INTERNATIONAL
LABOUR
ORGANIZATION

# CONSTRUCTION OF LOW VOLUME SEALED ROADS

## GOOD PRACTICE GUIDE TO LABOUR-BASED METHODS








DWT / Country Office Pretoria

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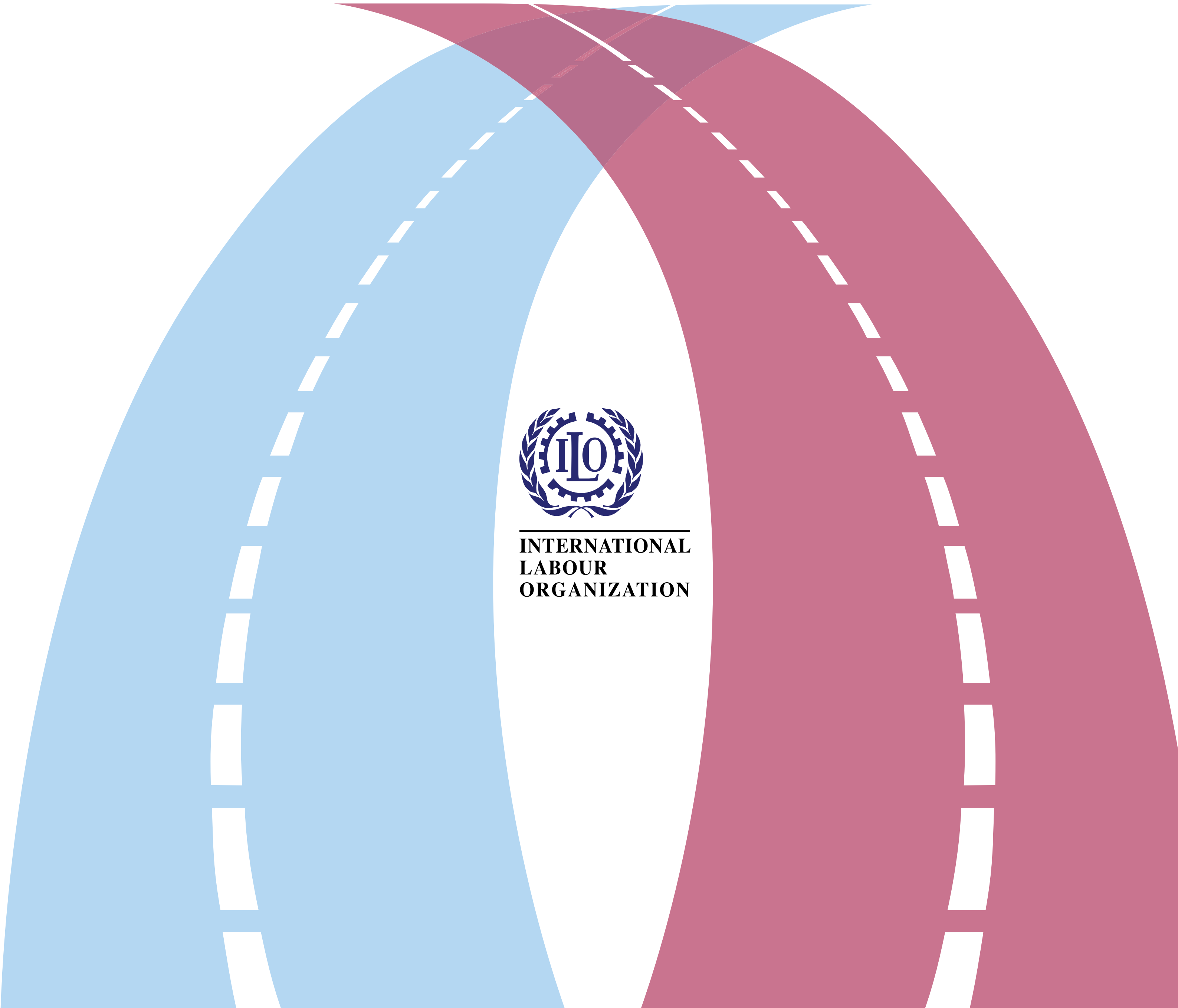

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First published 2013



Construction of Low Volume Sealed Roads - Good Practice Guide to Labour-Based Methods.

This document is not for sale.

**ISBN: 978-92-2-127464-3** (print)
**ISBN: 978-92-2-127465-0** (web pdf)

ILO Cataloguing in Publication Data.



**Photographs:**
Most photographs used in the document are from the authors' own collection while a few are from publications acknowledged herein.

Printed in South Africa.

# PREFACE

The Guideline is primarily targeted at Small-Scale Contractors and their Supervisors who are involved in low-volume road works using Labour Based Methods (LBM). Established Contractors, Professional Engineers, Technologists, and Technicians, Programme Managers, and Planners may also use this book as a reference for some of their design work and Construction Supervision services.

Illustrations included herein give real life examples and work methodologies based on universal experience which will assist the reader to develop effective construction techniques.

Relevant International Labour Organization (ILO) publications and others on road works should also be referenced for these works.

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## ACKNOWLEDGEMENT

This Guideline was largely developed from materials of a pilot project and research works carried out since 2001 in South Africa by the ILO in collaboration with the South Africa's Council for Scientific and Industrial Research (CSIR) and is complementary to a set of five manuals on Implementing Employment Intensive Road Works published on Construction Industry Development Board (CIDB) website. Also extracts from ILO-ASIST, and other publications were used and adapted to the Southern African context.

The ILO Country Office for South Africa, Botswana, Lesotho, Namibia and Swaziland -is grateful to authors for undertaking the assignment under challenging circumstances. The guideline was made possible with the assistance of many people who have been acknowledged in the preface and other contributors whose publications are referenced. The support of the Government of South Africa and in particular the National Department of Public Works (NDPW) and the Limpopo Department of Public Works (LDPW) is greatly acknowledged in facilitating the production of this Guideline.

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South Africa Botswana, Lesotho, Namibia and Swaziland

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## List of Abbreviations and Acronyms

| | |
|---|---|
| AADT | Average Annual Daily Traffic |
| AASHTO | American Association of State Highway and Transportation Officials |
| ASIST | Advisory Support, Information Services, and Training |
| ACV | Aggregate Crushing Value |
| ADT | Average Daily Traffic |
| ALD | Average Least Dimension |
| BC | Beginning of Curve |
| BoQ | Bill of Quantities |
| BSS | British Standard System |
| BVC | Beginning of Vertical Curve |
| CBR | California Bearing Ratio |
| CIDB | Construction Industry Development Board |
| COLTO | Committee on Land and Transport Officials |
| CSIR | Council for Scientific and Industrial Research |
| DCP | Dynamic Cone Penetrometer |
| EC | End of Curve |
| EIIP | Employment Intensive Investment Programme(s) |
| EPWP | Expanded Public Works Programme |
| ETB | Emulsion Treated Base |
| EVC | End of Vertical Curve |
| GM | Grading Modulus |
| GPS | Global Positioning System |
| ILO | International Labour Organization |
| LBC | Labour Based Construction |
| LBM | Labour Based Methods |
| LBS | Labour Based Sealing |
| LBT | Labour Based Technology |
| LDPW | Limpopo Department of Public Works |
| LIC | Labour Intensive Construction |
| LVSR | Low-Volume Sealed Road |
| NDPW | National Department of Public Works |
| NGO | Non-Governmental Organization |
| OMC | Optimum Moisture Content |
| OPC | Ordinary Portland Cement |
| PI | Point of Intersection |
| P.I | Plasticity Index |
| SA | South Africa |
| SABS | South African Bureau of Standards |
| SANS | South African National Standards |
| SC | Spiral to Curve |
| ST | Spiral to Tangent |
| STM | Standard Test Method |
| TRH | Technical Report for Highways |
| TRL | Transport Research Laboratory |
| TS | Tangent to Spiral |
| USA | United States of America |
| UTRCP | Ultra-Thin Reinforced Concrete Pavement |
| VAT | Value Added Tax |
| VIP | Vertical Intersection Point |
| vpd | Vehicles per day |

# SECTION 1: INTRODUCTION

## 1.1 STATEMENT OF THE PROBLEM

### 1.1.1 Poverty and unemployment

The World Bank estimates (February 2010) that the number of people living in extreme poverty (less than $1.25/ day) stands at 1.4 billion (25%) of world population. Based on recent economic developments the International Labour Organization (ILO) also estimates that global unemployment in 2010 stood at 205 million which is a 27.6 million increase prior to the advent of the global economic crises in 2007. In addition, the Global Employment Trends Report indicates that more than 400 million new jobs will be needed over the next decade to avoid further increase in unemployment. Some 900 million workers, mostly in developing economies, could be pushed into extreme poverty. 74.8 million young people between the ages of 18 and 24 are unemployed (2011). Globally, the unemployment rate for youth is three times higher than for adults with women and children being the most vulnerable. More women are working than ever before, yet they are more likely than men to get low-paid jobs, with no social protection, basic rights nor voice at work.

These inequalities experienced by large numbers of people have already led to social crises and violence in some countries. It has now reached the stage whereby inaction at times result in social unrest, and these situations will occur more and more frequently. To address this situation, governments and its development partners need to show genuine commitment to sustainable change matched by a strong determination to intervene so that the millions of people now living in poverty have their livelihoods improved.

The primary goal of the ILO has always been to promote opportunities for women and men to obtain decent and productive work, in conditions of freedom, equity, security and human dignity. There is no overstating the priority of job creation as access to work is the surest way out of poverty. Moreover, getting people into productive activities is the way to create the wealth that enables the achievement of social policy goals.

Productive work and new employment opportunities can be created through different ways with investments in infrastructure being one of the options. In developing countries there is a huge demand for improving local roads and streets in both rural and urban communities. The average wage rate is relatively low in developing countries compared to other industrialized countries whilst almost all plant and machinery with associated spare parts are imported using scarce foreign exchange. By introducing labour-based work methods, more employment can be created and more cash income can be offered to job-seekers in the communities for which the infrastructure is intended. At the same time, relying more on local labour as a local resource, reduces the reliance on foreign imports.

*Roads without maintenance*

### 1.1.2 Deteriorated road networks

Huge backlogs in maintenance, rehabilitation and upgrading of road infrastructure exist in many developing countries. This situation is often more pronounced on local roads. The disrepair of rural and urban access roads adds to the social and economic hardships of local communities.

*Dust generated by unpaved roads*

Unsealed earth or gravel roads, normally providing local access, have low traffic volumes in the neighbourhood of less than 200 vehicles per day. However, due to other non-traffic-related factors such as climate, terrain, soil conditions and lack of maintenance, these roads deteriorate

[1] World Bank Global Economic Prospects, February 2010

[2] ILO: Decent work, Report of the Director-General, International Labour Conference, 100th Session, Geneva, 2011.

[3] ILO: Global Employment Trends 2012, International Labour Office – Geneva, 2012.

rapidly thus resulting in limited access and high transport operating costs. Furthermore through dust pollution, these roads result in environmental degradation and pose as health hazards. The fast depletion of non-renewable construction materials (gravel) in some countries makes the rehabilitation and maintenance of the expanding network unsustainable.

*Fast depletion of gravel sources*

Standard designs used for low-volume roads very often ignore varying local conditions and do not harness local resources thus resulting in over-design and expensive works.

Since the early 1970s, thousands of kilometres of rural roads have been constructed using Labour Based Methods (LBM) in developing countries in Africa, Asia and Latin America. These roads have vastly improved access in remote rural areas and opened up significant development opportunities particularly in the agricultural sector. In addition, these programmes generated substantial paid employment in rural areas where such opportunities were previously at best very scarce and often non-existent.

The use of labour-based methods for road building has in the past (and still is to a large extent) almost entirely been used on gravel and earth roads, the main surfacing material being natural gravel obtained from sources located in the vicinity of the roads. It is often viewed as a low cost mode of construction, which does not merit detailed design scrutiny. A major emphasis when initiating many of these projects focused on the potential social benefits emanating from the increased employment generation with less consideration to the engineering life-time cost and benefits. This has in some cases resulted in unacceptable financial and environmental costs.

There is also a growing environmental concern among road users and the general public on dust from unpaved roads which is a potential health hazard - particularly in residential areas. Gravel and earth roads with higher traffic levels require more frequent routine and periodic maintenance including re-gravelling works. When considering total life-cycle cost, this makes them more expensive compared to roads with a more durable bitumen-based surface. Moreover, the continuous use of natural gravel is rapidly depleting existing sources making it a scarce commodity and more costly to extract.

From the foregoing, there is thus the need to look at alternative long-lasting surfacing solutions, which rely on locally available resources and can be applied using intermediate technologies. It is also important to review engineering standards for roads built using labour-based works technology to ensure quality and value for money whilst addressing the high unemployment challenge.

## 1.2 UN-SURFACED ROADS: THE GRAVITY OF THE SITUATION

Appropriate approaches to the provision of Low-Volume Sealed Roads (LVSRs) are now required if developing countries are to improve road transport efficiency and attain broader goals of socio-economic growth and development.

Traditional approaches to the provision of low-volume sealed roads have stemmed from technology and research carried out in Europe and the USA in very different environments. Prevailing conditions in developing countries are usually very different in terms of climate, traffic, materials and road users. It is therefore not surprising that many of the imported approaches, designs and technologies are inappropriate.

The problems of unsealed roads require attention as it is becoming increasingly difficult to maintain them, and these roads continue to:

- Experience an increase in traffic volumes;
- Impose a growing logistical, technical and financial burden on road agencies due to constraints on physical, human, financial and natural resources; and
- Require the continuous use of a non-renewable resource (gravel) which is being seriously depleted in many parts of developing countries.

Regional research has shown that the use of bitumen-based seals instead of gravel is economically justified at less than 100 vehicles per day (vpd).[4] This conclusion is in contrast to the previously recommended threshold values for Sub-Saharan Africa, which were in excess of 200 vpd, a figure that still persists in the minds of many practitioners.

Failure to observe the optimal timing for sealing gravel roads can be very costly to national economies, not only in terms of incurring excessive transport costs but also, adverse socio-environmental effects due to the need to periodic regravelling requirement. This provides a strong impetus for policy change and the adoption of alternative, cost-effective surfacing strategies.

The whole-life cycle benefits of sealed roads include:

- lower transport costs (construction, maintenance and vehicle operating);
- increased social benefits (more reliable access to schools, clinics, etc.); and
- reduced adverse environmental impacts and health and safety problems (dust pollution affecting human and plant health).

Over the last two decades, the ILO and other agencies have invested considerable time and resources to demonstrate the continued effectiveness and applicability of "substituting" labour for machines in un-surfaced road infrastructure work. It has been proven that for many types of engineering work, a largely labour-based unit can produce cost effective, timely and quality outputs. However, with some notable exceptions, the methods have still not been widely adopted.[5]

There is a great deal of literature on the technical details of labour-based work, which will not be elaborated at this stage.[6] All that needs to be stated at this point is that the basic principle of labour-based approaches, combining a well-organized and motivated work force (provided with good quality hand tools) with the necessary light equipment to construct quality infrastructure still remains viable. The ratio of labour to equipment varies with the nature of the work, with labour being from 10 to 60 percent of the total value of the works.

In recent years, several research and development initiatives have been undertaken by a number of institutions with the aim of improving engineering designs for sealed roads built using labour-based methods. New work methods and designs have been developed using different combinations of locally available materials together with bituminous binders in order to come up with alternative pavement solutions which are appropriate and environmentally friendly.

This Guideline therefore demystifies a common claim that Labour Based Technology (LBT) is an inferior mode of construction, which does not merit detailed design scrutiny. It documents innovative low-volume road design, construction and maintenance methods, procedures and best practices tried and proven through research and actual implementation works carried out in South Africa over the last ten years, which have been replicated in several countries including Indonesia, Tanzania and Kenya.

The extensive research carried out using labour-based methods to improve the qualities of local materials with emulsion and cement/lime as a base course placed on an acceptable quality subgrade and capping the pavement with an appropriate seal has proved to be cost-effective and extended the lifespan of low-volume roads with 300 – 500 vehicles per day to beyond 10 years even with limited maintenance.

These work methods and design solutions have also proved to be more compatible with the involvement of small and medium sized contractors as there is the limited need for heavy construction equipment. In essence, the

[4] Guidelines to Low-Volume Sealed Roads, Southern African Development Community, July 2003

[5] In Africa Lesotho, Botswana, South Africa, Zambia, Kenya, Ghana, Uganda, Ethiopia and Mozambique have well established labour-based road construction and maintenance programmes.

[6] The ILO ASISTDOC database lists reports, manuals, guidelines and other relevant documents.

methods promoted in this guideline do not require more equipment than what is required when applying labour-based methods for building gravel roads.

This document provides essential design standards and specifications and also gives guidelines and recommendations on practical work methods. In some instances, local conditions may demand modifications to some of these recommendations at the discretion of the designer.

