

The heavy traffic mix at trading points and in villages require “village treatments” of these sections as per the recommendations in the Malawi DCP Design Manual, with different cross sections and possibly different surfacings than on the open road to cater for high NMT and traffic turning actions.

Generally driving speeds should not be greater than 50-60 km/h on these roads and in villages limited to 30-40 km/h. Traffic calming measures should therefore be installed at potential hazard spots (curves, crests, village entry points etc.) to ensure low driving speeds rather than altering the alignments to facilitate higher speeds.

In the preliminary design all roads had been designed with a cross section of 6.50 m including shoulders throughout the entire length. The decision on the cross section should be more responsive to the total road environment and should be revised accordingly in the final design.

It must also be noted that the decision on the width of the carriageway will impact on the Design Traffic Loading estimates. Reference is made to the relevant section in the Malawi DCP Design Manual in that regard.

3.2.9 Pavement and surfacing options

In the preliminary design all roads had been designed with 19 mm Cape Seal, probably because this type of seal has been widely used in Malawi. On that basis it may be a sound choice since local contractors are likely to have prior experience with this type of surfacing and also because It is a durable seal. However, it is relatively costly due to the high bitumen content used and is not as construction friendly for small contractors, as is the case with other types of seals.

Extensive discussions were held with the consultant as regards different pavement and surfacing options related to the terrain and occurrence of surfacing aggregates as well as options for constructing the surfacing with local labour.

Bituminous surfacing of any kind is in the team's opinion not the best option for D11 in Chitipa District due to the frequent steep grades often in excess of 10 %. For this road full width (4.5 m) concrete pavement could be considered on the steepest sections, and either full width concrete or concrete strips on the flatter sections. On the last km or so within Misuku village which is fairly flat, a bituminous surfacing may still be considered.

With the high poverty and unemployment rates in Malawi, labour friendly surfacing options should in the team's opinion be high on the priority list. Cold Mix Asphalt stands out as the most labour friendly and easily taught surfacing option and is particularly suitable in Chikwawa where suitable surfacing aggregates can be obtained near to site. In Ntcheu and Mwanza Districts, hand-knapping of fresh granite aggregates were done in the villages along the alignment, thus making Penetration Macadam a potentially viable alternative.

In the final instance, budget limitations, life cycle costing and a thorough consideration of all influencing factors should guide the choice of surfacing option.

3.2.10 Drainage aspects

On most sections satisfactory drainage can normally be achieved by minor fills and/or incorporation of one or two additional pavement layers combined with excavations or restoration of proper side drains. On flat sections with less than, say, 1% grade, it is advisable to satisfy the H_{min} and D_{min} recommendations as per the Malawi DCP Design Manual. These requirements can be relaxed somewhat on steeper grades and if the drains are lined.

Particular drainage issues observed include:

- On D11 Kalenge-Misuku (Chitipa District) – sub-surface "French Drains" to intercept seepage from higher ground, lining of drains and scour checks on steep sections
- On T357 Lifuwu Road (Salima District) – restoration and lining of RHS side drain to cope heavy with run-off from hills
- On S134 Ksinje-Kandeu (Ntcheu District) – protection of highly erodible soils in the alignment, lining of side drains and outlets to prevent erosion, downstream protection of large drift
- On D387 Nsangwe-Dolo (Chikwawa District) – substantial lifting of first section on the flood plains, restoration or reconstruction of many drifts

Within built-up areas negotiations must be held with the residents to secure drain outlets at reasonable intervals. The costly alternative may be to provide lined drains for substantial lengths within the villages.

In trading areas, particular attention must be paid to hygiene and access to shops and roadside stalls through provision of shallow dish drains or similar, easily maintainable solutions.

3.2.11 Construction considerations

3.2.11.1 Construction methods

Whereas it is not envisaged, nor is it expressed as a project objective, to use labour-based methods for the construction of these roads, certain aspects lend themselves to use of labour if labour-based methods are not excluded by design.
As mentioned above, certain bituminous surfacing, which can be successfully constructed entirely by labour and light plant, could be considered. This together with drainage works, provision of surfacing aggregates (hand-knapping), erosion control measures etc. will give ample employment opportunities for local labour.

With some training inputs contractors and labourers will quickly acquire the necessary skills to produce high quality surfacings. These skills can later be utilised for road maintenance.

3.2.11.2 Quality control

Most construction quality problems are directly related to materials in one way or another, such as:

- Incorrect working of borrow pit and substandard materials being imported to the road;
- Incorrect or insufficient testing of the materials being used;
- Substandard quality of surfacing aggregates being used.

Construction related problems include:

- Inadequate process control during mixing and compaction of the pavement layers;
- Excessive proportion of oversize in pavement materials;
- Exceeding construction tolerances resulting in inadequate layer thickness, incorrect shape/camber;
- Incorrect setting out of the works;
- Incorrect batching of concrete and bituminous mixes;
- Incorrect and/or uneven application rate of bitumen and aggregates for bituminous surfacing;
- Poor site management and work planning.

It is recommended that the Site Supervisors develop a comprehensive check list for their supervisory tasks to ensure that no important items are left without being checked and approved or rejected.

A high level of quality control is essential to achieve durable roads. Durability of the pavement is directly related to pavement stiffness. During construction one should therefore always aim for the maximum achievable density with the available compaction plant, i.e. compaction to refusal without breaking up the layer, as opposed to the traditional 93% for subgrade, 95% for subbase and 98% for the base. With little extra compaction effort densities at 98% Mod AASHTO and above can normally be achieved for all pavement layers.

Density tests of pavement layers are normally done with the Sand Replacement Test, which is cumbersome and time consuming. The DCP can be used to quickly check layer densities when it has first been calibrated against a properly executed Sand Replacement Tests or through establishment of the target (maximum) DN value for the layer through a triplicate Laboratory DN test for the material being used.

Using the DCP in this way, many tests can be done very quickly to approve or reject the works without unnecessarily holding back the contractor from proceeding with the works.

3.3 Project specific observations

3.3.1 Kapoka – Kalenge – Misuku (S100/D11): Chitipa District

Site visit undertaken on 3 October 2014.

The road comprises both the gravel road rehabilitation section and the 8 km upgrading section. The first part up to Kalenge Bridge goes through rolling terrain with some relatively short sections with steep grades. The gravel rehabilitation section covers part of D11 from Kalenge Bridge to Misuku and comprises sections that are equally steep and difficult as those on the upgrading section.

The team therefore suggests taking a holistic view on this road to provide all weather reliable access on the entire route rather than looking at the gravel rehabilitation section and upgrading section separately. It may therefore be more appropriate to pave parts of the gravel rehabilitation section and leave parts of the upgrading section as gravel road or alternatively pave with concrete strips. The following comments should be seen in that light.

Picture 3: Typical section of D11 with steep grades up to 20% in short sections

Picture 4: One of the many sharp and blind curves on D11

- Evaluate the possibility of surfacing through built up area at the entrance of the gravel rehabilitation section (up to first school)
- Attention to road safety particularly around school area
- Review the environmental aspect
- Consideration of sociological aspect (market, schools…) through widening and surfacing
- Apply Environmentally Optimised Design approach (EOD)
    a. In the choice of the pavement / surfacing:
        i. Grade <=6%: Gravel/Bituminous surfacing/Concrete strips
        ii. Grade 6 to 10%: Bituminous surfacing/Concrete surfacing
        iii. Grade >=10%: Concrete surfacing

  b. Spot improvement approach for weak areas:
    i. Identify possible cause of weak spot
    ii. Remove the weak spot from uniform section, delimit the weak spot by re-doing a “close spaced” DCP and treat it specially and separately (e.g. subsoil drains to cut off seepage)
    iii. Re-assess the uniform sections without weak spot
- Due to budget constraint, limit surfacing width to 4.5 m on steep sections and increase surfacing length, i.e.:
  a. Steep section: full concrete
  b. Less steep section: concrete strip
  c. Flatter section : re-graveling
  d. Full concrete around the curves
- Consideration of road safety around blind curves
- Powder material in the existing road way to be replace by approved gravel
- Side drain improvement on steep grade (lined drain and scour checks
- French drains in steep side long ground to cut off seepage and keep pavement dry
- Concern about reliability of traffic count. Census point should be where there is through traffic (no diversion).
- Compaction on steep grades may be difficult, hence concrete pavement may be the best option.