## 1.3 TARGET USERS

Experience shows that the successful implementation of employment-intensive investment programmes (EIIPs) need the cooperation of all spheres of government and stakeholders including private sector players. It is vital that key members of staff in these organizations have the requisite knowledge and capacity to implement works using labour-based technology. Labour-based approaches need to be well understood and appreciated by all staff involved in the various stages of the project cycle including at policy formulation level, pre-planning, planning, design, implementation, and monitoring and evaluation.

The use of labour-based works technology allows for a wider range of contractors to participate in works implementation. Small-scale contractors usually lack the resources and skills to implement conventional road construction works though these locally trained contracting firms have the potential to employ large numbers of workers. This guideline is therefore primarily targeted at the small-scale contractors and the organisations in charge of work supervision. In addition, this document contains valuable reference information for planners, programme managers, consulting engineers and larger contracting firms involved in labour-based works. Table 1- 1 below gives a full overview of potential users of this guideline.

**Table 1-1: Target users**

| Sector | Target users |
|---|---|
| Central Government | Policy makers |
| | Programme and project managers and planners |
| | Engineers and technicians |
| Provincial and Local Government | Decision makers |
| | Programme and project managers and planners |
| | Engineers and technicians |
| NGO/CBOs | Programme and project managers and planners |
| | Engineers and technicians |
| Private sector | Consulting engineers |
| | Specialists and technicians |
| | Small-scale contractors |
| | Major contractors |
| | Bitumen product suppliers |
| | Precast concrete product suppliers |

## 1.4 SCOPE OF THE GUIDELINE

The Guideline aims to assist users in the construction of low-volume sealed road through the use of labour-based work methods. It outlines basic setting out methods, suitable task rates and effective work methods and organisation applying labour-based approaches.

## 1.5 TERMS AND TERMINOLOGY

The Guideline has adopted the standard terminology used in road planning, design, construction and maintenance. To ensure that all target users are able to effectively use this document, the most common terms are elaborated in Appendix 1.

## 1.6 STRUCTURE OF THE GUIDELINE

By and large the chapters in this Guide are meant to be all-encompassing for each subject. Users can thus benefit from their particular subject of interest without necessarily reading through the other chapters. However, for users without prior experience with labour-based works technology it is recommended that the chapters on Introduction, Labour-based construction, Clearing and Earthworks be appreciated as well. A synopsis of the individual chapters of the Guideline is provided Table 1-2:

**Table 1-2: Synopsis of the chapters of the Guideline**

| | | |
|---|---|---|
| **Section 1:** | Introduction | - This section highlights issues of poverty, unemployment, and deteriorated road networks prevalent in developing countries and the need to use appropriate and cost-effective methodologies in resolving these issues. It also specifies the target users of the Guideline followed by a concise synopsis of the document. |
| **Section 2:** | Employment-intensive construction | - Introduces the user to labour-based works technology and the key prerequisites for successful implementation. |
| **Section 3:** | Setting out road works | - This chapter focuses on basic techniques and equipment for accurate setting out of road alignments. It covers setting out straight lines, gradients and curves. |
| **Section 4:** | Site clearing and Earthworks | - A brief coverage of labour-based aspects of site clearing is provided in this section. It is followed by details of labour-based methods for bulk earthworks including excavation requirements, fills and measurement of earthwork quantities. Task work rates for various soil conditions and means of verification of soil characteristics are also provided. This section also covers borrow pit preparation, excavation and loading works. |
| **Section 5:** | Pavement layer works | - This section describes road pavement types, in-situ soil surveys, methods of soil stabilization including emulsion treated base courses. |
| **Section 6:** | Drainage | - This chapter covers all road drainage works including surface drainage, cross-drainage works including culverts and drifts, sub-surface drainage and soil protection works. |
| **Section 7** | Concrete works | - A brief overview is included on basic concrete technology, explaining in detail concrete materials, composition, mix designs, methods of producing concrete by hand and by machine and good practice in transporting, placing, compaction and curing concrete. |
| **Section 8:** | Sealing options using labour-based methods | - This section covers the core and most important subject in this Guideline, presenting good practice guidelines and procedures for a variety of labour-based sealing options based on extensive research and their application over the past ten years. In this section the general function, factors affecting choice of surfacing types, the advantages and disadvantages of the various seal types, and methods of construction are described. Other forms of low-volume road pavements are also recommended. |
| | References | - All reference documents and materials used are listed in this section using the Oxford standard format of referencing. |
| **Appendix 1:** | Road terminology | - For the purposes of common understanding, definitions of all road terminology used in this guide are outlined in this Appendix. |

## Notes

# SECTION 2: LABOUR-BASED CONSTRUCTION

## 2.1 USE OF LABOUR-BASED METHODS

Labour-based work methods (LBM) basically involve the use of innovative approaches to execute projects or manufacture products in order to maximize employment and also transfer skills to the target worker groups without compromising the quality of the final asset or product. In infrastructure projects, this is achieved by substituting machines with manual labour when carrying certain work activities while still maintaining quality of works and cost competitiveness. Other reference literature refers to this as Labour-based Construction (LBC) or Labour-based Technology (LBT), whilst some refer to the same as Labour-intensive Construction (LIC)[7]. In this document these terms may be used interchangeably.

## 2.2 DEFINITION OF LABOUR-BASED METHODS

Labour-based methods involve the use of an appropriate mix of labour and capital equipment in construction of infrastructure, with a preference for labour where technically and economically feasible, while maintaining established quality standards. Preference is commonly made for the use of light construction equipment for such work activities that cannot be replaced by labour. International and local experience show that, with well-trained site supervisory staff and an appropriate employment framework, labour-based methods can be successfully applied to certain types of infrastructure works without increasing costs or compromising quality.

The extent to which labour-based work methods are applied can be evaluated on the basis of the proportion of the project expenditure that ends up as wages for unskilled and semi-skilled workers. Wages can account for some 20 to 50 percent of the total project expenditure when applying labour-based methods for the construction of low-volume roads, resulting in a significant cash injection into local economies. In routine maintenance of such roads, the labour intensity can be as high as 80 percent. In other infrastructure works such as water and sanitation schemes and building works, costs of materials such as piping, pumps, bricks and so forth may account for a larger proportion of project expenditure. The optimal use of labour-based methods in these type of projects can still bring the wage bill to 15 to 25 percent of total expenditure as compared to less than 10 percent when relying on conventional equipment-based work methods.

### 2.2.1 Advantages of labour-based construction

The benefits of using labour-based methods compared to conventional machine-based methods are numerous, amongst others include:

- Employment creation for people in local communities
- Provides job opportunities to women and youth. This improves social security protection to vulnerable groups
- Increased job opportunities and cash income may reduce the risk of civil unrest
- Creation of and support to local entrepreneurs, especially small, medium and micro enterprises
- Promotes local economic development and livelihoods especially in rural and low-income urban areas where economic activities are limited
- Mitigates rural-urban migration
- Skills transfer to workers (essential for routine road maintenance by labour)
- Instils a higher sense of ownership of infrastructure in local communities
- Requires fewer skilled operators
- Optimizes the use of local resources
- By concurrently operating several work sites it is possible to dispel the myth that labour-based work methods are slow
- Projects are less dependent on foreign exchange
- Construction of technically sound and economically efficient infrastructure
- Provision of infrastructure in areas where it is not feasible to use conventional machinery such as in remote and inaccessible mountainous areas, deep valleys and informal settlements

[7] Some literature refers to labour-intensive construction methods as a complete omission of construction equipment, only relying on manual labour. This approach is commonly applied in some cash or food for work programmes.

## 2.3 PREREQUISITES FOR SUCCESSFUL LABOUR BASED IMPLEMENTATION

For successful implementation of labour based projects, the following basic prerequisites, criteria and principles should be fulfilled:

### 2.3.1 Training and capacity development of stakeholders

Training is a prerequisite for personnel or stakeholders who intend to participate in labour based works and yet do not possess the relevant knowledge and skills to carry out these works. Training is also meant to assist in changing mind set and skills of people who are sceptical about the approach. Hence it is important that all the different stakeholders comprising client project managers, consultants/technical staff for the design and work supervision, as well as contractors with their site supervisory staff, and the workers carrying out the work should be knowledgeable in labour based works to be able to play the different roles and also work together as a team.

**Group discussion during training session**

### 2.3.2 Stakeholder Identification and Communication Strategy

Consultation and participation of all key stakeholders is essential for successful implementation of labour based projects which are mostly community-based programmes.

Prior to commencement of the Project, it is important to identify the key local stakeholders who need to participate in the project implementation and with whom the Client of the Project, Consultants and Contractors need to interact. Key stakeholders should include amongst others, the relevant local government authorities, traditional leaders, community development structures and representatives.

**Involvement of community leaders in recruitment of workers**

### 2.3.3 Socio-economic conditions

When implementing labour-based works projects certain conditions should prevail for these projects to be successful. Labour-based approaches will be ideal where there is a dense population, high unemployment, underemployment, low wage rates and high levels of poverty. With daily wage levels of up to US$15.00 and even higher, it is usually feasible to apply labour-based work methods as the accrued social benefits tend to outweigh other considerations. In more sparsely populated areas or areas where unemployment is lower, the labour availability needs to be carefully assessed. There may still be a conducive environment for the use of such approaches, however the works then needs to be carefully planned on the basis of available labour and the demand for employment and cash income.

### 2.3.4 Availability of local labour

Preferably, the project locations should be in close proximity to large settlements where abundant labour supply can be obtained (ideally within walking distance of a maximum 5 km radius). Absence of labour within the project vicinity can result in increased project costs (in transportation/accommodation) and administration (projects have been successfully implemented in sparsely populated areas in countries such as Botswana, Namibia and Laos).

### 2.3.5 Site conditions and complexity of project

The nature and scope of the project should not be too sophisticated and difficult for the use of labour-based methods. For very hard or rocky ground conditions such as in steep terrain[8] as well as for infrastructure work involving massive earthworks, appropriate plant and equipment may be necessary to complement the use of labour. Care must also be taken in the selection of construction materials to ensure quality and durability of infrastructure works.

### 2.3.6 Use of locally available resources

During the design stage, the selection of construction materials should emphasize more on materials that maximize employment creation during construction. Furthermore, the design should optimize the use of locally available materials such as stone masonry, grouted stone pitching and gabion works. Where local skills such as bricklayers and stone masons are available, structures should be designed to make maximum use of such human resources. For example, a project can specify the casting of kerbs and culvert pipes on site instead of relying on precast concrete products thereby increasing the labour intensity, harnessing locally available skills as well as reduce transport and overall project costs. Even though the above are common concerns of all road designers, the use of labour-based works technology takes the approach a step further in maximizing the use of local labour.

*Stone pitched drain*

***During Contruction*** ***After***

*Stone masonry bridge*

***During Contruction*** ***After***

*Stone pitched culvert wing wall*

[8] With proper organization and resources, labour-based work methods are being successfully used in road works in steep and rocky terrain in countries such as Lesotho, Ethiopia, Pakistan and Nepal.

The following tips should be considered in design of road works projects with the objective of maximizing employment creation:

- Minor earthworks should be designed using LBM. Materials excavated from side drains that meet earthworks specifications should be reused in order to limit haulage distances.
- Vertical and horizontal road alignments should be adjusted to optimize cut and fill, minimize longitudinal haulage distances, and deep or hard excavation or areas requiring specialist engineering inputs, for example dewatering or specialist ground stabilization.
- Trapezoidal open side drains are hydraulically more efficient and easy to excavate by hand and should be specified in favour of conventional V-shaped drains.
- Suitable construction material should be sourced to the extent possible in close proximity to the work sites. Soil excavated from the side drains should be tested to determine its suitability for road pavement works. Such material may reduce the demand for additional imported material.
- The distance between quarries/borrow pits or sand sources should preferably not exceed 4 to 5 kilometres, thereby allowing for the effective use of small volume local transport. Efforts should be made to identify new material sources rather than relying only on existing quarries with due consideration to minimizing environmental damage.

### 2.3.7 Work organization

The organization and spacing of workers is important in order to secure high production outputs and to ensure adequate safety in the work area. Design considerations such as benching and terracing should be applied to soil excavation situations which may constitute a safety hazard for workers. If such measures cannot be taken, then such works must be excluded from the labour-based work activities.

### 2.3.8 Labour laws

The appropriate labour laws governing working conditions and welfare of workers need to be observed and should be inserted into the contract documents under the Special Conditions of Contract.

### 2.3.9 Prompt payments

Without a framework that ensures prompt payment of contractors by the Client, and subsequently the timely payment of workers' wages by the contractors, any labour-based project, no matter how well planned and implemented, is bound to fail. Unlike conventional machine-based projects, labour-based works rely on human beings as the main production units, who need to be paid promptly to be able to sustain themselves and their families and thus allowing them to continue to work. Delays in payment of wages can lead to strikes or other industrial action and civil unrest. Late payments of contractors have detrimental effects on their cash flow, forcing them to reduce work activities. Hence prompt payment is key to the success of labour-based works projects. It is therefore of paramount importance that the client bodies streamline their payment procedures to ensure prompt payment to contractors for completed works. It is strongly recommended that contractors be paid within a maximum of ten working days (two weeks) from the date when completed works are measured and approved on site.

There are instances when contractors have failed to pay their workers on time resulting in serious social unrest, with the workers ultimately demanding payment direct from client bodies. In standard contract documents, the client has no contractual obligations related to the wages of the workers employed by the contractors. To enable the client to remedy such situations, it is common practice on labour-based works projects to add a clause under the Special Conditions of Contract as shown below:

*"Contractor's default in payment to labourers and employees*
*Any dispute between the Contractor and labourers, regarding delayed payment or default in payment of fair wages, if not resolved immediately may compel the Employer to intervene. The Employer may, upon the Contractor defaulting payment, pay the moneys due to the workers not honoured in time, out of any moneys due or which may become due to the Contractor under the Contract".*

### 2.3.10 Use of good quality hand tools

The use of good quality hand tools is crucial in order to reach good productivity levels as well as avoiding that workers are unduly strained when carrying out their work activities. Though for tendered works, the onus is on the contractor to provide hand tools, it is still equally the responsibility of the client to ensure that the contractor provides the workers with such quality tools and in the required quantities as the costs of the tools are included in the project cost and eventually paid by the client. To enforce this provision, the following clause is therefore commonly added to the Special Conditions of Contract:

***"Provision of hand tools***

*The Contractor shall throughout the project duration, provide his/her labour force with hand tools of adequate quality, sufficient in numbers and make the necessary provisions to maintain the tools in good and safe working conditions".*

### 2.3.11 Appropriate low-volume sealing design options

There are a number of appropriate seal designs recommended for low-volume roads constructed using labour-based work methods, such as the modified Otta seals, slurry seals, pre-mixed cold asphalt and interlocking concrete blocks.[9] Hot bituminous seals, can also be executed using labour based work methods although they are not labour-friendly due to the high temperatures of the materials during their application as well as requiring longer stretches of completed base formation (minimum 700m) for economic tanker delivery.

### 2.3.12 Low volume roads employment potential

With appropriate selection, design and supervision by consultants knowledgeable in LIC, and constructed by well trained and equipped contractors, construction of low volume sealed roads have very high employment potential. When all activities are in operation the employment generated can be between 150 to 200 workers as illustrated in Table 2-1 below:

**Table 2-1: Typical Low volume road employment potential**

| Item # | Description | Unit | Average Quantity per km | Average Task Rate | Employment Potential | |
|---|---|---|---|---|---|---|
| | | | | | Worker-days per km | Number of workers |
| 1 | Setting out of works including pegging | m | 1000 | 10 | 100 | 5 |
| 2 | Quarry preparation including overburden | $m^2$ | 2500 | 9 | 278 | 14 |
| 3 | Excavation of borrow material | $m^3$ | 822 | 3.00 | 274 | 14 |
| 4 | Loading of borrow material | $m^3$ | 945 | 5 | 189 | 10 |
| 5 | Bush clearing | $m^2$ | 9000 | 200 | 45 | 3 |
| 6 | Grubbing | $m^2$ | 10000 | 100 | 100 | 5 |
| 7 | Earthworks (cut & fill) | $m^3$ | 3500 | 3 | 1167 | 59 |
| 8 | Ditching | $m^3$ | 288 | 2.5 | 116 | 6 |
| 9 | Fore- and back-slopes | $m^3$ | 912 | 2.5 | 365 | 19 |
| 10 | Base layer formation | $m^3$ | 945 | 7.5 | 126 | 7 |
| 11 | Culvert installation | No. | 4 | | 72 | 4 |
| 12 | Mitre drains/catchwater drains | $m^3$ | 270 | 2 | 135 | 7 |
| 13 | Scour checks | No | 100 | 5 | 20 | 1 |
| 14 | Sealing/paving works | $m^2$ | 5500 | 20 | 275 | 14 |
| **Total average Employment per km** | | | | | **3262** | **168** |

[9] Guidelines for Construction of Bituminous Seals using Labour and Light Plant/Equipment, ILO/CSIR, November 2007

Table 2-2 also illustrates the impact of employment generation based on choice of technology and the selection of road surfacing material type in low-volume road construction/rehabilitation:

**Table 2-2: Comparison of Labour/Employment Generated to Road Surfacing Type**

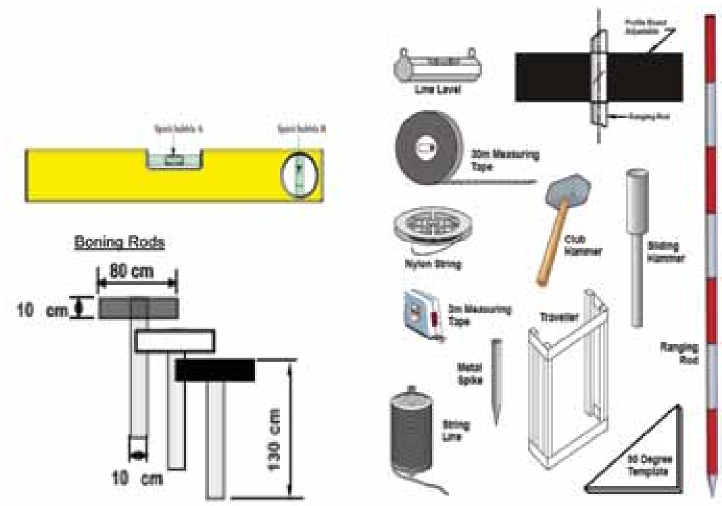
| Road type | Width | Construction technology | Labour input per km. (worker-days) | % increase in labour content |
|---|---|---|---|---|
| Class D Gravel Road | 5 m | Plant-based | 309 | 742% |
| | | Labour-based | 2 294 | |
| Class D Asphalt Road | 3 m | Plant-based | 864 | 302% |
| | | Labour-based | 2 610 | |
| | 5 m | Plant-based | 1 246 | 317% |
| | | Labour-based | 3 956 | |
| | 6 m | Plant-based | 1 586 | 359% |
| | | Labour-based | 5 693 | |
| Class D Concrete Block Road | 3 m | Plant-based | 819 | 312% |
| | | Labour-based | 2 558 | |
| | 5 m | Plant-based | 1 103 | 341% |
| | | Labour-based | 3 763 | |
| | 6 m | Plant-based | 1 509 | 407% |
| | | Labour-based | 6 143 | |
| *Source: South Africa's Construction Industry Development Board (CIDB) Best Practice Guideline Part 1* | | | | |

# SECTION 3: SETTING OUT

Setting out is the process of determining the correct horizontal and vertical alignment as well as positioning of the road geometry on a project site. Proper setting out is very critical to the technical and economic success of the road project. Low-volume roads are normally constructed in very remote areas far from the capital and regional centers. In many developing countries where expensive and sophisticated precision setting out instruments like theodolites, GPS, and dumpy levels are scarce, labour based works can still be set out with sufficient accuracy[10] through the correct use of simple equipment and tools. Even in cases where precision instruments have been used by surveyors for the original setting out, day-to-day re-establishment of levels and other intermediate setting out points during construction can be done using these simple basic set of equipment such as profile boards,bonning rods, string lines and line levels. A team of 4 to 6 can set out 40 to 100m of a road section in a day.

## 3.1 BASIC SETTING OUT EQUIPMENT

**Table 3-1: Basic setting out equipment**

| The basic set of equipment normally used for setting out comprises of: | |
|---|---|
| • Ranging rods<br>• Boning rods (ranging rods with adjustable profiles)<br>• Travelers (1m long fixed profile on base plate)<br>• Fish line<br>• Line level<br>• Tape measures, 5m and 30m<br>• Sliding hammer (for driving down ranging rods)<br>• Pegs, wooden and steel<br>• String line<br>• Hammer (1 kg for driving down pegs) |   |

The above instruments can be used to set out all works including centerline, cross-sections, gradient of the ground, drainage, horizontal, and vertical alignments, and minor earthwork quantities.

Some of the above most commonly used setting out instruments in LIC works are described below:

### 3.1.1 Reference Pegs

Reference pegs are used to mark the centre lines and transfer levels in road works. They are usually made of wooden stakes although steel rods (400mm long and 12mm diameter) can also be used where readily available. Pegs must be protected with stones and painted for visibility. Reference details should be recorded on a steel plate attached to the pegs or on the wet cast concrete.

Typically there are two types of reference pegs, namely centre line and transfer pegs. Centre line pegs are removed during excavations whilst Transfer pegs are offset at a reasonable distance from the centreline depending on the width of the road. To avoid loss or damage to transfer pegs they are usually embedded in concrete.

[10] In extremely flat terrain it can often be difficult to determine the natural gradient of the ground. In such cases use of a level instrument may be warranted.

### 3.1.2 Tape measures

Tape measures are normally made of steel and PVC. Lengths of 10, 20, 30, 50 or 100 metres can be employed efficiently. Steel tapes are expensive, liable to damage and illegibility after a long period of use but are however the most accurate compared to other cheaper materials which tend to stretch and lose their accuracy. Smaller tapes, 2m, 3m or 5m in length, are useful for small construction elements, such as culverts etc.

### 3.1.3 Ranging rods, profile boards and boning rods

#### 3.1.3.1 Ranging rods

The ranging rods are made of hollow metal tubes, often 25mm diameter galvanized water pipe, with a pointed end of sharpened reinforcement steel. They are normally 2 metres long, and are painted red and white to make them easy to see during setting out. Ranging rods can also be made of wooden or hardened plastic poles. They can be used for setting out vertical and horizontal alignments.

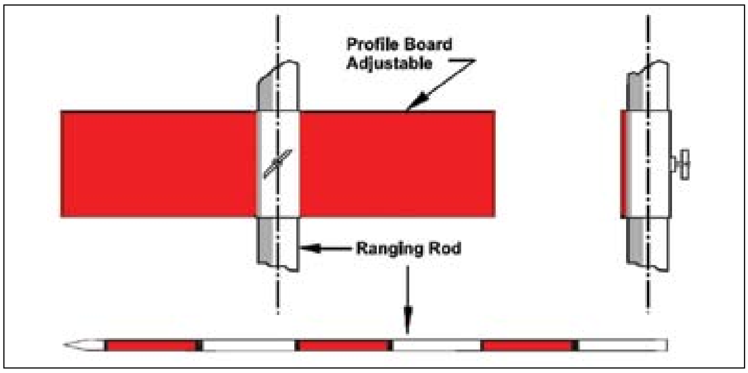



**Figure 3-1: Ranging Rod and Profile Boards**

#### 3.1.3.2 Profile boards

A long lasting profile board is made from thin steel plate which is welded to a short length of metal tubing that can slide up and down and be clamped to a metal ranging rod. A useful size for the metal profile boards has been found to be 40 cm by 10 cm, painted red to make it visible against the background of most environments. Profile boards can also be made from timber. Profile boards are used for setting out levels for vertical alignment. See Figure 3-1 below.

#### 3.1.3.3 Boning rods

These are generally manufactured on site from wooden laths to a "T" profile and of uniform height. A simple stand can also be manufactured if preferred as shown in Figure 3-2.

Boning rods are used in sets of 3 and the crosspiece is normally painted, ideally each with a different colour. They are used to establish additional levels between fixed levels (interpolation) or beyond (extrapolation). They are particularly useful to check gradients of culvert trenches and finished final levels (longitudinal and transverse.

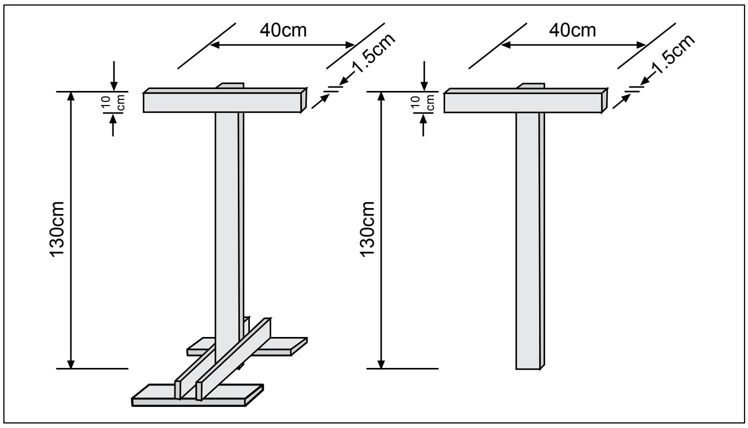



**Figure 3-2: Boning rods**

The profile boards, ranging and boning rods (travellers) are inexpensive and can easily be made by a local metal work business.

Before starting setting out works, make sure that there are sufficient supply of ranging rods and profile boards.

In very compact or rocky ground, it is useful to first make a hole for the ranging rod. This can be done by hammering down a metal spike produced from high tensile reinforcement steel to produce the hole. Crow bars can also be used for this purpose.

A very useful additional tool is a sliding hammer with a weighted head that fits over the ranging rod and can be used to drive the ranging rod into the ground.

### 3.1.4 Line level

The level of each of the profile boards can be controlled by using a line level. The line level is a short spirit level (about 100 mm long) with a hook at each end to hang it from a nylon string (fish line). It should be hung at approximately the midpoint between the two ranging rods.

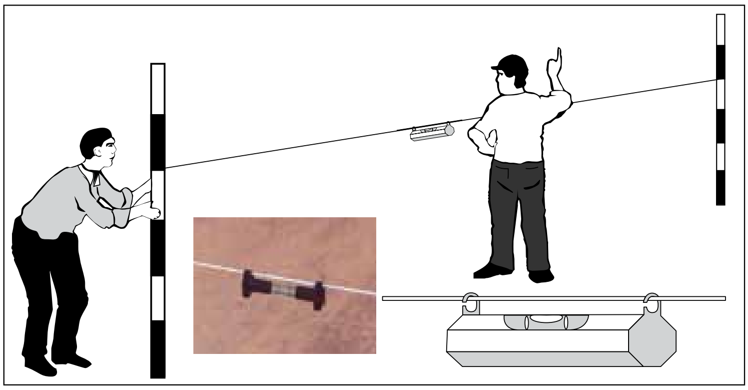


**Figure 3-3: Line level**

This instrument needs at least two persons to operate - one at the end of the line, and the second to watch the spirit level. The line operator moves the string up or down until the bubble is centred in the middle. The string line will then indicate the horizontal line. The line level can be used to:

- Transfer the exact level of one profile board to another profile, thereby ensuring that both are at the same level,
- Measure up or down from a known horizontal level, and set a new level, and
- Find the slope between two fixed profile boards.

The line level has an accuracy range of up to about 50 metres beyond which its accuracy might be reduced. It is easy to carry around and with care can be used for setting out levels and slopes not flatter than 1 in 300.
Points to remember when using a line level:

- The string used should be a thin nylon fishing line, enabling the line level to easily slide along the string.
- The line level must be placed half-way between the two ranging rods. Use a measuring tape to find the exact middle point.
- Keep the string tight - do not let it sag.
- The line level is a delicate instrument, look after it - do not throw it around and treat it roughly.
- Check the accuracy of the line level regularly in the field.

The following procedure should be followed to check accuracy of line level:

- Place two ranging rods 10 metres apart.
- Fix a fish line at 1 metre mark on one of the rods and transfer the level to the other rod using the line level and mark this level.
- Keeping the fish line in place turn the line level around and adjust the fish line again until the bubble centres.
- Mark the new level and measure the distance between the two levels.
- If the difference is less than 10 centimetres the correct level shall be in the middle of the two marks. If the difference is more than 10 centimetres then the line level is faulty and should be replaced.

## 3.2 SETTING OUT A STRAIGHT LINE

For road projects, it is imperative that straight lines are established, for example the centre line, cross sections, and drainage structures.

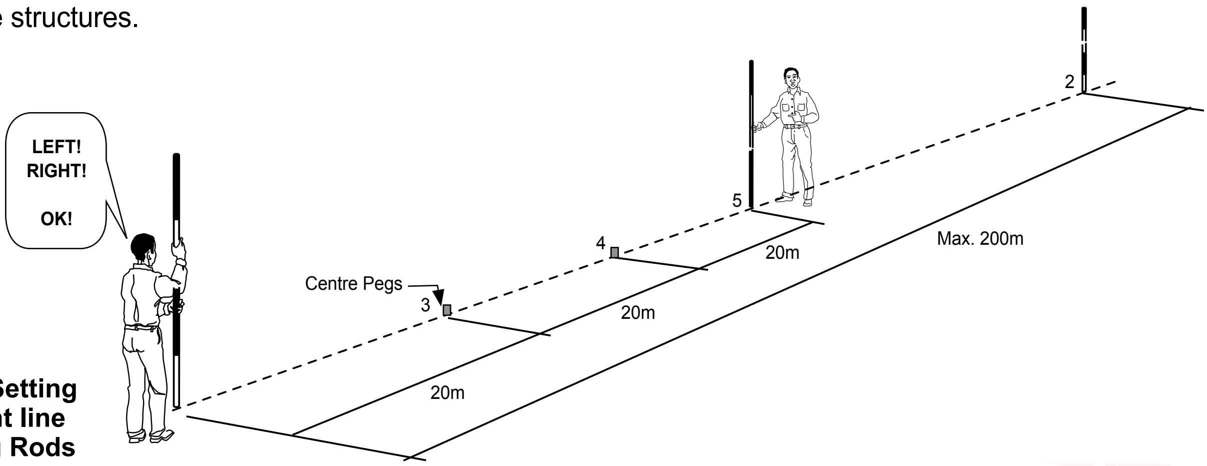



**Figure 3-4: Setting out a straight line with ranging Rods**

### 3.2.1 Interpolation

The two end points of the straight line to be established are each marked with a ranging rod. The intermediate points can be found by sighting from one end rod to the other and moving a third rod until it is aligned with the two end rods (see Figure above).

### 3.2.2 Extrapolation

The same procedure can be used to extend a straight line. Place two ranging rods at a certain distance, e.g. 20 metres, along the line you would like to establish. Walk with the third rod to the next point of the line, e.g. another 20 metres ahead. Sight the first two rods and shift the third rod until all three rods are in a straight line. Mark this point with a peg and repeat the same procedure every 20 metres until you have reached the end of your straight line. Check the entire line again.

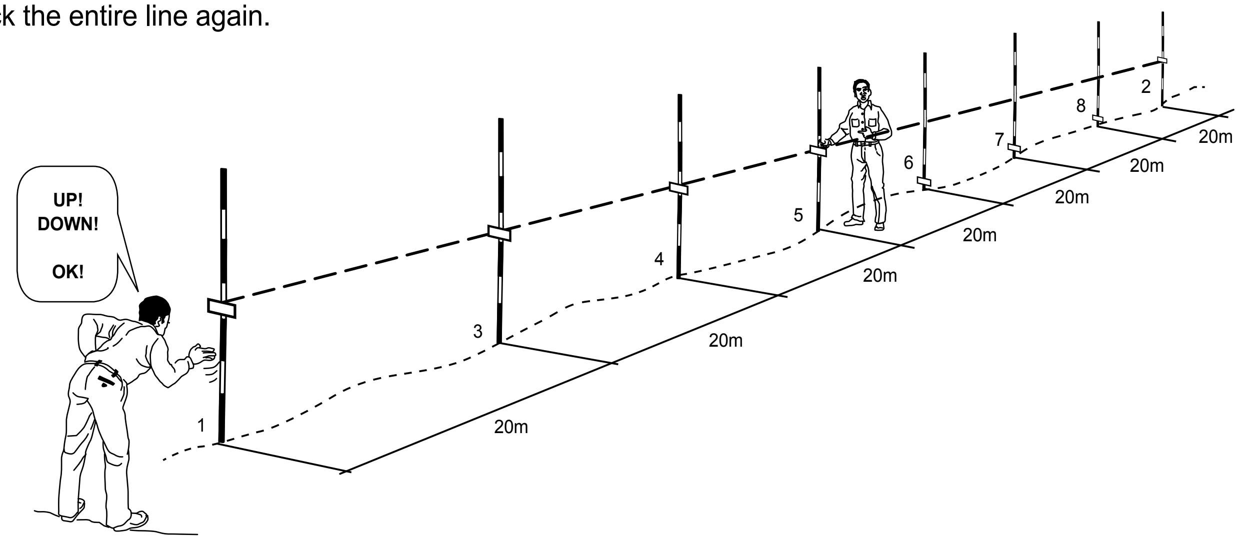



**Figure 3-5: Fixing intermediary ranging rods in setting out Straight Lines**

### 3.2.3 Transferring levels

To transfer the level at point A to point B, the following steps should be followed:

1. Fix a profile at 1m above the level point A, and same at point B.
2. With the line level fixed on the string line mid-point between points A and B, the string line should be raised up and down until the line level bubble centres.
3. Measure up or down on rod B the difference 'y' in between the old and the new level and put a mark on the rod as the transferred level.