3.3.2 Kasinje-Kandeu (S134): Ntcheu District

Site visit undertaken on 6 October 2014.

Picture 5: Erosion around existing drift

Picture 6: Severe erosion in side drain

- The in-situ material is sandy and appears to be highly erodible in the first part of the road. Several deep erosion gullies were observed on the first part up to km 4.0. Erodability testing might be required.

- Terrain generally gently sidelong draining towards the road from the right. Drainage seems to be a major problem, particularly protection of the erodible soils against erosion.

- The level of the road to be raised at certain locations where the water has been crossing the road.

- Steep grade notice at certain locations

- The second part of the road is characterised by rocky in-situ material
- DCP tests should be completed in the second part of the road where the in-situ material is not rocky.
- Penetration macadam could be considered as a surfacing option due to the availability of local crushed (hand-knapped) stones. This presents also a potential benefit in terms of labour enhanced activities and reduction of haulage distance for surfacing aggregates.
- Drain lining on the first section is required to prevent erosion. Locally manufactured clay bricks may be used.
- The borrow pit visited contained weathered granite and not laterite as suggested in the consultant report

3.3.3 Nsangwe-Dolo road (D487), Chikwawa District

Visit done on 7 October 2014

Picture 7: First section flat and prone to flooding

Picture 8: Severe erosion around existing drift

The first section is flat area and prone to flooding. Road needs to be raised considerable above ground level.

- For the remaining sections attention should be paid at the topographical contours before deciding on the level of the road (some areas drain away from the road while others drain toward the road).
- Consider non-bituminous pavement / concrete blocks at the junction with main road due to traffic turning actions.
- The road has a number of drifts which are generally not in good condition.
- 1st existing drift (weak spot); suggested to be replaced with box culvert
- Traffic class LE0.3 estimated. Counting was done in the built-up area at the entrance from the main road, traffic figures likely to include local traffic. Location of traffic census point to be revised (outside built up area and both ends?)
- The first bridge - repair necessary. Proposed twin box culvert

- Nyambiro borrow pit (next to the road). Material is a conglomerate seemingly containing lime stone
- 2nd drift to be replaced with culvert to allow water drainage upstream and downstream
- Vertical and horizontal alignments look acceptable for the purpose
- 3rd drift – decision to be made whether to repair or replace
- 4th drift - bad condition to be replaced by another drift
- 5th drift - bad condition to be replaced by another drift
- 6th drift - to be rehabilitated (km 4.9)
- 7th drift - fit for purpose but need some rehabilitation
- Drifts to have road edge / level markers for road safety
- Upgrading section (km 8.0) ends in the middle of nowhere. Consider shortening to end in nearest village.
- In built-up area consider increasing road width to cater for non-motorised users
- Borrow pit at km7.5: materials - weathered basalts (very weak aggregates)
- Nkhawangwa borrow pit materials are similar to the Nyambiro borrow pit
- Nearby quarry offers supply of good quality basalt crushed stone in various fractions. Opportunity for Cold Mix Asphalt surfacing as an option.
- Traffic observed during the time of visit +- 3 hours: 1 pickup and 1 truck (low bed)

3.3.4 Mwanza- Kunenekude (S135): Mwanza District

Site visit undertaken on 8 October 2014

Picture 9: Very busy trading area at road entrance from main road.

Picture 10: Section with blind curves and sharp crest that needs fully engineered solution

- Typical busy trading area at the junction with the main road. Consider block paving or cobble stones at this area
- High local traffic was observed, especially non-motorised traffic and motorbikes.
- Attention should be paid to traffic calming measure in this area
- Consider wide cross section to accommodate non-motorised traffic

- At short concrete section +/- 4.8m wide, consider covered drain as a road widening measure
- Road classified as Secondary Road, but currently functions as access road. Engineered alignment vs. non-engineered alignment with regards to the road classification should be discussed
- Blind curves and sharp crest at km 6.3 needs fully engineering solution. Suggest widening and straightening over a short section and mark with solid centre line to segregate traffic in both directions
- Good quality subgrade. Carry out Lab DN at OMC and 98% Mod AASHTO to determine strength of material
- Scarcity of good gravel material in the area. Consider surfacing on subgrade if sufficiently strong and/or armouring of in situ material
- If hauling in material, start construction at far end to avoid construction traffic on completed pavement.
- Borrow pit 1: Highly weathered granite with mica
- Borrow pit 2: Highly weathered granite.

3.3.5 Parachute Battalion - Lifuwu (T357), Salima District

Site visit undertaken on 11 October 2014

Picture 11: Typical severe erosion in RHS side drain.

Picture 12: Non-functional drift in village on sandy sections

- Main concern is restoration of right hand side drain to cater for heavy run-off from the mountain range alongside the road.
- Two major types of in-situ material:
    a. First section up to bridge at km 4.3: clayey silty sand
    b. Second section: loose sand
- Raise the level of road especially at culverts approaches

- Include centre line materials results in the report
- Consider re-instate the old borrow pit at Km 3.6
- Blasting needed of rock outcrops situated in the road alignment
- Clear the bed river crossing the bridge at km 4.3
- Overtopping of bridge approaches likely due to overgrown river bed partially blocking the river. Lift the bridge approaches and do repair work where required
- Re-look at the function of the culvert next to the bridge, consider removal as it seems not to serve any purpose. Water in side drains can be drained off into the river.
- Replace the drift at km 6.5 with a proper culvert and consider to remove the following small nearby culvert
- Kapiri borrow pit contains quarzitic gravel and some weathered granite. It is also a source of hand-knapped aggregate (granite) that can be used for surfacing such as Penetration Macadam instead of hauling single size aggregates from Lilongwe for Cape Seal.
- Kalima borrow pit contains laterite of seemingly good quality.

3.4 Way Forward

The plan is to start construction at the end of the wet season in May 2015. Time is therefore at a premium for completion of the designs and the tendering process.

With this design review, additional training and discussion of possible solutions for each particular road, the Design Consultant should have a good idea of what is required to complete the designs and tender documents. It is nonetheless recommended that the revised Design Reports be submitted to the team for a final review before tendering to iron out any outstanding issues. This review can be done from home office.

The team will also be at the disposal of the Design Consultants during the preparation of the final documents for clarifications and interpretation of test results, e.g. the Lab DN test results. It is proposed that the current contracts with AFCAP for M. Pinard and J. Hongve be extended to facilitate this.

Equally important is good quality control during construction for which a second assignment by the AFCAP team has been planned when construction is underway May/June 2015.

These projects will serve as demonstration and reference projects in Malawi, and the region, for the EOD and DCP Design approach. It is therefore imperative that the final designs can be defended in all aspects on sound engineering principles and that strict quality control during construction is undertaken to ensure high quality, fit-for purpose end products.

4. TRAINING ASPECTS

4.1 General Approach

With the first review of the preliminary Design Reports, the team was able to obtain a good impression of the additional training needs.

The general approach to the training was to discuss the various issues identified through the preliminary Design Reports during the field visits and follow up with further elaborations and explanations during the formal classroom training session. Much of the training of the Consultant thus took place through the joint field visits and discussions on site.

In short the areas that needed clarifications and additional training were identified as:

- Interpretation of DCP data combined with field investigations to identify problem areas, the probable cause for the abnormal DCP DN values and possible solution to the problems.
- DCP data analysis excluding the abnormal DCP DN values for identification of uniform sections
- Application of the Environmentally Optimised Design principles
- Surfacing options
- Alignment soil investigations and testing
- Borrow pit investigations and logging of test pits
- General materials testing requirements
- Laboratory DN test

4.2 Design Consultants

A formal training session was held on 13 October in the Consultant’s office. The discussions and elaboration on various issues was continued 14 October in a joint meeting with the Roads Authority, the World Bank representative, the ASWAP-SP Project Manager and the Consultant’s team.