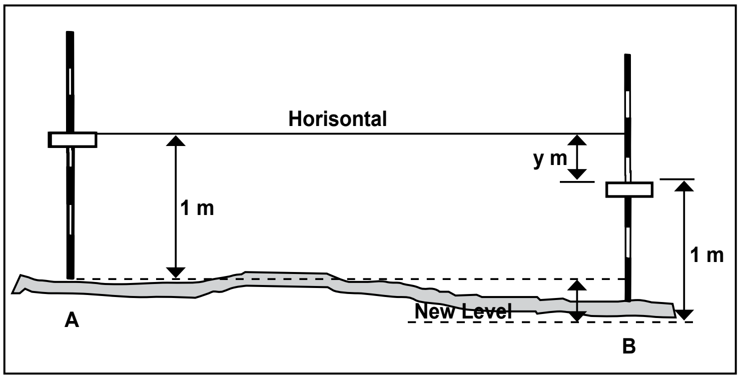



**Figure 3-6: Transferring levels**

**Transferring levels through a section with uniform gradient**

The two processes described above in sections 3.2.2 and 3.2.3 for setting out straight line and transferring heights can respectively be combined to transfer levels through a section with uniform gradient and thereby determine cut and fill heights as illustrated below.

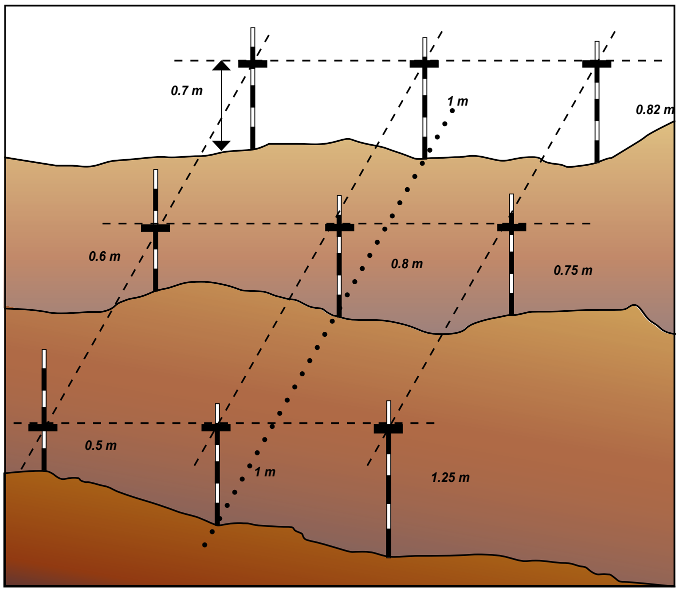



**Figure 3-7: Transferring heights**

**Transferring levels in practice**

## 3.2.4 Setting out angles

**Setting out of a right angle (90°)***

The right angle is established by measuring a triangle with side lengths of 3, 4 and 5 metres as illustrated in the figure[11].

Measure the length AB of 4 metres along the defined centre line. Set pegs exactly at points A and B. Hold the zero point of the tape measure on the peg A.

A second person holds the 8.00 metre mark of the tape measure on peg B. A third person holds the tape measure at the 5.00 metre mark which will lead to fixing point C when the tape measure is pulled tight.

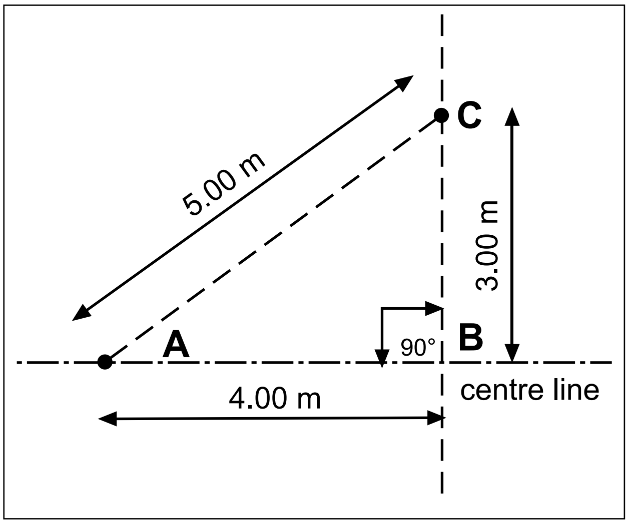



**Figure 3-8: : Setting out of a 90° angle**

[11] Where there are space constraints a right angle can be set out using a triangle of any dimensions where the sides have a 3:4:5 ratio.

### Setting out of a 45° angle

First establish a right angle as shown above.

Set out the same distance on both of the two lines (L) starting from the intersection point B, e.g. 3.00 metres, and fix pegs A and C.

Span a string line between points A and C and measure this length A to C. Divide the length A to C by two and set peg D exactly in the middle of this length.

Establish the new line B to D with a string line and extend beyond peg D if necessary.

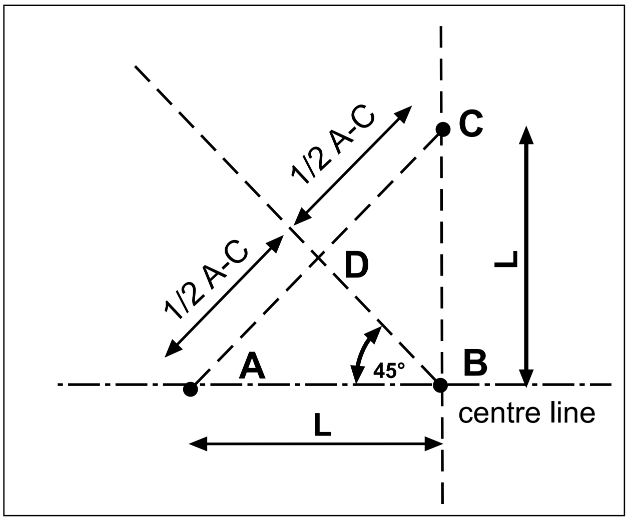



Figure 3-9: Setting out of a 45° angle

### Setting out of 30° and 60° angles

First establish a right angle as shown above.

Set out the same distance on both of the two lines (L) starting from the intersection point B, e.g. 3.00 metres, and fix pegs A and C.

Span a string line between points A and C and measure this length A to C. Divide the length A to C by three and set pegs D (for 30°) after one third of the length A to C, or E (for 60°) after two thirds of the length A to C.

Establish the new lines B to D or B to E with a string line and extend beyond peg D or E if necessary.

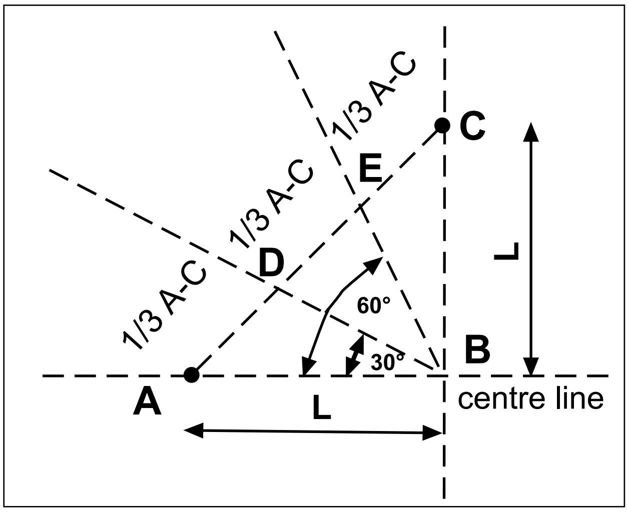



Figure 3-10: Setting out of 30° and 60° angles

### Setting out a right angle to Centreline in a Curve

To set out a right angle to the centreline in a curve at point B:

1. Fix points A and C at same distance (6m say) respectively from B.
2. Secure pegs at D and E, 3m from point B along A-B and B-C respectively.
3. Take a long string line 12m long and mark the middle point.
4. Two persons hold the ends of the string at D and E while a third person tightens the string line with a peg at the middle mark at F,

B-F is now at right angles to the curve (and its tangent) at point B.

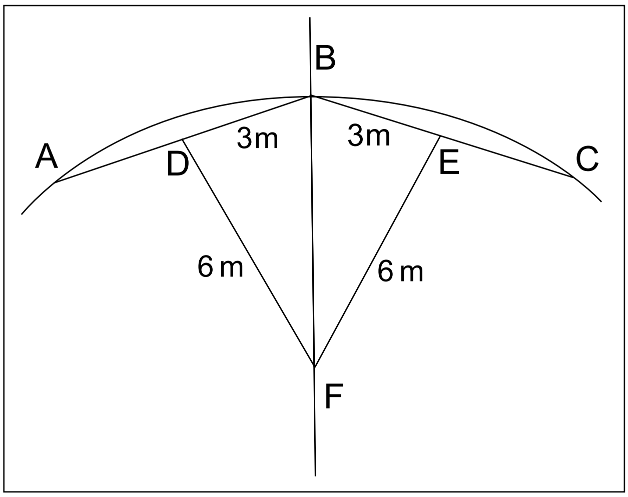



Figure 3-11: Setting out a right angle to Centreline in a Curve

Sight in chainage pegs and/or profiles across the centreline through points B and F

### 3.2.5 Setting out gradients

#### 3.2.5.1 Checking or confirming an existing gradient

- Fix ranging rods vertically at the two end points of the slope firmly into the ground.
- Tie the string line at the 1 metre mark[12] of the ranging rod at the higher point of the slope.
- Whilst holding the string line at the lower ranging rod, let a second person hook the line level at the middle point between the two ranging rods.
- Move the string line at the lower point ranging rod up or down until the second person indicate the level bubble is exactly centred. Mark this level at the lower ranging rod, turn the line level around and mark the level again. Measure the middle of the difference of the two marks – this is the exact horizontal level transferred from the higher to the lower ranging rod.
- Measure the difference between your horizontal level mark and the one metre mark at the ranging rod (= D).
- Measure the exact distance (length) between the two ranging rods (= L)[13].
- Calculate the gradient (percentage) of the slope. The calculation is as follows: D divided by L multiplied by 100 = the percentage of the slope. Use centimetres for all measurements.

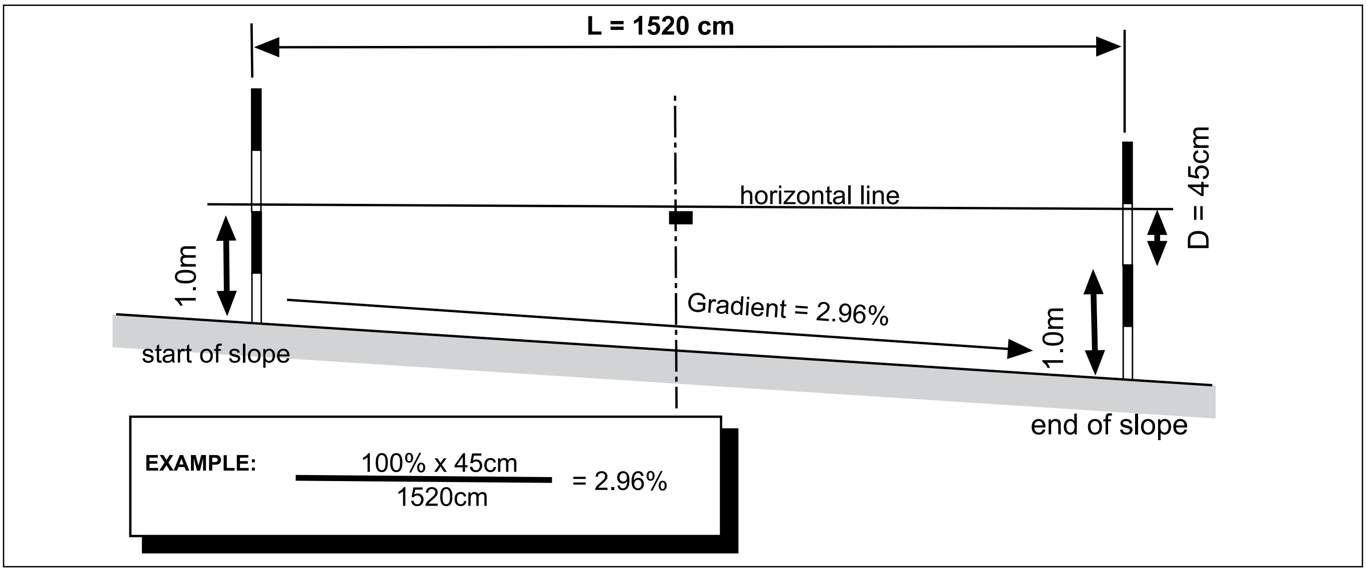



**Figure 3-12: Confirming gradients**

In general if the height on the upper ranging rod is "a" from the ground and that on the lower ranging rod is "b" after line level bubble is centred. Then the gradient (G) is given by: $D = \frac{L}{100\%} \times G$.

## 3.3 SETTING OUT A DESIGN GRADIENT

To set out a design gradient D on the ground, the following are steps involved:

- Define level difference (D): = divide L by 100% and multiply by given % (e.g. 3% as in example below).

$$G = \frac{(b-a)}{L} \times 100\%$$

- Fix the string line 1m on the upper ranging rod
- With a line level fixed mid-way, move the string on the lower ranging rod so that the line is horizontal and mark the point on the lower ranging rod.

[12] On very steep slopes this 1m height may have to be adjusted as necessary.
[13] Where feasible, use lengths (L) in multiples of 10 metres for ease of calculation.

- Now add D to 1 m and measure from the level mark downwards. You will see that if the existing ground slope is less steep than D, then in order to be able to measure this new height, you need to dig a small slot next to the ranging rod. Dig the slot in small steps until you can measure the exact height (D + 1 m). The bottom of this slot is now at the required level.
- In order to transfer the gradient uniformly you have to use 1m boning rods or profile boards. Set a boning rod at each end point, for every few metres dig a small slot, set the third boning rod (traveler) at the bottom of the slot and deepen or raise the slot until all three boning rods are in line with one another.

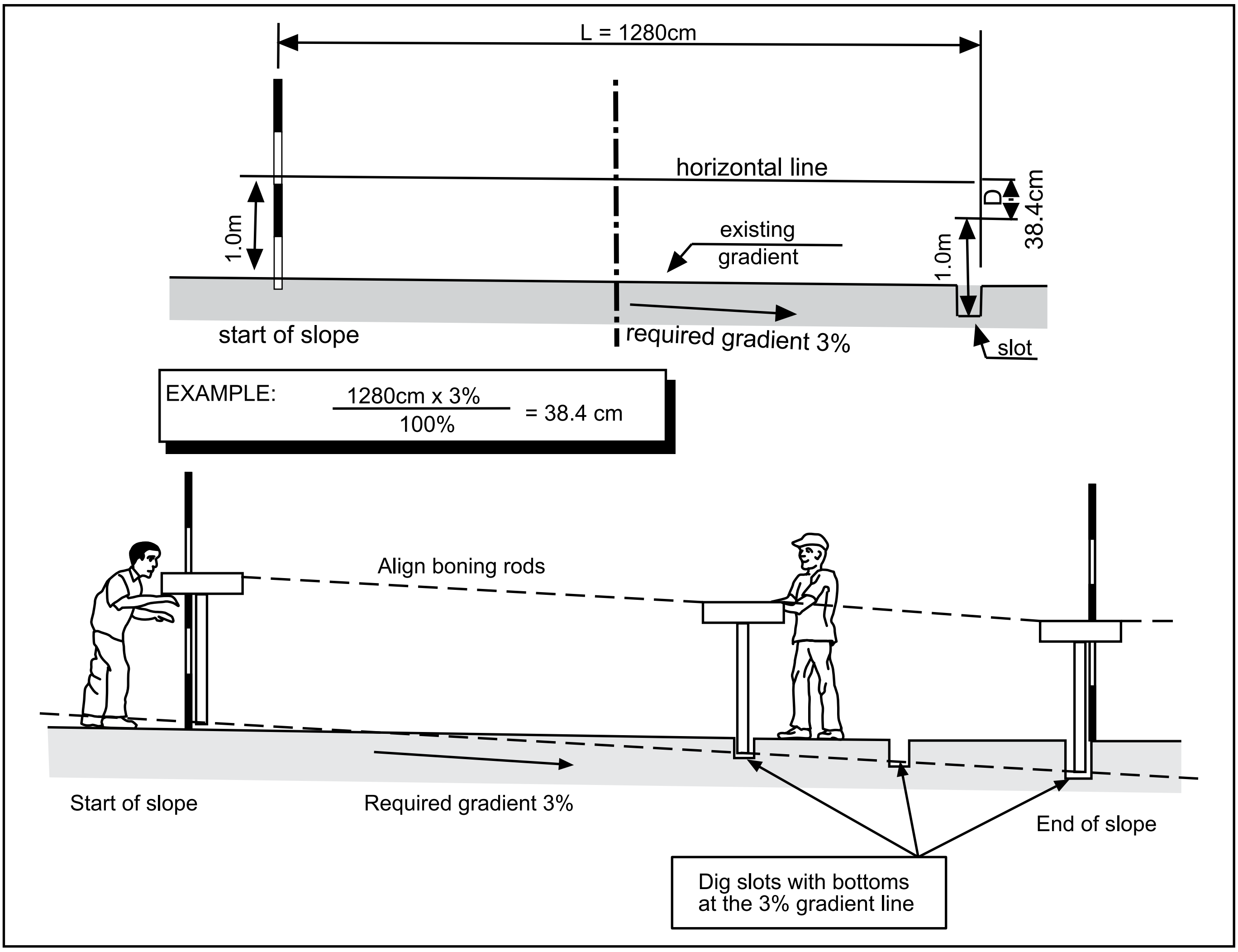



**Figure 3-13: Setting out gradients**

Note that if the existing ground is steeper than D, then the new level of D +1 will be above the existing ground which will imply that there has to be filling to achieve the desired slope.

## 3.4 CHECKING THE UNIFORMITY OF A GRADIENT

In order to achieve a reasonably smooth and aligned surface (horizontal or gradient) without unnecessary depressions or humps it is necessary to control the levels. The simplest method is to use a set of boning rods and travelers.

The procedure is as follows:

- Fix boning rods or ranging rods with profile boards at the two ends of the straight line that has to be checked, ensuring the two points have the correct levels. If profile boards are used, make sure the two end boards are fixed at the identical measure on the rod, e.g. 1.0 metre from the ground.

- While sighting from one end to the other, let an assistant place the third boning rod or profile board at any point you want to check in between the two end rods, e.g. the first rod is at the upstream invert of a culvert, the second placed at the invert of the downstream invert of the culvert and the third is used to check whether the gradient between the two culvert inverts is uniform.

## 3.5 SIMPLE HORIZONTAL CURVES

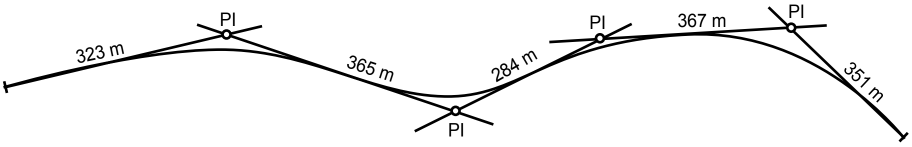


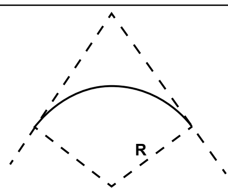
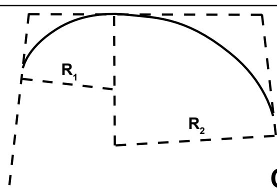
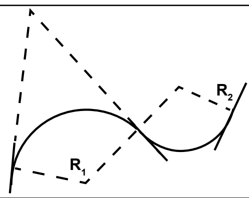
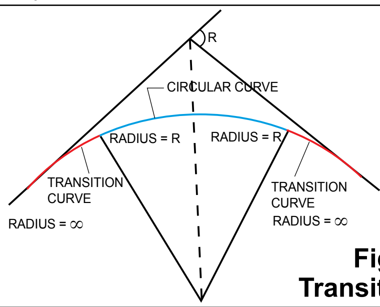

**Figure 3-14: Horizontal curves connecting straight centrelines**

The road centerline is initially set out by a series of connected straight lines (tangent sections). Where the straights change directions, they are joined by circular curves to allow for smooth vehicle operation at the design speed selected for the roadway. The design and construction of curves is an important aspect of route surveying of roads.

A horizontal curve is provided at the point where the two straight lines intersect in the horizontal plane. The horizontal curves are generally circular. Horizontal curves are of four types namely:
i) Simple circular curve; ii) Compound curve; iii) Reverse curve and iv) Transition curve.

Table 3-2 briefly describes each of these types of curves.

**Table 3-2: Types of horizontal curves**

| | |
|---|---|
| **Circular curve**<br>A simple circular curve consists of a single arc of a defined radius of the circle (Figure 3-15). The curve is tangential to two straight lines of the route centreline. | <br><br>**Figure 3-15: Circular curve** |
| **Compound curve**<br>A compound curve consists of two circular arcs of different radii with their centres of curvature on the same side of the common tangent, as illustrated in Figure 3-16. | <br><br>**Figure 3-16: Compound curve** |
| **Reverse curve**<br>A reverse curve consists of two circular arcs with same or different radii which have their centres of curvature on the opposite side of the common tangent (Figure 3-17). | <br><br>**Figure 3-17: Reverse curve** |
| **Transition curve**<br>A transition curve is a horizontal curve of varying radius. It provides a gradual change from the straight line to the circular curve and again from the circular curve to the straight line (Figure 3-18). Transition curves are required on roads to lessen the discomfort at sudden change in curvature at the junction of a straight line and a curve. | <br><br>**Figure 3-18: Transition curve** |

### 3.5.1 Properties of a horizontal circular curve

Figure 3-19 shows two straight lines crossing at the point $PI$ (Point of Intersection) subtending a deflection angle $\phi$. The circular curve to connect the two straight centerlines starting from the tangent point $BC$ (Beginning of Curve) and ending at point $EC$ (End of Curve), can be set out utilizing the following basic properties of a circular curve:

$$T = R \times \tan\left(\phi/2\right)$$

$$a = R\left(\sec\left(\phi/2\right) - 1\right)$$

$$b = R\left(1 - \cos\left(\phi/2\right)\right)$$

$$L = \frac{2\pi R\phi}{360}$$

Where:

T = Tangent length
R = Given radius of the curve
L = Length of the curve

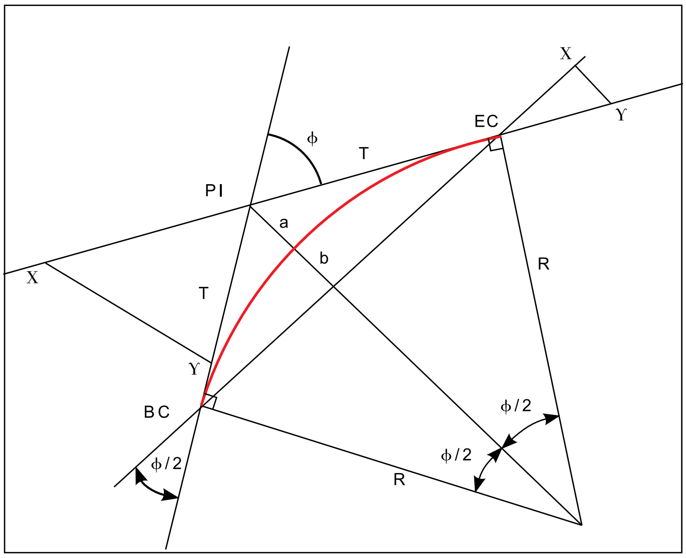



**Figure 3-19: Properties of a horizontal circular curve**

### 3.5.2 Techniques for setting out of horizontal curves

Unlike gravel and earth roads with very low traffic volumes where approximate methods are used in setting out curves, sealed roads with relatively higher traffic volumes and design speeds should be accurately set out to improve safety. The following simple techniques can be employed in accurately determining the parameters and setting out horizontal curves:

**i. The curve radius *R***
The applicable curve radius is a function of the design speed and will be provided by the Engineer based on the prevailing site conditions.

**ii. Measurement of the deflection angle $\phi$**

**a. Use of a protractor**
The deflection angle can be measured by a circular protractor if the site conditions are level such that the angle can be easily measured. However, in most cases, the point of intersection is inaccessible or obstructions cause inaccurate measurement of the angle by a protractor.

**b. Use of Chart**
Where the site conditions are such that it is not feasible to place a protractor at the $PI$ and measure the angle, the following procedure can be used to accurately measure the deflection angle:

i. Establish the straight lines and secure a ranging rod at $PI$ as shown in Figure 3-19 above.
ii. Set out $X$ and $Y$ 10m or 20m from $PI$ and measure the distance $X$-$Y$
iii. Using the measured distance $X$-$Y$, the deflection angle $\phi$ can be found by reading out the value using Chart 3-1.

*For example, if the points $X$ and $Y$ were respectively set out at distance 10m from the point $PI$, and the measured distance $X$-$Y$ is say 12.0m, then moving horizontally from the 12.0m mark on the $X$-$Y$ axis of Chart 3-1 to cut the 10m $X$-$Y$ curve, and moving vertically down to the horizontal axis, you read off the corresponding Deflection Angle $\phi$ = 74°.*

*If the points X and Y were set out 20m from PI, the measured distance X-Y would have been 24.0m and the 20m X-Y graph was used, the same answer of Deflection Angle ϕ = 74° will be obtained.*

**c. Measurement of tangent length *T***

Chart 3-2 can be used to determine the tangent length *T* as follows:

i. Locate the determined deflection angle ϕ from *b*) on the *x*-axis of Chart 3-2.

ii. Moving vertically to cut the given Radius curve *R*, move horizontally and read off the Tangent length *T* on the *y*-axis.

Using the example:

*i) Locate the determined deflection angle 74° from example 1 on the x-axis of Chart 3-2.*

*ii) Moving vertically to cut the given Radius curve R=100m (say), move horizontally and read off the Tangent length T = 75.5 (say 76m) on the y-axis.*

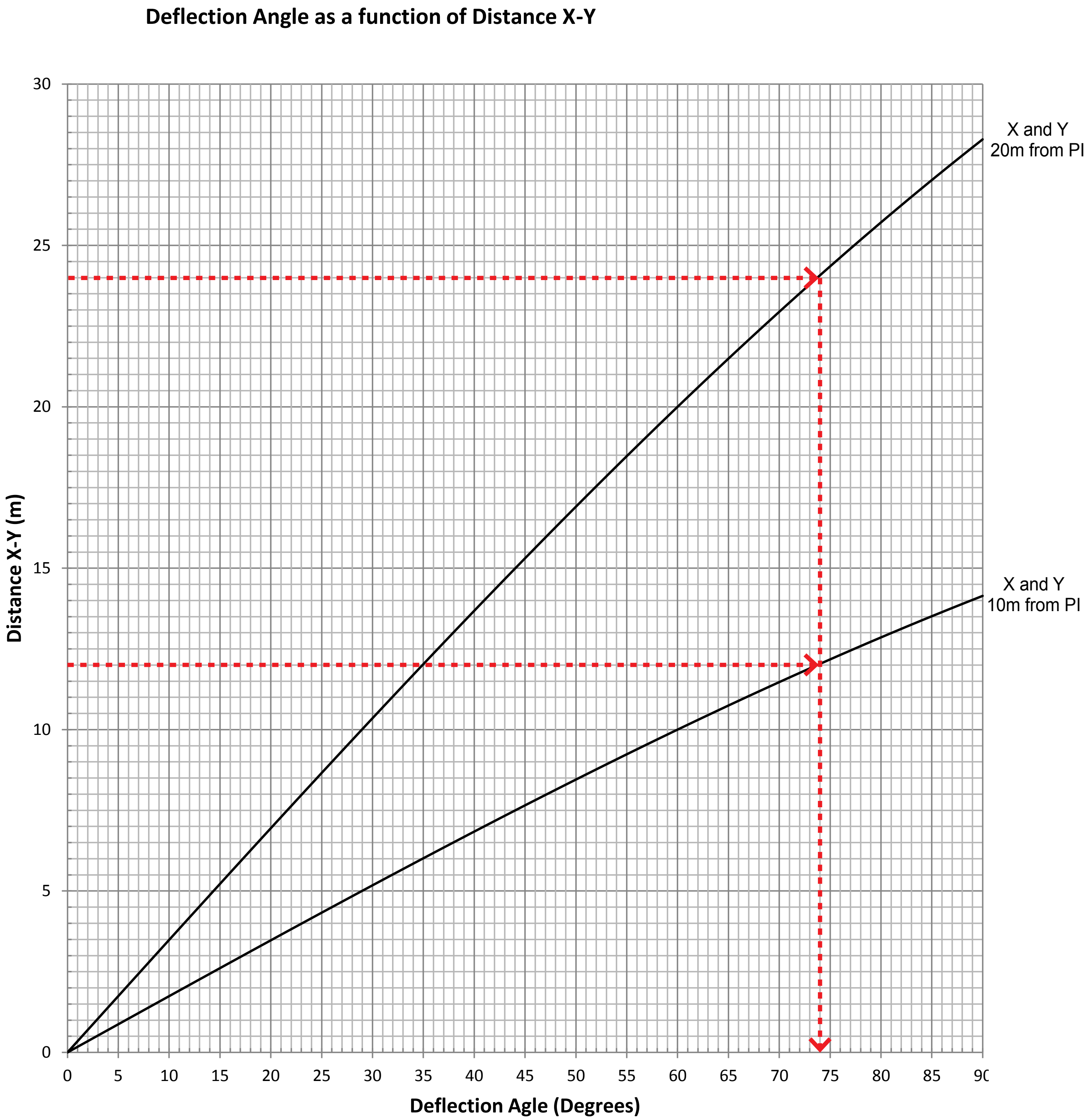



**Chart 3-1: Deflection angle as a function of distance**

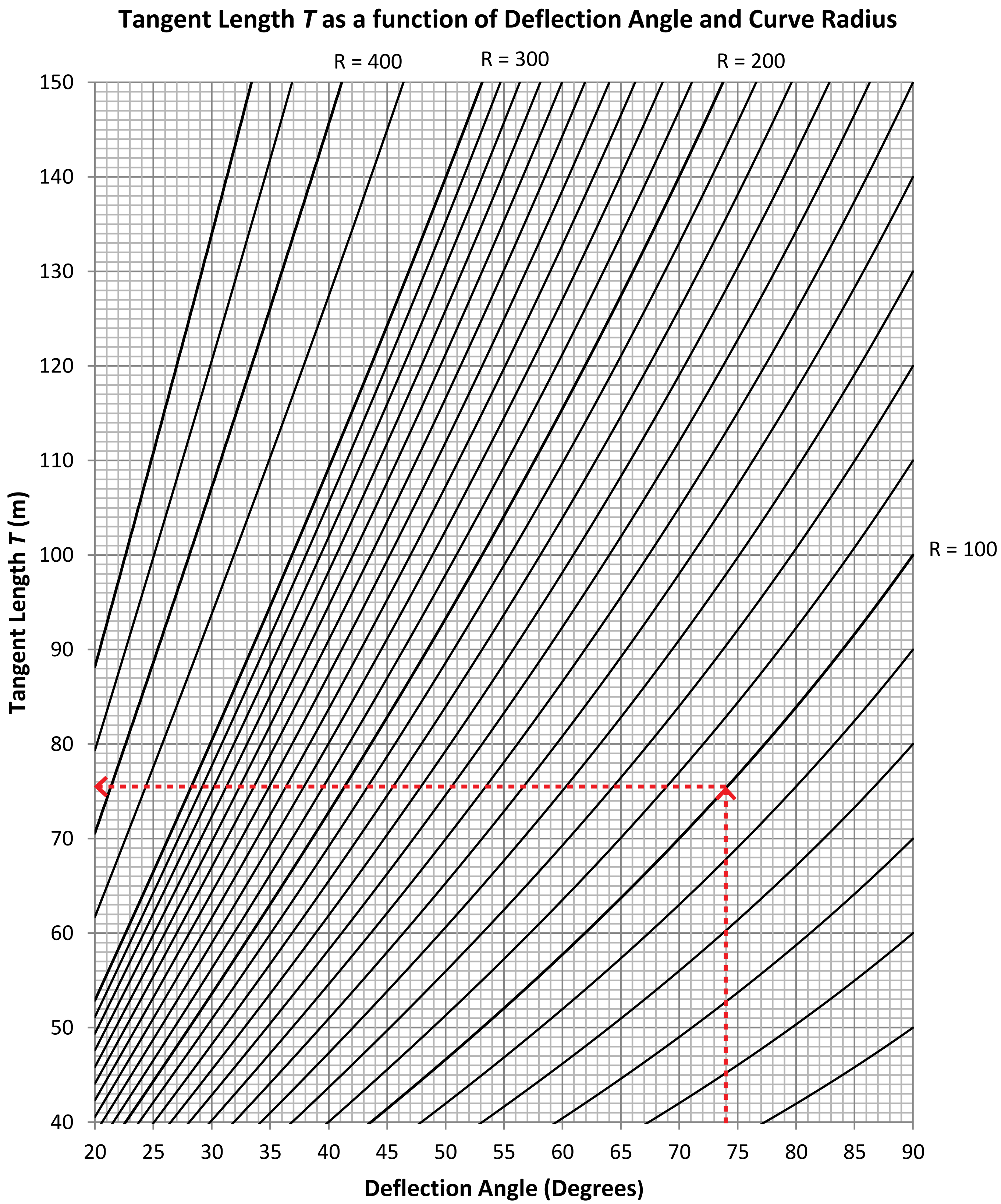



**Chart 3-2: Tangent length as a function of deflection angle and curve radius**

### 3.5.3 Methods for setting out horizontal curves

Low-volume sealed roads have higher traffic volumes and design speeds than unsealed rural roads hence, simplified but accurate methods of setting out curves are to be employed other than the approximate methods like the String line method which are normally employed on low-trafficked and lower design speed unsealed roads. Some of the suitable methods of setting out are described below:

#### 3.5.3.1 The deflection angle method

In this method of setting out the first thing to do is to determine the deflection angle $\phi$ as described in the preceding Section 3.5.2, as well as determining the other curve parameters like the tangent length $T$, the Curve radius $R$, offset lengths $a$ for the intermediate points of the curve.