4.2.1 DCP data interpretation and analysis

From the material presented in the preliminary Design Reports it was evident that the consultant had a reasonably good grasp of the WinDCP software and the method for analysing the data including identification of uniform sections, application of correct percentiles and the pavement design for each section.

The training was therefore concentrated on interpretation of the DCP data to identify problem areas, probable cause for the abnormal DCP DN values and possible solutions. This part of the training was mostly done during the field visits by stopping at the locations with abnormal DCP DN values and examining the micro environment at these spots to identify the problems and solutions. The discussions on site were then followed up in the classroom session by redoing the data analysis excluding the abnormal DN values and identification of new uniform sections.

The consultant was also shown how to perform a Sensitivity Analysis of the design by varying the Traffic Class and/or percentile for the DN values to see how this would affect the pavement design.

4.2.2 Application of EOD principles

As it turned out, the application of EOD principles became the major focus of the design review and training. All five project roads have widely different conditions in terms of:

- Macro/micro climate
- Terrain and alignments
- Geology and soils
- Occurrence and type of materials
- Source of surfacing aggregates

The only aspects that are common to all five roads are:

- Low AADT or 4-wheeled traffic
- High proportion of motorbikes and NMT particularly in villages/trading areas

It was clear to the team that one blanket basic design would not be the most appropriate solution for all the roads. During the field visits in-depth discussions were therefore held to explore possible design solutions that could be appropriate for each site. The purpose of these discussions and the follow-up training in the classroom was to make the consultant think through and analyse the options as a basis for the final design decision and not to prescribe certain solutions.

4.2.3 Surfacing options

Discussions were held during the field visits as to the possible options for surfacing of the various roads as outlined above under Sections 2.2.5 and 3.2.9. Due to extremely long hauling distances (100 -140 km) for surfacing aggregates on some of the projects, the consultant was advised to look into alternative to the Cape Seal as proposed in the preliminary designs.
Examples of Life Cycle costing as a basis for choosing between alternative solutions were also shown and explained.

4.2.4 Alignment soils investigations and testing

This forms the basis for the interpretation of the DCP data and application of percentiles for the data analysis and pavement design. The consultant’s data was used during the field visit to demonstrate how the moisture condition at the time of the DCP survey influences the DCP data and choice of percentiles for the design as well as identification of problem areas.
The proper method for alignment soils investigations and testing was explained during the classroom session. See also 3.2.4.1 above.

4.2.5 Borrow pit investigations and logging of test pits

Proper procedures for borrow pit investigations and logging of the test pits are of paramount importance for the design, in the attempt to optimise the use of locally available materials, as well as for the correct working of the borrow pits during construction.

Again, the issue was highlighted during the field visits as for the most part the test pits were quite shallow and therefore in all likelihood did not show the true properties of the materials in each pit.

The guidelines for borrow pit investigations and logging of test pits used in South Africa was explained during the classroom training. The Consultant was also given electronic copies of the guidelines.

4.2.6 General materials testing requirements

It appeared that all test results presented in the report was based on one test only and could therefore be grossly misleading. It was stressed that all materials tests must be done at least in triplicate to have some confidence in the results on which important design decisions are based.

Unreliable materials test results can, and has frequently done so, lead to premature failures of the pavement.

4.3 Laboratory Technicians

A formal training session for Laboratory Technicians was held 16 October at Sunbird Hotel, Lilongwe. Practical demonstration of the Laboratory DN test was carried out at Shire Construction's laboratory.

The training session had 17 participants including all Engineers and Technicians from the of the Consultant's current team as shown in Table 4-2 below. The registration sheet is shown in Annex 2.

Table 4-1: List of participants in the training on materials investigations and testing

Name	Designation	Organisation
1. Diana Kunje	Materials Technician	CML
2. Jenipher Bwanausi	"	CML
3. Emoly Kachale	"	CML
4. B.D J. Mkanda	"	CML
5. J. P. Tchilima	"	CML
6. A. Mkololoka	"	CML
7. Hastings Zimba	"	CML
8. F. B. Mthini	Senior Materials Technician	CML
9. E. G. S. Machila	"	CML
10. Francis Mburu*	Engineer	Royal Associates
11. Bina Sinclair Mhango*	"	Royal Associates
12. Samuel Ndikuno	"	Royal Associates
13. J. Mtope	Materials Technician	Royal Associates
14. Nerhu J. Chakango*	"	Royal Associates
15. Boniface N. Kiriga*	Director	Royal Associates
16. Emmanuel Nkhuku	Materials Technician	Shire Construction
17. James J.T. Chikabadwa	Civil Engineer	Shire Construction

***Person did not participate in the initial training in March/April 2014**

The training focussed on the following issues:

- Borrow pit investigations and logging of results
- General materials testing requirements
- Demonstration of the Laboratory DN Test and interpretation of the results

The presentation on borrow pit investigations and materials testing is shown in Annex 1.

Samples had been prepared the week before for the Laboratory DN test in accordance with the specified procedures and spare cones with the correct shape been borrowed from the Central Materials Laboratory.

In all 15 tests were carried out of which three were discarded due to incorrect falling height of the DCP hammer.

Back in the classroom, the results were adjusted by eliminating abnormal DN values in the top of the samples. The results are shown in Annex 3.

4.4 Evaluation and Feedback

During the wrap-up of the training on 16 October, the participants asked to give their evaluation of the training on the form shown in Table 4-2.

The Laboratory Technicians were instructed to evaluate only the four items marked, whereas Royal Associates team members were supposed to evaluate all items, although not all of them had participated in the field visits. Based on the number of responses on each item, some of the Laboratory Technicians apparently scored some items that they did not have any basis for evaluating.

It should also be noted that only two of the current Royal Associates team participated in the initial training in March/April 2014, hence some of the items were scored low or not at all.

The responses nonetheless show that the objectives of the design review and follow-up training have generally been achieved.

The discussions with the Roads Authority and the World Bank were also fruitful and brought about a common understanding of the requirements for a successful and cost effective design and construction of these projects.

Table 4-2: Training evaluation summary

Training Evaluation Summary

Items for evaluation	Engineer	Technician	Lab Tech	Score (tick in the appropriate cell)				
				1	2	3	4	5
The objectives of the Design Review were achieved	X	X		5	2	2		
The Design Review has enabled me to apply the LVSR design principles in the final design of the ASWAP-SP projects	X	X		2	2	2		
The Design Review and follow-up training has improved my understanding of the following aspects of LVSR design method and principles:								
• The "Environmentally Optimised Design" principles	X	X		2	5			
• Appropriate geometric design & "Extended Design Domain" principles	X	X		1	4	1		
• The importance of addressing all road environment factors in undertaking LVSR design	X	X		2	2	2		
• Materials prospecting and logging of results	X	X	X	12	5			
• General materials testing requirements and procedures	X	X	X	13	4			
• The Laboratory DN test and interpretation of results	X	X	X	9	8			
• Utilization of locally available materials and assessment of risk related to in-service performance	X	X		4				
• Choice of appropriate surfacing	X	X			4	2		
• Interpretation of DCP data and assessment of required interventions based on the DCP data and field observations	X	X		3	2	3		
• Strategic selection of Traffic Census points	X	X			2	2	1	
• Quality assurance in use of the DCP and field data collection	X	X	X	9	3	1		
• Operation of the WinDCP Software and Excel tables for data analysis	X	X		1	1	3	1	1
• Identification of uniform sections for separate analysis and design	X	X		1	4		1	1
• Performance of sensitivity analysis in the pavement design	X	X		1	4	1		
• The field trips and discussions on site were beneficial to the identification of particular problems and possible solutions for the respective projects	X	X		3	2			
• The field trips were beneficial to the classroom presentations and ensuing discussions	X	X		5				
• The classroom presentations were well presented and understood	X	X		12	1	1		

Scores: 1=Strongly agree, 2=Agree, 3=Partially agree, 4=Disagree, 5=Strongly disagree

5. SUMMARY

The five ASWAP-SP projects for upgrading to LVSR present a wide variety of engineering challenges and require different solutions in terms of pavement design, materials utilisation and surfacing to tailor the design cost-effectively to the natural and operational road environment. Although some of the roads are classified as Secondary roads, their current function is more for reliable all-weather access to villages and settlements and for transport of agricultural produce to markets. The benefits to be derived from the upgrading projects are mostly social benefits which are difficult to quantify in monetary terms. This situation is not likely to change dramatically within the next 10-15 years, hence a design in accordance with current function and not according to the classification is recommended.