Procedure:

1. Once $\phi$ has been determined from Chart 3-1, the relationship between $\phi$, $T$, and $R$ is shown in Chart 3-2. Use the Chart 3-2 and using the radius $R$, read the corresponding $T$.

2. Measure the distance $T$ from $PI$ on both straights and drive down pegs at $BC$ and $EC$.

3. From chart 3-3, which gives the relationship between $\phi$, $T$, and $T$ given by the formula:

$$T' = T\left(\frac{\tan(\phi/4)}{\tan(\phi/2)}\right)$$

,

find $T'$ and set out the two $PI$'s at distance $T'$ from $BC$ and $EC$.

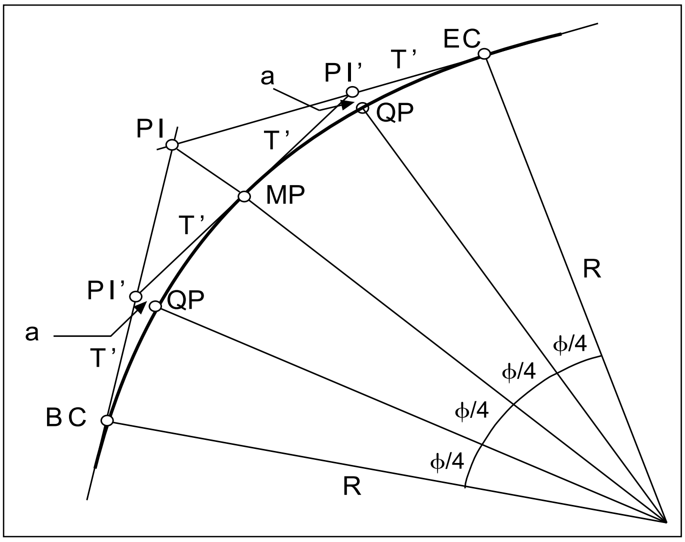


**Figure 3-20: Setting out using the deflection method**

From our example, tracing the angle $\phi$ = *74°* on Chart 3-3 to cut the $T$ = 76 line, and moving horizontally gives $T'$ = 34.

4. Sight in place a peg at $MP$ as the mid-point between the two $PI'$

5. Find offset '$a$' from Chart 3-4 and set out $QP$ (quarter points)

a. The relationship between $\phi$, $T'$ and offset '$a$' is shown in Chart 3-4. Read $\phi$ from the graph and set out the two $QP$s at distance $a$.

b. Drive down pegs at the two $QP$s and inspect the curve by pulling a string line through the curve.

Following the example at hand, and using Chart 3-4 to trace $\phi$ = 74° onto $T'$ = 33.7 (say 34) and moving horizontally, the offset '$a$' is read off as 5.5m.

The five set points are adequate to set out the centerline and chainage pegs in the curve, if the curve is relatively short.

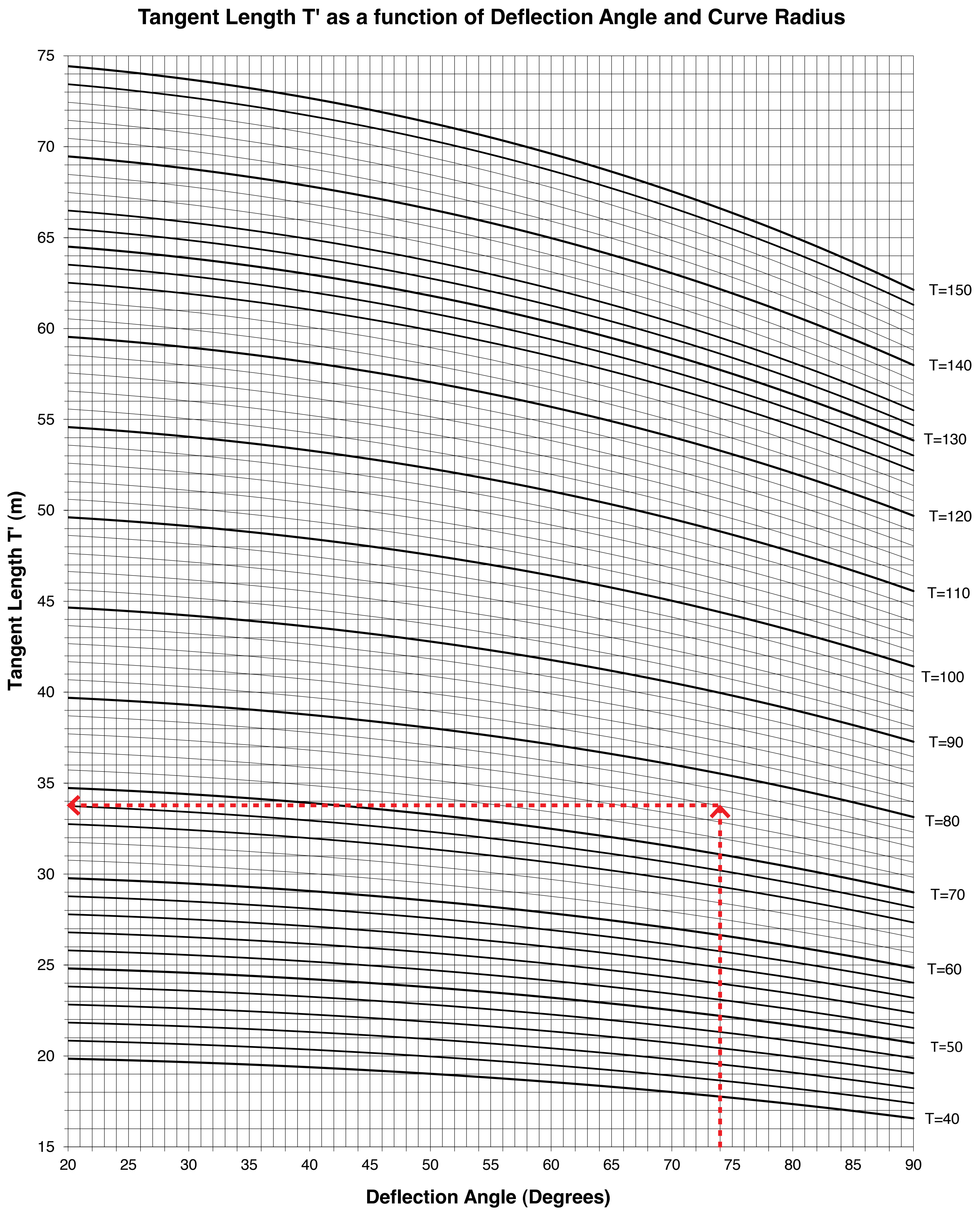



**Chart 3-3: Tangent length T' as a function of deflection angle and tangent T**

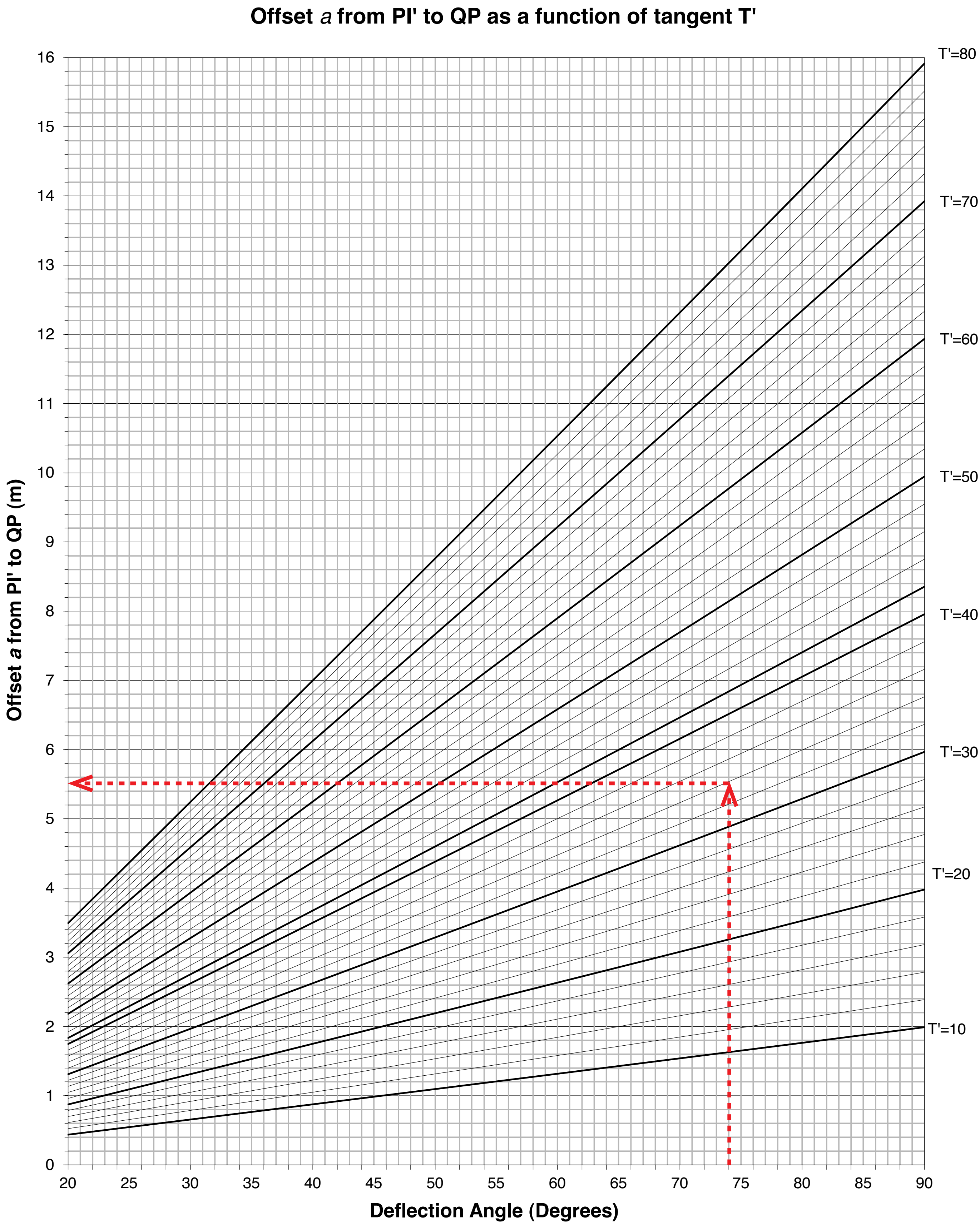



**Chart 3-4: Offset a from point of intersection as a function of the tangent**

For longer curves it may be necessary to find another four intermediate points. For this purpose another method known as the Quarter method can be used which is described below.

### 3.5.3.2 The quarter method

**Procedure:**

1. Find deflection angle, establish $BC$ and $EC$ at equal distance T from $PI$ and check that The given curve radius satisfies the design criteria as in 'Deflection angle method'.
2. Establish point $A$ halfway between $BC$ and $EC$.
3. Use Chart 3-5 to find $b$ and set out $MP$ at distance $b$ from point $A$.
4. Establish $X$ and $Y$ halfway between $BC$ and $MP$ and $EC$ and MP respectively.
5. Set out the two $QP$'s at distance $a = b/4$ from $X$ and $Y$ respectively.
6. Place intermediate pegs if necessary to form smooth curve with string line.

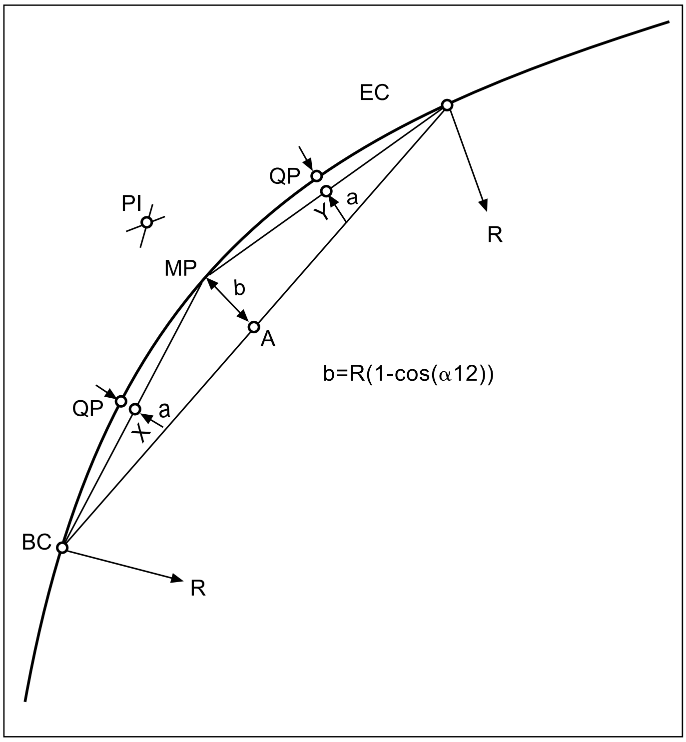



**Figure 3-21: Setting out using the quarter method**

This Quarter method is only suitable for short curves if it is used as a stand-alone method. It can however also be used as a supplement to the Deflection angle method to establish four more points on the curve halfway between $BC/EC$ and the $QP$'s and $MP$. The offset from the mid-point of the straight lines between these points will be $b/4$.

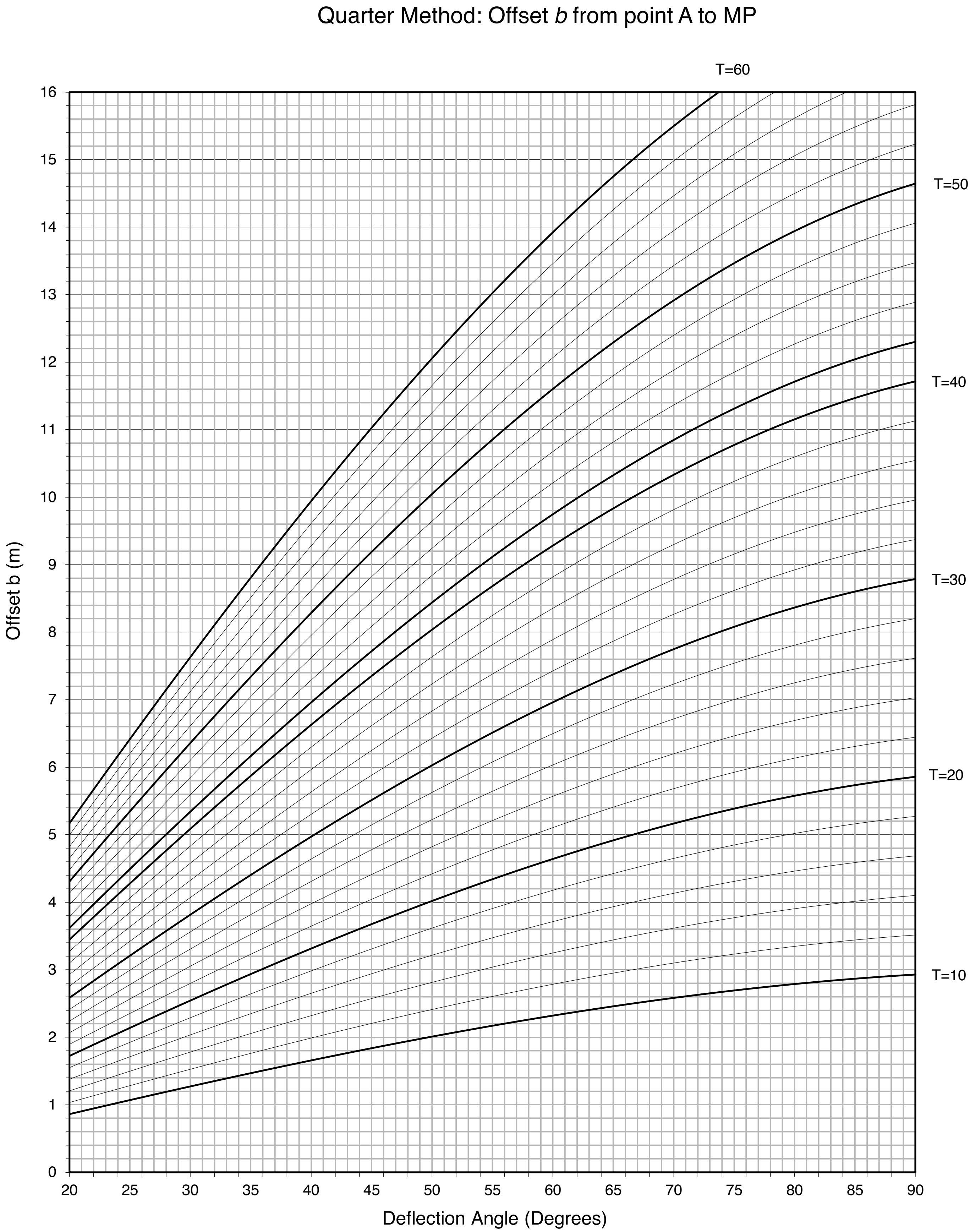



**Chart 3-5: The quarter method**

#### 3.5.3.3 Perpendicular tangent offset method

If the deflection angle is small (<20°), the curve can be set out by measuring perpendicular offsets from the tangents.

If $O_x$ is the offset perpendicular to the tangent at $Q$, which is at a distance of $x$ from $T_1$, then drawing $PP_1$ perpendicular to the radial line $T_1O$. from the triangle $PP_1O$,

$$(P_1O)^2 = (PO)^2 - (PP_1)^2$$

or,

$$(R - O_x)^2 = R^2 - x^2$$

or,

$$O_x = R - \sqrt{R^2 - x^2}$$

The above relation has been used to create Table 3-3 based on selected curve radius, to determine the perpendicular offsets for setting out the curve.

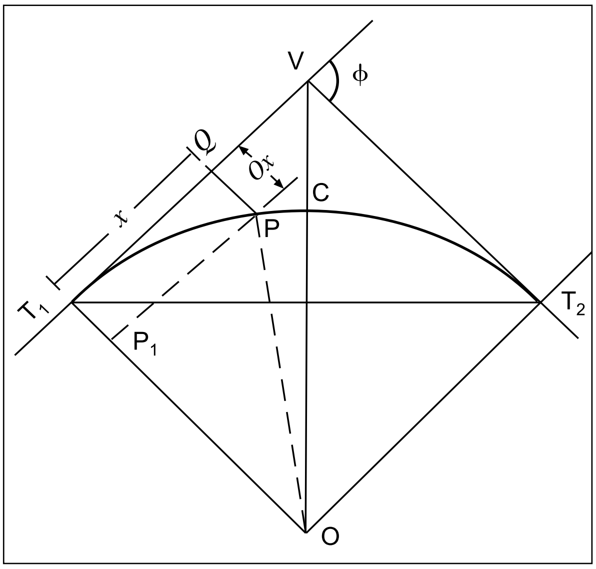



**Figure 3-22: Perpendicular Tangent Offset Method**

**Procedure for setting out curve:**

1. Set out $PI$ and find the deflection angle using Chart 3-1. If the deflection angle is less than $20°$, proceed with step 2, otherwise use another method.

2. Set out $BC$ and $EC$ at distance equal to the determined tangent length from $PI$.

3. Set out temporary pegs along the tangents at 10m distance starting from $BC$ and $EC$ and as many as will fit within the tangent length.

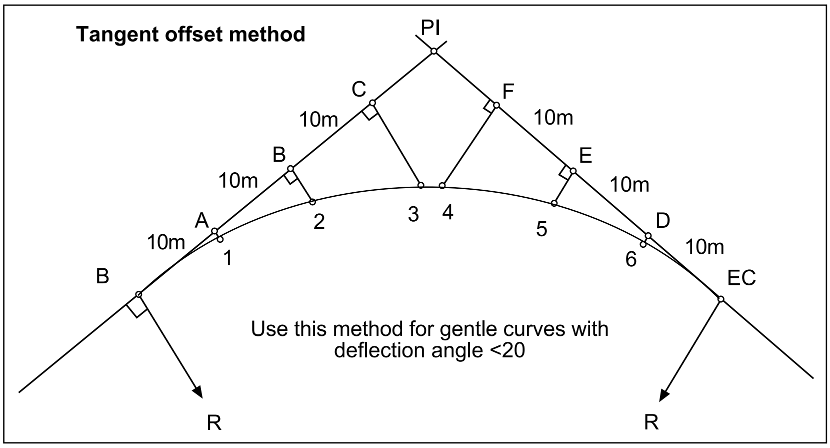



**Figure 3-23: Perpendicular Offset Method**

4. From Table 3-3 using the given radius, read off the offsets and fit as many offset points as possible.

*Note that this method should only be used for gentle curves with deflection angle less than 20°. For curves with deflection angle greater than 20° for tangents longer than tabulated, another method as explained above should be used.*

| Perpendicular offsets from tangent (m) for deflection angle < 20° | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Tangential Distance x (m)** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **Curve Radius R (m)** | **Offset distance Ox from beginning and end of curve (m)** | | | | | | | | | |
| 150 | 0.33 | 1.34 | | | | | | | | |
| 160 | 0.31 | 1.25 | | | | | | | | |
| 170 | 0.29 | 1.18 | | | | | | | | |
| 180 | 0.28 | 1.11 | 2.52 | | | | | | | |
| 190 | 0.26 | 1.06 | 2.38 | | | | | | | |
| 200 | 0.25 | 1.00 | 2.26 | | | | | | | |
| 210 | 0.24 | 0.95 | 2.15 | | | | | | | |
| 220 | 0.23 | 0.91 | 2.06 | | | | | | | |
| 230 | 0.22 | 0.87 | 1.96 | 3.50 | | | | | | |
| 240 | 0.21 | 0.83 | 1.88 | 3.36 | | | | | | |
| 250 | 0.20 | 0.80 | 1.81 | 3.22 | | | | | | |
| 260 | 0.19 | 0.77 | 1.74 | 3.10 | | | | | | |
| 270 | 0.19 | 0.74 | 1.67 | 2.98 | | | | | | |
| 280 | 0.18 | 0.72 | 1.61 | 2.87 | | | | | | |
| 290 | 0.17 | 0.69 | 1.56 | 2.77 | 4.34 | | | | | |
| 300 | 0.17 | 0.67 | 1.50 | 2.68 | 4.20 | | | | | |
| 350 | 0.14 | 0.57 | 1.29 | 2.29 | 3.59 | 5.181 | | | | |
| 400 | 0.13 | 0.50 | 1.13 | 2.01 | 3.14 | 4.526 | 6.17 | | | |
| 450 | 0.11 | 0.44 | 1.00 | 1.78 | 2.79 | 4.018 | 5.48 | | | |
| 500 | 0.10 | 0.40 | 0.90 | 1.60 | 2.51 | 3.613 | 4.92 | 6.44 | | |
| 550 | 0.09 | 0.36 | 0.82 | 1.46 | 2.28 | 3.283 | 4.47 | 5.85 | | |
| 600 | 0.08 | 0.33 | 0.75 | 1.33 | 2.09 | 3.008 | 4.10 | 5.36 | 6.79 | 8.39 |
| 650 | 0.08 | 0.31 | 0.69 | 1.23 | 1.93 | 2.775 | 3.78 | 4.94 | 6.26 | 7.74 |
| 700 | 0.07 | 0.29 | 0.64 | 1.14 | 1.79 | 2.576 | 3.51 | 4.59 | 5.81 | 7.18 |
| 750 | 0.07 | 0.27 | 0.60 | 1.07 | 1.67 | 2.404 | 3.27 | 4.28 | 5.42 | 6.70 |
| 800 | 0.06 | 0.25 | 0.56 | 1.00 | 1.56 | 2.253 | 3.07 | 4.01 | 5.08 | 6.27 |
| 850 | 0.06 | 0.24 | 0.53 | 0.94 | 1.47 | 2.120 | 2.89 | 3.77 | 4.78 | 5.90 |
| 900 | 0.06 | 0.22 | 0.50 | 0.89 | 1.39 | 2.002 | 2.73 | 3.56 | 4.51 | 5.57 |
| 950 | 0.05 | 0.21 | 0.47 | 0.84 | 1.32 | 1.897 | 2.58 | 3.37 | 4.27 | 5.28 |
| 1000 | 0.05 | 0.20 | 0.45 | 0.80 | 1.25 | 1.802 | 2.45 | 3.21 | 4.06 | 5.01 |

**Table 3-3: Data for perpendicular offset tangent method**

Other approximate methods which may also be used are explained below:

### 3.5.3.4 The string line method

Procedure for setting out curve:

1. Find the deflection angle using Chart 3-1, establish *BC* and *EC* at equal distance *T* from *PI*. *T* should be divisible by an integer number, i.e. *4, 5, 6* etc.

2. Divide the tangents into equal number of parts and number them as shown in Figure 3-24.

3. The points on the curve lie on the intersection of the lines *1-1* with *2-2, 2-2* with *3-3, 3-3* with *4-4* and so on, established with sisal twine or using ranging rods. Note that the number of points on the curve will always be one less than the number of parts into which the tangents are divided.

4. Place intermediate pegs if necessary to form smooth curve with string line.

5. Establish centreline - and chainage pegs.

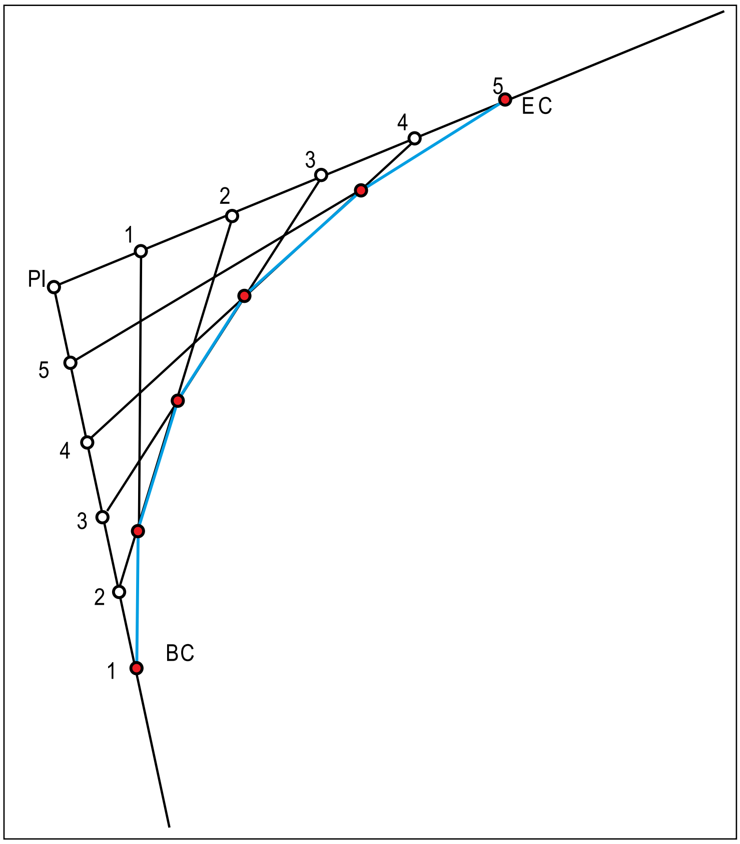



**Figure 3-24: The string line method**

### 3.5.3.5 The Offset Method

This is a trial and error approach for re-establishing existing alignments.

For any given radius and assumed tangential distance x the offset y is given by the formula: $y = \frac{x^2}{R}$

From this formula, Table 3-4 has been generated for determining the offsets for setting out the curve.

| Radius R (m) | Distance x (m) | Offset y (m) | Distance x (m) | Offset y (m) |
|---|---|---|---|---|
| 500 | 10 | 0.20 | 20 | 0.80 |
| 450 | 10 | 0.22 | 20 | 0.89 |
| 400 | 10 | 0.25 | 20 | 1.00 |
| 350 | 10 | 0.29 | 20 | 1.14 |
| 300 | 10 | 0.33 | 20 | 1.33 |
| 250 | 10 | 0.40 | 20 | 1.60 |
| 200 | 10 | 0.50 | 20 | 2.00 |
| 150 | 10 | 0.67 | 20 | 2.67 |
| 100 | 10 | 1.00 | 20 | 4.00 |
| 50 | 5 | 0.50 | 10 | 2.00 |

**Table 3-4: Data for setting out by offset method**

**Procedure for setting out the curve:**

1. Establish *PI* as the intersection of the straight centre lines.
2. Choose the beginning of the curve *BC* on one tangent.
3. Assume distance *x* (normally 10m) and use Table 3-4 to determine the offset *y*.
4. Set out point *A* on the tangent at distance *x* from *BC*.
5. Set out point *B* at perpendicular offset y/2 from A.
6. Set out point *C* at distance *x* from *B* on the extension of *BC*.
7. Set out point *D* at perpendicular offset *y* from *C*.
8. Repeat until you reach the other tangent at point *H*.
9. Set out point *I* on the extension of *F-H*.
10. Set out point *J* at perpendicular offset *y/2* from *I*. This should be on the straight centre line.

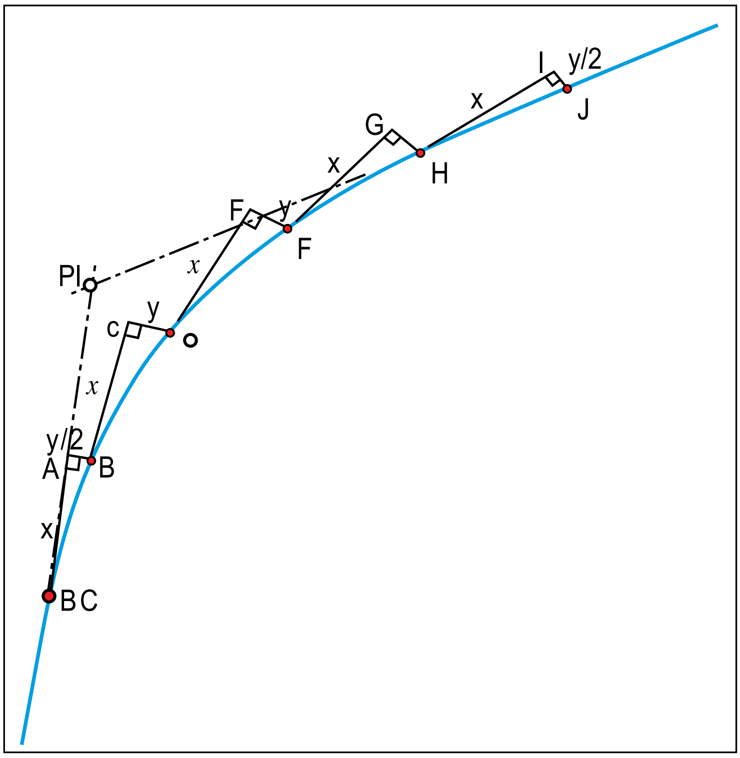



**Figure 3-25: The Offset Method**

If it is not possible to reach the other tangent satisfactorily, you will have to select another starting point *BC* and repeat the setting out.

## 3.5.4 Problems in setting out curves

Due to certain site circumstances, the following cases of constraints may occur during setting out of curves:

- Case 1. Point of intersection (*V*) not accessible.
- Case 2. Point of curve ($T_1$) not accessible.
- Case 3. Point of tangency ($T_2$) not accessible.
- Case 4. Three Straights to be joined by a Curve.
- Case 5. Curve must pass through a Fixed Point.

The solutions of the above problems are discussed below.

**Case 1. Point of intersection (*V*) not accessible.**

Sometimes, the point of intersection (*V*) falls in a lake, river, pond, thick forest or any other inaccessible place. In such a case, it is not possible to determine the deflection angle (ϕ) by the methods described earlier. It is also not possible to locate the points $T_1$ and $T_2$ by measuring the tangent distance *T* from *V*. Therefore the following procedure may be employed to overcome the situation in setting out the curve.