The preliminary project designs need to be enhanced in line with the suggestions and recommendations in this design review, although the final design decision is entirely in the hands of the Design Consultant in conjunction with the ASWAP-SP Project Manager, the Roads Authority and the World Bank.

5.1 Lessons Learnt

The following lessons have been learnt on this project:

- The design of LVSR is a specialised civil engineering discipline. Engineers who have only experience with traditional design methods and design of high volume roads can have a difficult time in grasping the EOD concepts and the DCP design approach for LVSR.
- The design review indicated clearly that it is not only the DCP design method that need to be carefully scrutinized but, equally importantly, the broader LVSR design issues such as an appreciation of the role of the road environment and the application of EOD/SID principles that are all required to produce an optimum design.
- Extensive re-training is therefore required. The two-stage training that has been carried out for this project seems to be the minimum requirement and could form the basis for future training courses on LVSR and DCP Design.
- Yet, more consultations and clarifications may be required before the completion of the final designs.
- A common understanding of the project objectives and challenges must be sought between the Design Consultant, the Client and the Donor as well as the local authorities and political leadership where the projects are to be constructed in order to iron out possible misunderstandings and clarify the design and construction approach.
- The experiences from this project have highlighted issues that need to be expanded upon and incorporated in a future update of the DCP Design Manual, e.g. more detailed explanation of materials testing procedures and requirements, borrow pit investigations and logging of test pits, traffic counting procedures and strategic selection of traffic count census points.
- Supply of quality DCP instruments and spares needs to be secured.

5.2 Next Steps

The following steps need to be carried out before the projects can go out to tender:

- Traffic re-counting at strategic locations to differentiate between local traffic and trough traffic.
- Completion of materials investigations and testing in line with recommendations.
- Completion of pavement design including specific investigations and design of problematic spots.
- Community consultations and information meetings to clarify the project objectives and design and construction approach.
- Compilation of BOQs and Tender Documents.

5.3 Conclusions

The design review has highlighted shortcomings in the preliminary designs and hopefully engendered a better understanding of the requirements for appropriate design of LVSR in general and these five projects in particular.

The action list is long, but the required improvement of the designs in line with the suggestions and recommendations is achievable given that the necessary resources are mobilised. The field investigations already done by the Design Consultant are useful, but need to be supplemented with additional investigations and tests in order to arrive at the most appropriate design for each road.

Some consultations with the AFCAP team may still be required for vetting of the final designs.

5.4 Recommendations

Malawi is in the forefront in Africa in the application of the DCP Design Method for LVSR and is currently the only country with an officially endorsed DCP Design Manual.

Several LVSR with light pavements had previously been constructed based on sound engineering judgement. These roads, that all show excellent performance, have proven that significant cost savings can be achieved compared to roads designed and constructed with traditional methods.

The DCP Design Manual was then produced in co-operation with AFCAP on the basis of a request by the Roads Authority which was seeking a formalised method for LVSR design.

Thus, for the current projects and embedment of the DCP Design Method and LVSR design concept in Malawi, the following recommendations are made:

- That the ASWAP-SP Project Manager assesses the need for further assistance by the AFCAP team and seeks approval for a limited extension of their contracts.

- That Roads Authority takes an active lead in promoting the concepts for LVSR design on the basis of their own experiences and the endorsed DCP Design Manual. The concept needs a champion if it is to be widely accepted and actively used.

- That a similar training exercise be planned to start early 2015 to involve the local consulting industry.

- That the Roads Authority consults with potential donors for funding of another batch of rural road upgrading projects. The training can only be effective if it is tied to real projects like the current ASWAP-SP projects. This training exercise forms a good model for future training, with some slight modifications. Projects need to be identified and first training to be held before consultants bid for Design contracts. This will give the consultants a better foundation for submitting of realistic bids.

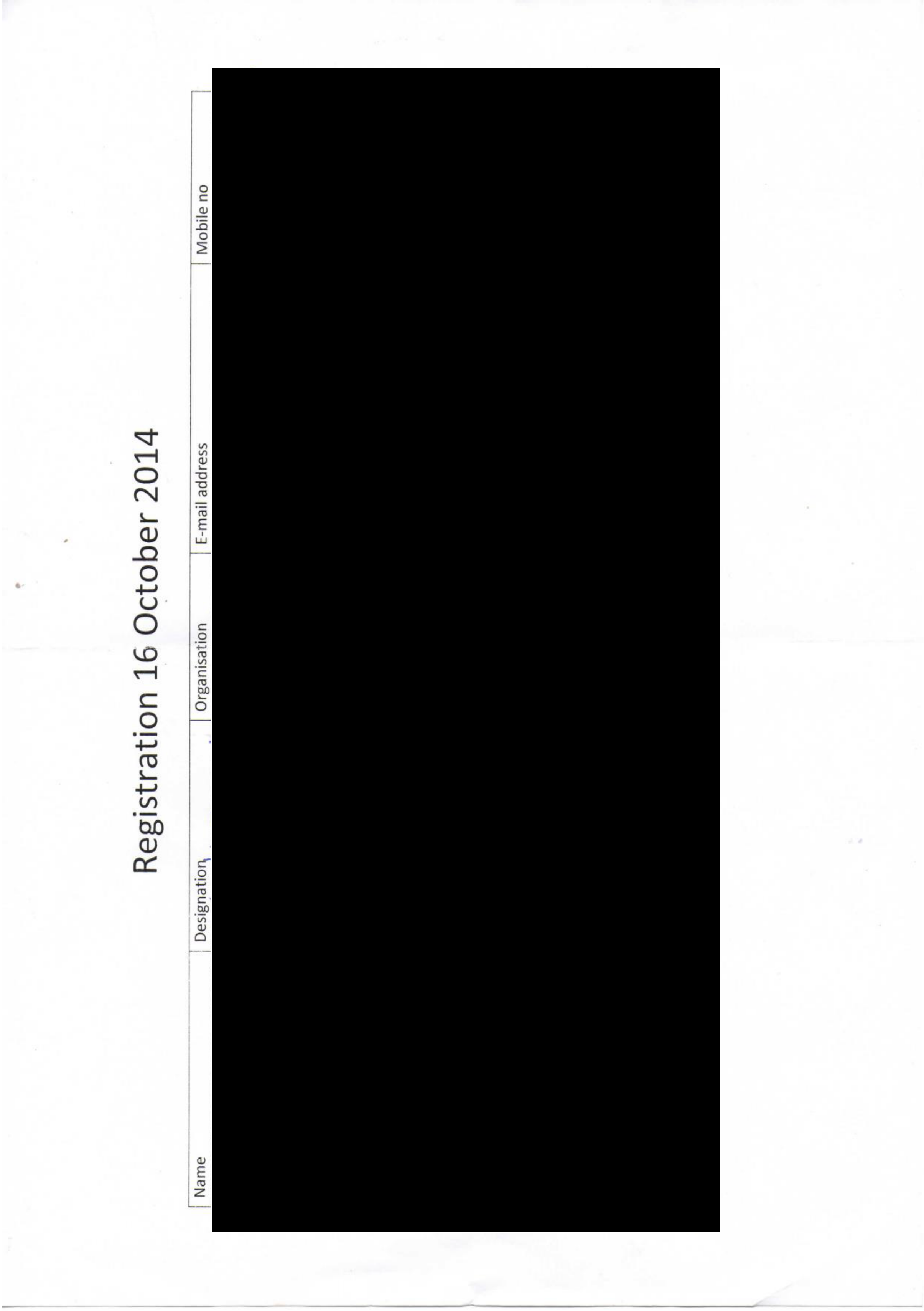
- That the World Bank and ASWAP-SP Project Manager re-evaluate Royal Associates' contract in the light of the findings of this design review. It is quite evident that Royal Associates did not fully anticipate the intricacies of designing LVSRs based on EOD principles and use of the DCP Design Method. They now do, and should be in a position to complete the designs in a proper manner. Ultimately, it is in everybody's interest that these projects are well designed and constructed in accordance with the full requirements of LVSR technology.

ANNEXES

Annex 1 – Mission Schedule

Date	Activity
29 Sep	Arrival Lilongwe J. Hongve & M. Pinard, initial meeting for mission preparations
30 Sep	Arrival Lilongwe E. Mukandila, mission preparations, meeting with Roads Authority
1 Oct	Document review, mission preparations
2 Oct	Travel to Chitipa District
3 Oct	Field visit to S100/D11
4 Oct	Return to Lilongwe
5 Oct	
6 Oct	Travel to Ntcheu District, field visit to S134, overnight in Blantyre
7 Oct	Travel to Chikwawa District, field visit to D387/D390, return to Blantyre
8 Oct	Travel to Mwanza District, field visit to S135, return to Lilongwe
9 Oct	Reporting, preparations for training sessions
10 Oct	Reporting, preparations for training sessions
11 Oct	Travel to Salima, field visit to T357, return to Lilongwe
12 Oct	
13 Oct	Classroom training with Royal Associates
14 Oct	Joint meeting with Roads Authority, World Bank and Royal Associates
15 Oct	Preparations for lab training, M. Pinard travel to Botswana
16 Oct	Training for Laboratory Technicians (J. Hongve & E. Mukandila)
17 Oct	Reporting, J. Hongve & E. Mukandila travel to South Africa
18 Oct	Reporting
19 Oct	
20 Oct	Meeting at CSIR on Concept Note for Training of Trainers and other issues
21 Oct	Reporting, drafting Concept Note, J. Hongve & M. Pinard departure from South Africa
22 Oct	M. Pinard arrival in Botswana; J. Hongve arrival in Norway
23 Oct	
24 Oct	Reporting
25 Oct	Reporting

Annex 2 – Registration for Training of Laboratory Technicians



Registration 16 October 2014

Name	Designation	Organisation	E-mail address	Mobile no
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

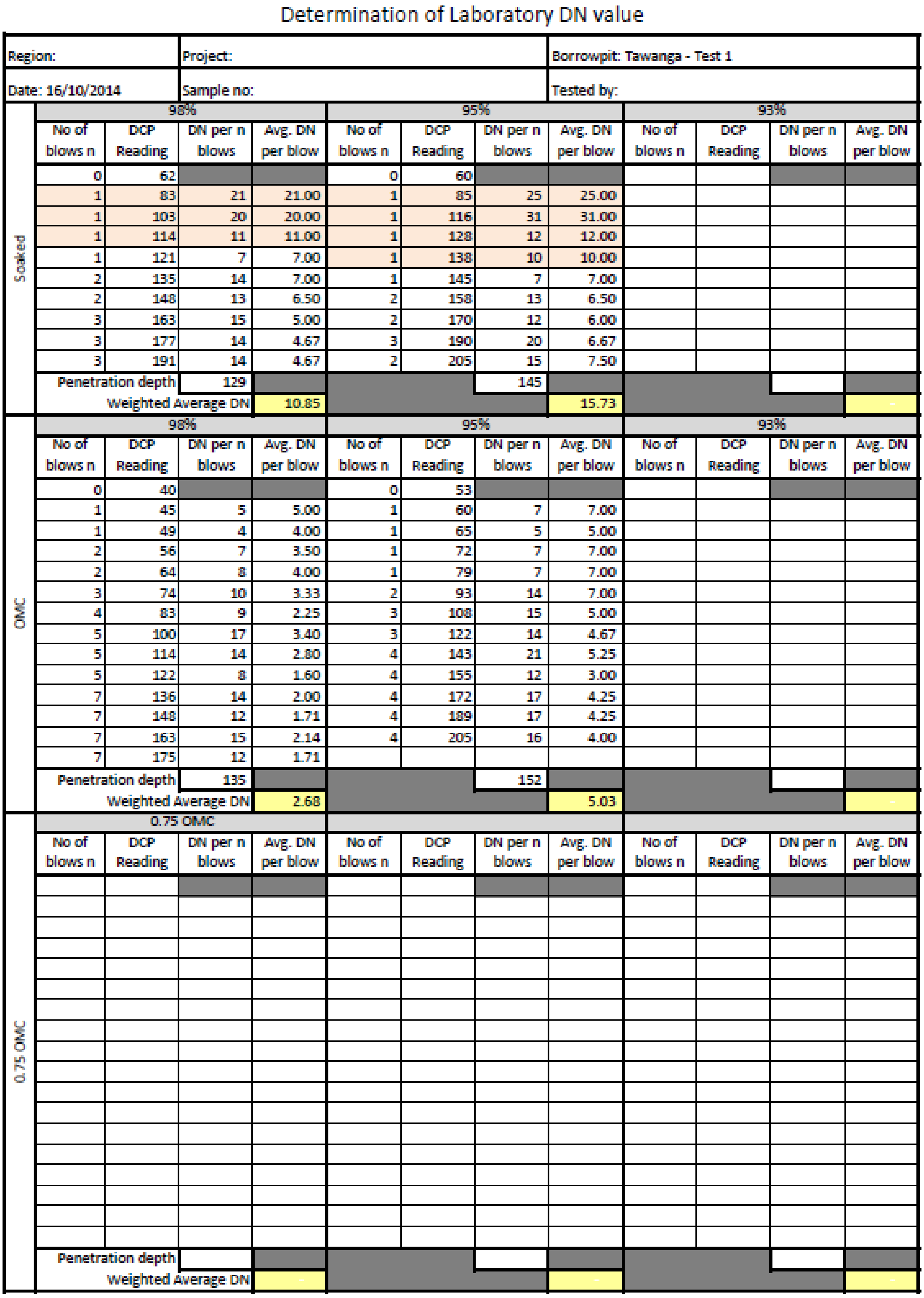
Registration 16 October 2014

Training of Laboratory Technicians

Name	Designation	Organisation	E-mail address	Mobile no
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

*Person did not attend the first training March/April 2014 **Female

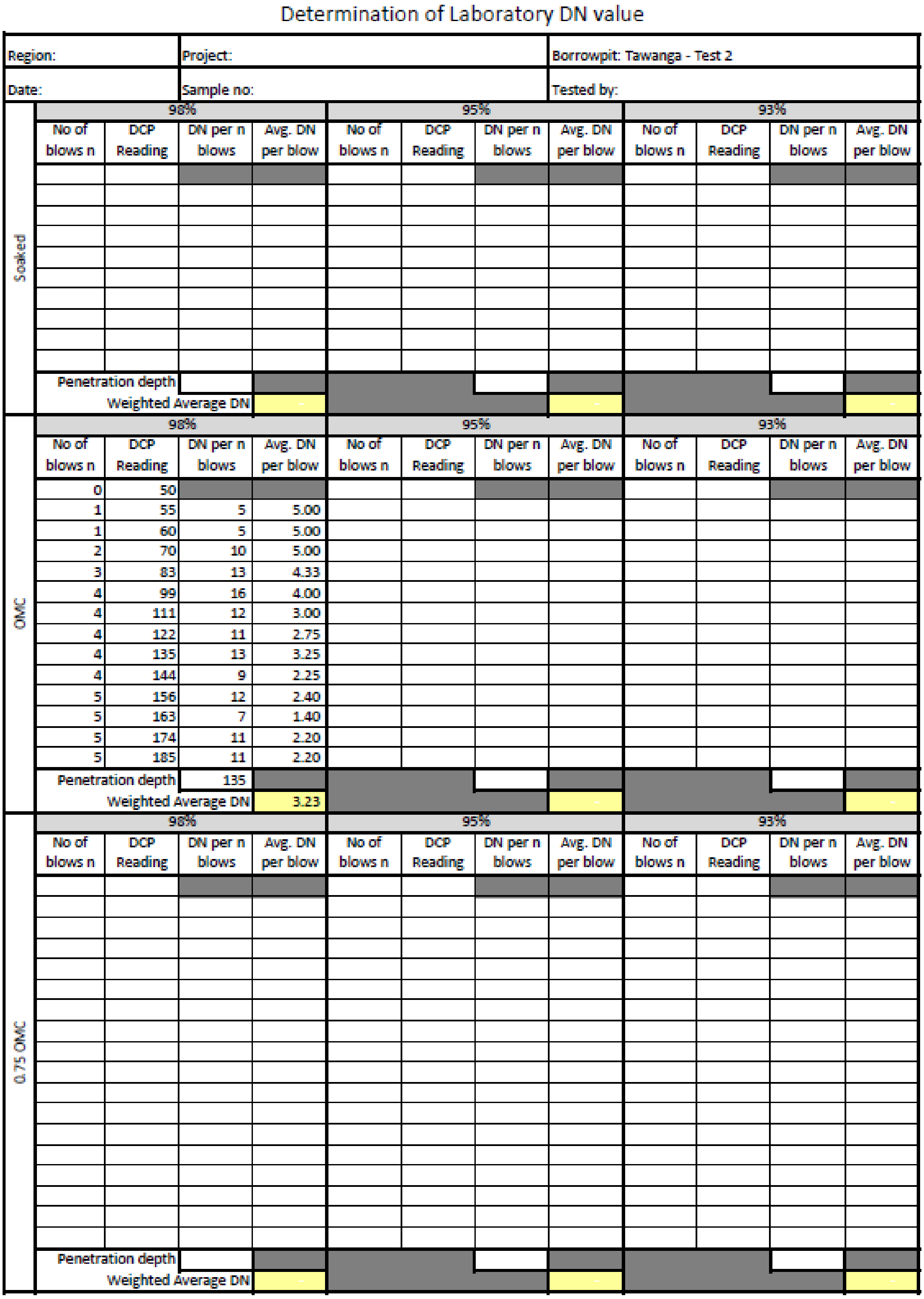
Annex 3 – Laboratory DN Results



Determination of Laboratory DN value

Region:			Project:					Borrowpit: Tawanga - Test 1				
Date: 16/10/2014			Sample no:					Tested by:				
	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
Soaked	0	62			0	60						
	1	83	21	21.00	1	85	25	25.00				
	1	103	20	20.00	1	116	31	31.00				
	1	114	11	11.00	1	128	12	12.00				
	1	121	7	7.00	1	138	10	10.00				
	2	135	14	7.00	1	145	7	7.00				
	2	148	13	6.50	2	158	13	6.50				
	3	163	15	5.00	2	170	12	6.00				
	3	177	14	4.67	3	190	20	6.67				
	3	191	14	4.67	2	205	15	7.50				
	Penetration depth		129				145					
	Weighted Average DN			10.85				15.73				-
	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
OMC	0	40			0	53						
	1	45	5	5.00	1	60	7	7.00				
	1	49	4	4.00	1	65	5	5.00				
	2	56	7	3.50	1	72	7	7.00				
	2	64	8	4.00	1	79	7	7.00				
	3	74	10	3.33	2	93	14	7.00				
	4	83	9	2.25	3	108	15	5.00				
	5	100	17	3.40	3	122	14	4.67				
	5	114	14	2.80	4	143	21	5.25				
	5	122	8	1.60	4	155	12	3.00				
	7	136	14	2.00	4	172	17	4.25				
	7	148	12	1.71	4	189	17	4.25				
	7	163	15	2.14	4	205	16	4.00				
	7	175	12	1.71								
	Penetration depth		135				152					
	Weighted Average DN			2.68				5.03				-
	0.75 OMC											
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0.75 OMC												
	Penetration depth											
	Weighted Average DN			-				-				-

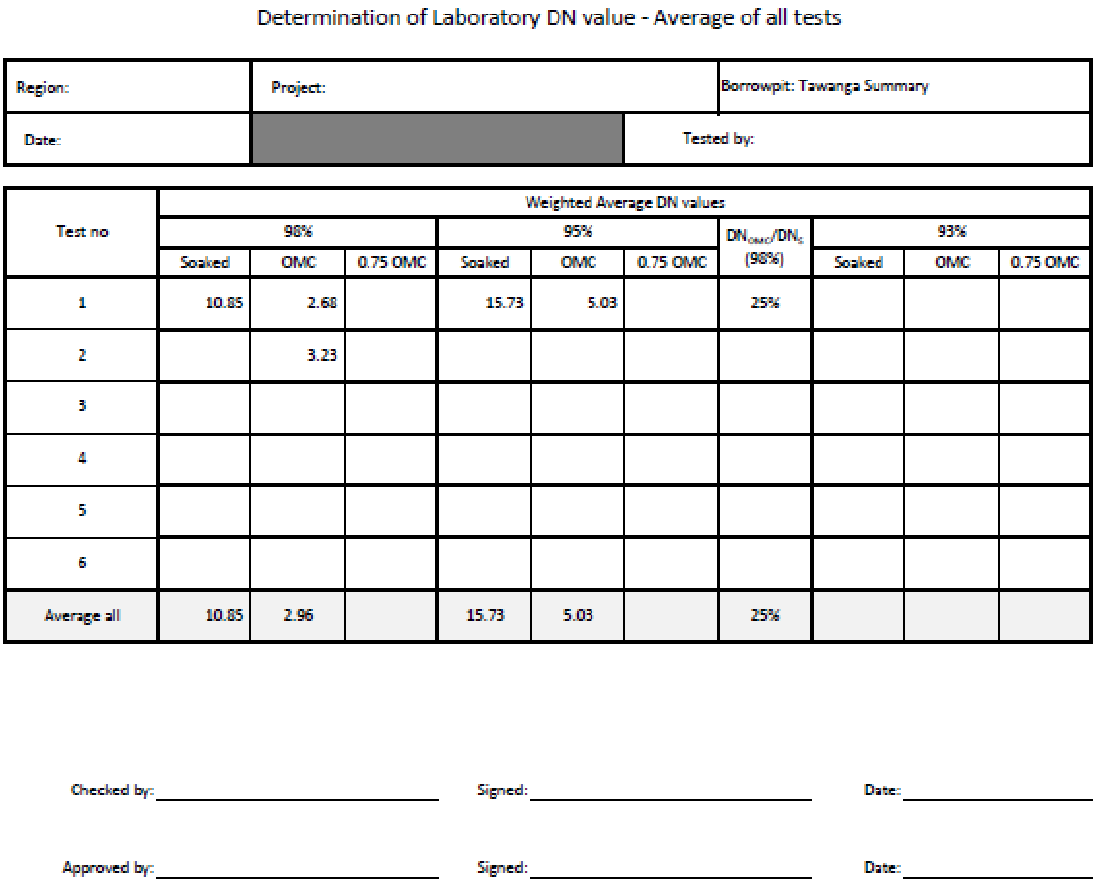
]



Determination of Laboratory DN value

Region:
Project:
Borrowpit: Tawanga - Test 2
Date:
Sample no:
Tested by:

	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
Soaked												
	Penetration depth											
	Weighted Average DN			-				-				-
	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
OMC	0	50										
	1	55	5	5.00								
	1	60	5	5.00								
	2	70	10	5.00								
	3	83	13	4.33								
	4	99	16	4.00								
	4	111	12	3.00								
	4	122	11	2.75								
	4	135	13	3.25								
	4	144	9	2.25								
	5	156	12	2.40								
	5	163	7	1.40								
	5	174	11	2.20								
	5	185	11	2.20								
	Penetration depth		135									
	Weighted Average DN			3.23				-				-
	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0.75 OMC												
	Penetration depth											
	Weighted Average DN			-				-				-



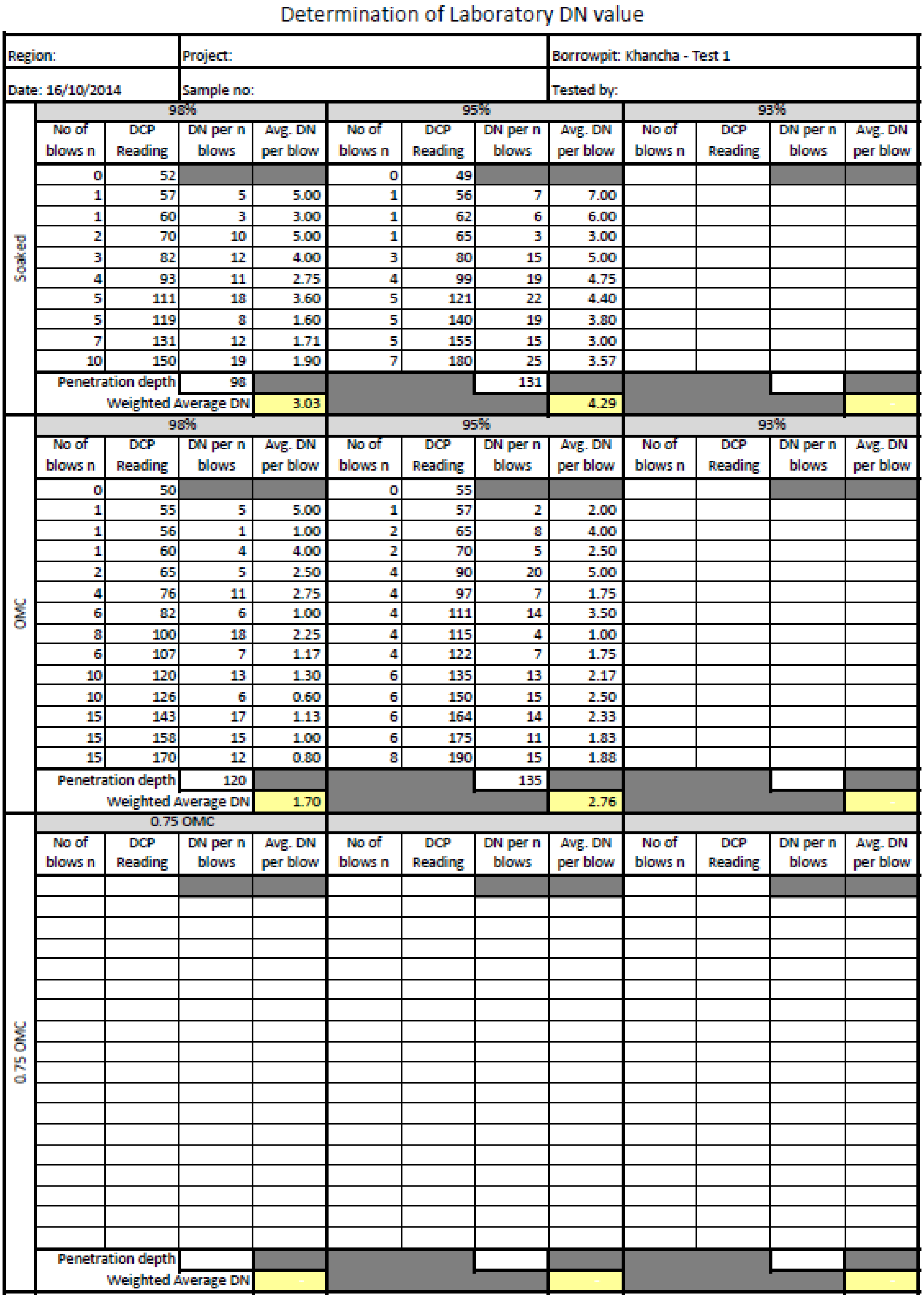
Determination of Laboratory DN value - Average of all tests

Region:	Project:	Borrowpit: Tawanga Summary
Date:	[redacted]	Tested by:

Test no	Weighted Average DN values									
	98%			95%			DN_{OMC}/DN_{S} (98%)	93%		
	Soaked	OMC	0.75 OMC	Soaked	OMC	0.75 OMC		Soaked	OMC	0.75 OMC
1	10.85	2.68		15.73	5.03		25%			
2		3.23								
3										
4										
5										
6										
Average all	10.85	2.96		15.73	5.03		25%			

Checked by: ______________________ Signed: ______________________ Date: ______________

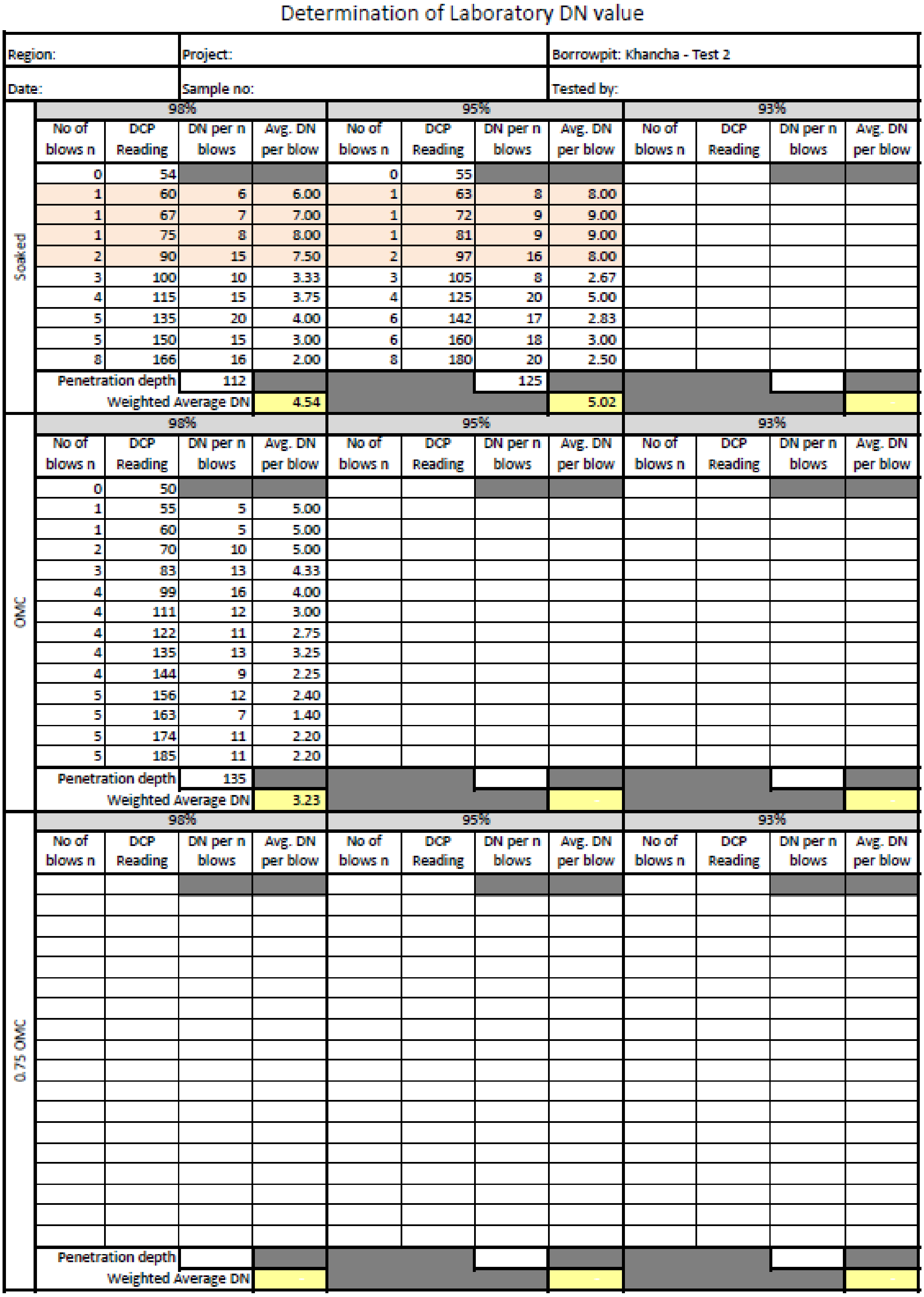
Approved by: ______________________ Signed: ______________________ Date: ______________



Determination of Laboratory DN value

Region:	Project:	Borrowpit: Khancha - Test 1
Date: 16/10/2014	Sample no:	Tested by:

	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
Soaked	0	52			0	49						
	1	57	5	5.00	1	56	7	7.00				
	1	60	3	3.00	1	62	6	6.00				
	2	70	10	5.00	1	65	3	3.00				
	3	82	12	4.00	3	80	15	5.00				
	4	93	11	2.75	4	99	19	4.75				
	5	111	18	3.60	5	121	22	4.40				
	5	119	8	1.60	5	140	19	3.80				
	7	131	12	1.71	5	155	15	3.00				
	10	150	19	1.90	7	180	25	3.57				
	Penetration depth		98				131					
	Weighted Average DN			3.03				4.29				-
	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
OMC	0	50			0	55						
	1	55	5	5.00	1	57	2	2.00				
	1	56	1	1.00	2	65	8	4.00				
	1	60	4	4.00	2	70	5	2.50				
	2	65	5	2.50	4	90	20	5.00				
	4	76	11	2.75	4	97	7	1.75				
	6	82	6	1.00	4	111	14	3.50				
	8	100	18	2.25	4	115	4	1.00				
	6	107	7	1.17	4	122	7	1.75				
	10	120	13	1.30	6	135	13	2.17				
	10	126	6	0.60	6	150	15	2.50				
	15	143	17	1.13	6	164	14	2.33				
	15	158	15	1.00	6	175	11	1.83				
	15	170	12	0.80	8	190	15	1.88				
	Penetration depth		120				135					
	Weighted Average DN			1.70				2.76				-
	0.75 OMC											
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0.75 OMC												
	Penetration depth											
	Weighted Average DN			-				-				-



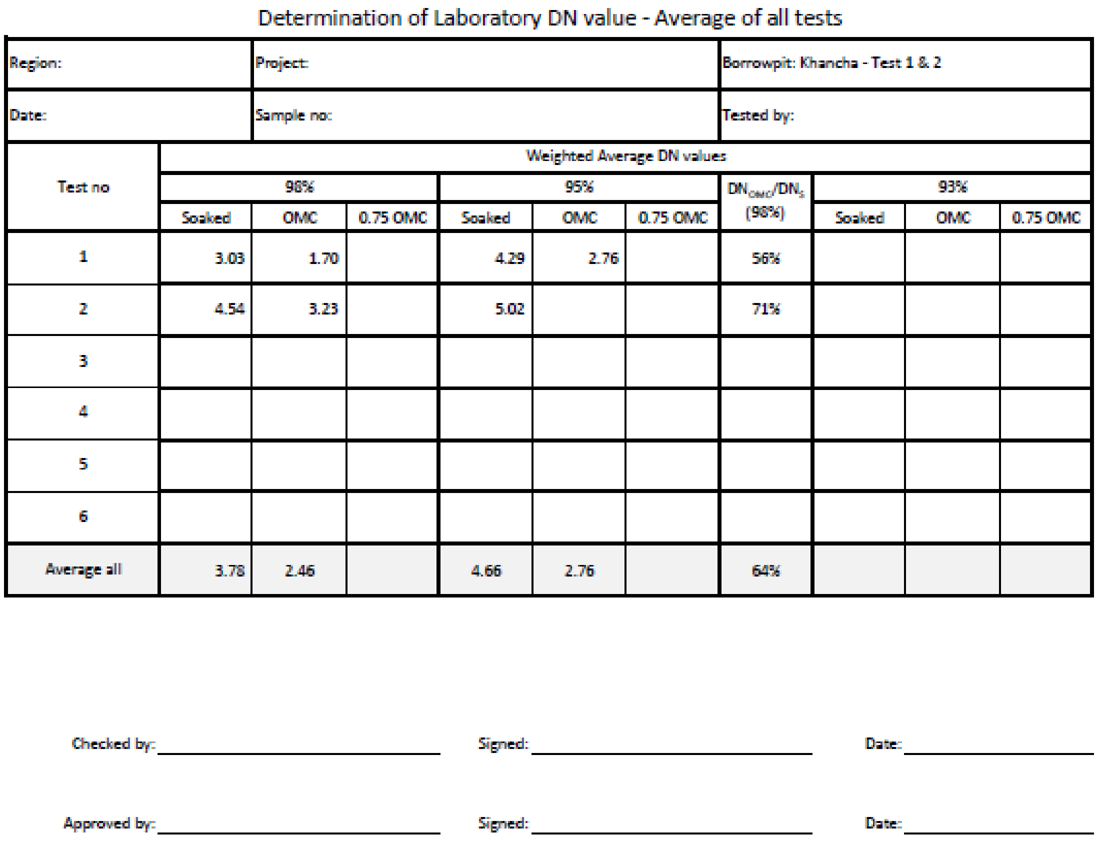
Determination of Laboratory DN value

Region:	Project:	Borrowpit: Khancha - Test 2
Date:	Sample no:	Tested by:

	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
Soaked	0	54			0	55						
	1	60	6	6.00	1	63	8	8.00				
	1	67	7	7.00	1	72	9	9.00				
	1	75	8	8.00	1	81	9	9.00				
	2	90	15	7.50	2	97	16	8.00				
	3	100	10	3.33	3	105	8	2.67				
	4	115	15	3.75	4	125	20	5.00				
	5	135	20	4.00	6	142	17	2.83				
	5	150	15	3.00	6	160	18	3.00				
	8	166	16	2.00	8	180	20	2.50				
	Penetration depth		112				125					
	Weighted Average DN			4.54				5.02				-

	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
OMC	0	50										
	1	55	5	5.00								
	1	60	5	5.00								
	2	70	10	5.00								
	3	83	13	4.33								
	4	99	16	4.00								
	4	111	12	3.00								
	4	122	11	2.75								
	4	135	13	3.25								
	4	144	9	2.25								
	5	156	12	2.40								
	5	163	7	1.40								
	5	174	11	2.20								
	5	185	11	2.20								
	Penetration depth		135									
	Weighted Average DN			3.23				-				-

	98%				95%				93%			
	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0.75 OMC												
	Penetration depth											
	Weighted Average DN			-				-				-



Determination of Laboratory DN value - Average of all tests

Region:

Project:

Borrowpit: Khancha - Test 1 & 2

Date:

Sample no:

Tested by:

Test no	Weighted Average DN values									
	98%			95%			DN_{OMC}/DN_S (98%)	93%		
	Soaked	OMC	0.75 OMC	Soaked	OMC	0.75 OMC		Soaked	OMC	0.75 OMC
1	3.03	1.70		4.29	2.76		56%			
2	4.54	3.23		5.02			71%			
3										
4										
5										
6										
Average all	3.78	2.46		4.66	2.76		64%			

Checked by: ______________ Signed: ______________ Date: ______________

Approved by: ______________ Signed: ______________ Date: ______________

Annex 4 – PowerPoint Presentations

Included as separate file.