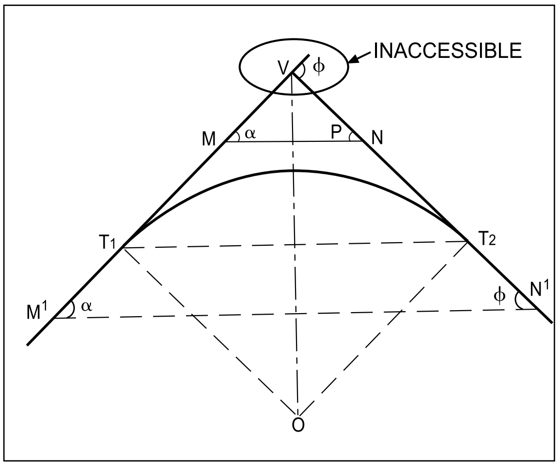



**Figure 3-26: Point of intersection not accessible**

**Procedure:**

1. Establish two points *M* and *N* on tangents which are inter-visible.
2. Find angles α and β (using chart 3-1)
3. Measure the length *MN* accurately
4. Deflection angle $\phi = \alpha + \beta$
5. Calculate the lengths *MV* and *NV* by solving the triangle MNV (using the Sine Rule)

i.e.

$$\frac{MV}{\sin\beta} = \frac{MN}{\sin\phi} = \frac{NV}{\sin\alpha}$$

$$\therefore MV = MN\frac{\sin\beta}{\sin\phi}$$

$$NV = MN \times \frac{\sin\alpha}{\sin\phi}$$

6. Calculate the tangent lengths $VT_1$ and $VT_2$

$$VT_1 = VT_2 = R\tan\left(\phi/2\right)$$

7. Determine the lengths $MT_1$ and $NT_2$:

$$MT_1 = VT_1 - MV$$

$$NT_2 = VT_2 - NV$$

8. Locate the points $T_1$ by measuring a distance $MT_1$ from $M$. Likewise locate point $T_2$
9. Use the Quarter method to set out the curve.

**Case 2. Point of curve ($T_1$) not accessible.**

**Procedure:**

1. Select a point M on the line $VT_1$ near the point $T_1$ but clear of the obstruction. Measure the distance $MV$.
2. Determine the distance $MT_1$

$$MT_1 = \text{Tangent length}(T) - MV$$

3. Select another point $N$ on the line $VT_1$ produced on the other side of the obstruction.
4. Determine the chainage of $N$ from the field records.
5. Select another point $Q$ on one side of the line $MN$, such that $NQ$ and $MQ$ are perpendicular, and measure distances $MQ$ and $NQ$. Determine the length $MN$ using Pythagoras theorem:

$$MN = \sqrt{(MQ)^2 + (NQ)^2}$$

6. Determine the chainage of $T_1$:

$$\text{Chainage of } T_1 = \text{Chainage of } N + MN - MT_1$$

7. Determine the chainage of $T_2$:

$$\text{Chainage of } T_2 = \text{Chainage of } T_1 + \text{Length of Curve}$$

8. Set out the curve in reverse direction from the point $T_2$, as a left-hand curve.

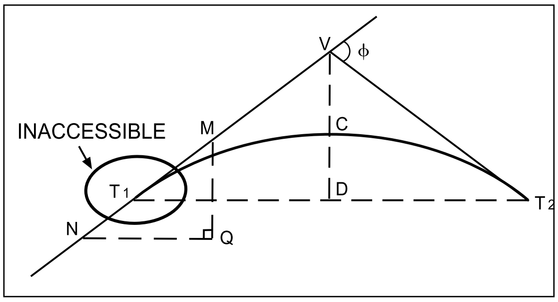



**Figure 3-27: Point of curve (T1) not accessible**

### Case 3. Point of curve ($T_2$) not accessible.

**Procedure:**

1. Select a point $M$ on the tangent $VT_2$ near the point $T_2$ but clear of the obstruction. Measure the distance $MV$.

2. calculate the distance $MT_2$

$$MT_2 = \text{Tangent length}(T) - MV$$

3. Select another point $N$ on the line $VT_2$ produced beyond the obstruction $T_2$.

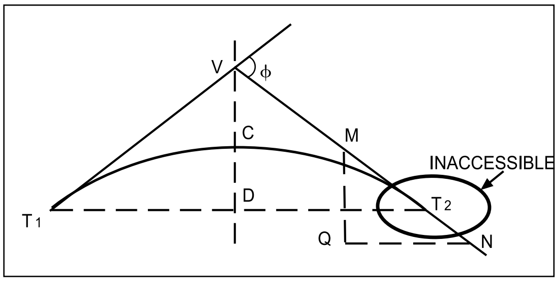



**Figure 3-28: Point of curve ($T_1$) not accessible**

4. Select another point $Q$ on one side of the line $MN$, such that $NQ$ and $MQ$ are perpendicular, and measure distances $MQ$ and $NQ$. Determine the length $MN$ using Pythagoras theorem:

$$MN = \sqrt{(MQ)^2 + (NQ)^2}$$

5. Determine the chainage of $N$:

$$\text{Chainage of } T_2 = \text{Chainage of } T_1 + \text{Length of Curve}$$

$$\text{Chainage of } N = \text{Chainage of } T_2 + MN - MT_2$$

### Case 4. Joining three Straights by a curve of unknown radius.

The condition to be fulfilled is that each straight must be a tangent to the curve of unknown radius $R$, which must be determined.

From Figure 3-29, the angles $\theta$ and $\alpha$ can be determined using chart 3-1.

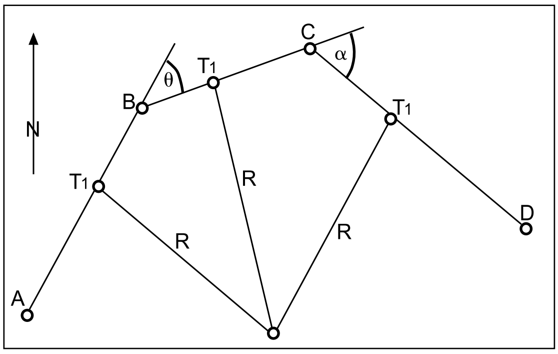



**Figure 3-29: Three straights to be joined by a curve**

$$BT_1 = BT_2 = R\tan\frac{\theta}{2}$$

Also $CT_2 = CT_3 = R\tan\frac{\alpha}{2}$

$$BC = (BT_2 + CT_2) = R\tan\frac{\theta}{2} + R\tan\frac{\alpha}{2}$$

Therefore $R = \dfrac{BC}{\left(\tan\frac{\theta}{2} + \tan\frac{\alpha}{2}\right)}$

Once $R$ has been determined; the curve can be set out using any of the methods described earlier.

### Case 5. Curve must pass through a Fixed Point.

Sometimes site conditions may constrain the curve to pass through a specific point, say $D$ as shown in figure 3-30. If $x, y,$ and $z$ are distances measured respectively from $V$, and $\phi$ is determined using Chart 3-1, then $\alpha$ can be calculated as:

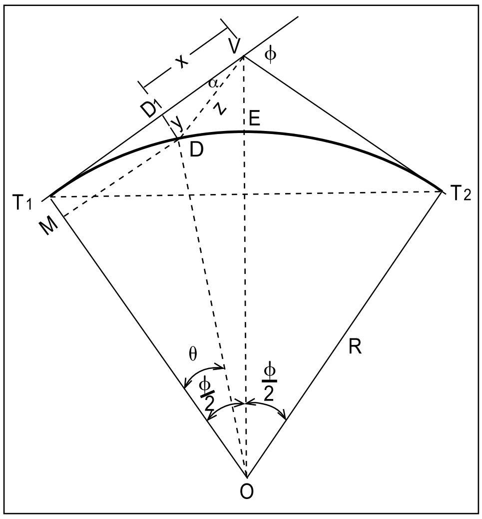


**Figure 3-30: Curve must pass through a fixed point.**

$Tan\ \alpha = \frac{y}{x}$ . Also it can be proven that:

$$\cos(\alpha+\theta) = \frac{\cos(\alpha+\phi/2)}{\cos\phi/2}$$

If $x, y, \alpha$, and $\phi$ are known, then $\theta$ can be calculated from the above equation.

The radius $R$ of the curve can be determined as follows:

Distance $T_1O = R = T_1M + MO = y + R\cos\theta$

$but\ y = z\sin\alpha$ , $therefore\ R = z\sin\alpha + R\cos\theta$ . Re-arranging gives:

$R(1-\cos\theta) = z\sin\alpha$.

Therefore, $R = \frac{z\sin\alpha}{1-\cos\theta}$.

Determine the tangent length, $T = R\tan\phi/2$

The curve with radius $R$ and the tangent distance $T$ shall pass through the point $D$.

### Compound curves

A compound circular curve is made up of two (or more) circular arcs of different radii on the same side of the common tangent. The curve with two circular arcs is called a two-centred compound curve whilst those with three are known as three-centred compound curves. Figure 3-31 shows a compound curve having two circular arcs $T_1T_3$ and $T_3T_2$, meeting at a common point.$T3$. The point $T_3$ is known as the point of compound curvature ($P.C.C.$). The curve has two centres $O_1$ and $O_2$ for the arcs $T_1T_3$ and $T_3T_2$, respectively. The points $T_1$ and $T_2$ are known as the points of curvature and tangency, respectively. Let the radius of the smaller arc be $R_s$ (= $R_1$) and that of the larger arc be $R_L$ ($R_2$). From geometry, the following formulae can be derived:

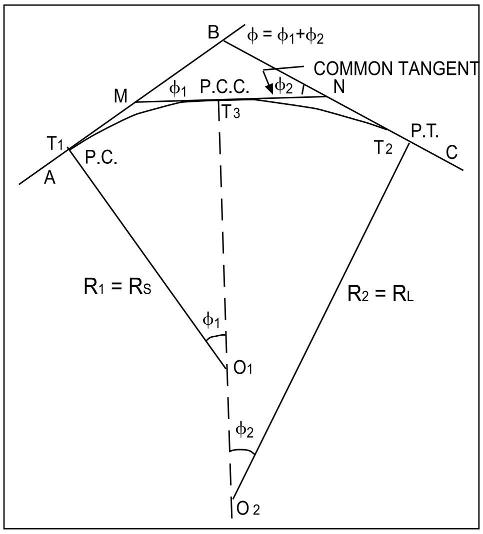


**Figure 3-31: Compound curves**

i. Length of smaller Tangent

$$T_1M = MT_3 = t_s = R_s\tan(\phi_1/2)$$

ii. Length of larger Tangent

$$T_2N = NT_3 = t_L = R_L\tan(\phi_2/2)$$

iii. $MN = MT_3 + T_3N = R_s\tan(\phi_1/2) + R_L\tan(\phi_2/2)$

From triangle $BMN$ using the sine rule,

iv. Total length of smaller tangent: $T_1M + MB = T_s = t_s + (t_s + t_L)\frac{\sin(\phi_2)}{\sin(\phi)}$

v. Total length of larger tangent: $T_2N + BN = T_L = t_L + (t_s + t_L)\frac{\sin(\phi_1)}{\sin(\phi)}$

vi. Total length of compound curve: $l = l_s + l_L = \frac{\pi R_1 \phi_1}{180} + \frac{\pi R_2 \phi_2}{180}$

vii. Chainage of $T_1$ = $Chainage\ of\ B - T_s$

viii. Chainage of $T_3$ = $Chainage\ of\ T_1 + \frac{\pi R_1 \phi_1}{180}$

ix. Chainage of $T_2$ = $Chainage\ of\ T_1 + \frac{\pi R_1 \phi_1}{180} + \frac{\pi R_2 \phi_2}{180}$

**Setting out of compound curves**

Since a compound curve is nothing but a combination of two (or more) simple curves, any of the methods discussed for setting out simple curves can be used to set out a compound curve once the parameters above are known.

The use of compound curves affords flexibility in fitting the road to the terrain and other controls, and the simplicity with which such curves can be used may tempt the designer to use them without restraint. Caution should however be exercised, because the driver does not expect to be confronted by a change in radius once he/she has entered a curve. Their use should also be avoided where curves are sharp.

**Reverse curves**

A reverse curve is composed of two circular curves turning in opposite directions with their centres on opposite side of the common tangent at the point of reverse curvature. The radii of the curves may be the same or different. On routes where the two centreline straights are parallel or when the angle between them is very small, reverse curves are required. They are also unavoidable in winding/serpentine roads in hilly regions. However, any abrupt reversal in alignment should be avoided. Such a change makes it difficult for the driver to keep within his/her own lane. There are several case scenarios that may be encountered in the field when setting out reverse curves and these are described below:

**Case 1. Non-parallel straights.**

Assumption: $R_1 = R_2 = R$
Given $\phi_1$, and $\phi_2$ ($\phi_2 > \phi_1$); Length of common tangent $BE$; Chainage of $V$.

Required: $R$; and chainages of $T_1$, $D$, and $T_2$.

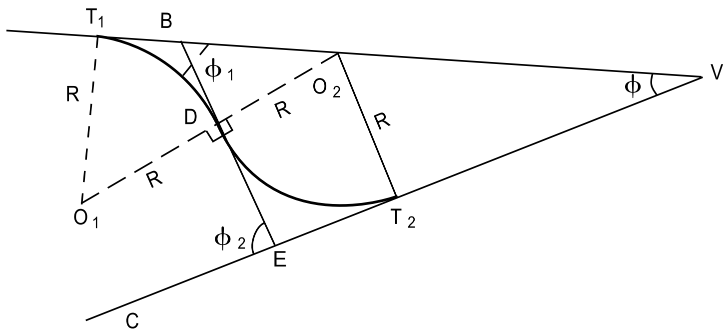


**Figure 3-32: Reverse curve with non-parallel straights**

Let $d$ be the length of the common tangent $BE$. Then

$$BE = BD + ED = d = R\tan\phi_1/2 + R\tan\phi_2/2$$

Therefore, $R = \frac{d}{\tan\phi_1/2 + \tan\phi_2/2}$

From the triangle $BEV$, $\phi_2 = \phi + \phi_1;\ or\ \phi = \phi_2 - \phi_1$

By Sine law, $BV = d\frac{\sin\phi_2}{\sin\phi};\ therefore\ T_1V = BT_1 + BV = R\tan\frac{\phi_1}{2} + d\frac{\sin\phi_2}{\sin\phi}$

Chainage of $T_1 = chainage\ of\ V - T_1V = chainage\ of\ V - \left(R\tan\frac{\phi_1}{2} + d\frac{\sin\phi_2}{\sin\phi}\right)$

Chainage of $D = chainage\ of\ T_1 + \frac{\pi R\phi_1}{180}$

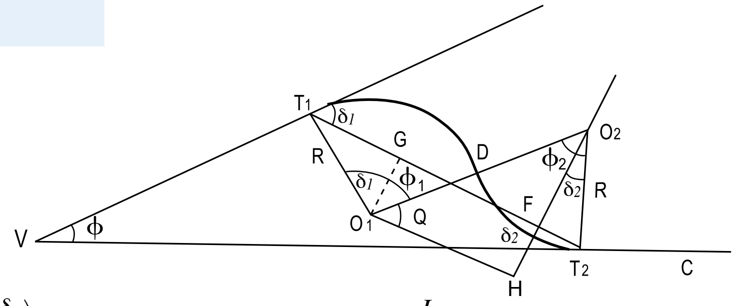
Chainage of $T_2 = chainage\ of\ D + \frac{\pi R\phi_2}{180}$

Note that the first section of the curve $T_1D$ is set out from $T_1$ whilst the second section $DT_2$ is set out from $D$.

### Case 2. Non-parallel Straights.

Assumption: $R_1 = R_2 = R$
Given angles $\delta_1$, $\delta_2$, and length $L$ of the line $T_1T_2$.

Required: Radius $R$.




It can be proven that the angle $\theta = \sin^{-1}\left(\frac{\cos\delta_2 + \cos\delta_1}{2}\right)$ ; and radius $R$ is: $R = \frac{L}{\cos\delta_1 + 2\cos\theta - \sin\delta_2}$

The central angle $\phi_1 = \delta_1 + (90^o - \theta)$; and $\phi_2 = \delta_2 + (90^o - \theta)$

The lengths of the arcs can be calculated from the values of $\phi_1$, $\phi_2$, and $R$.

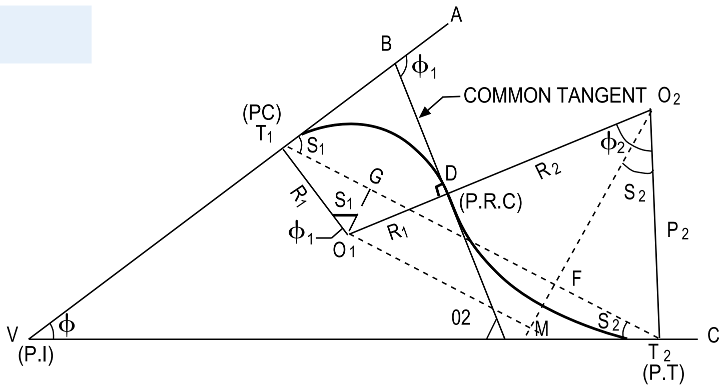
### Case 3. Non-parallel straights.

Given angles $\delta_1$, $\delta_2$, length $L$ of the line $T_1T_2$.; and one radius say $R_1$

Required: Radius $R_2$

The following formula can be deduced from geometry of the above diagram:

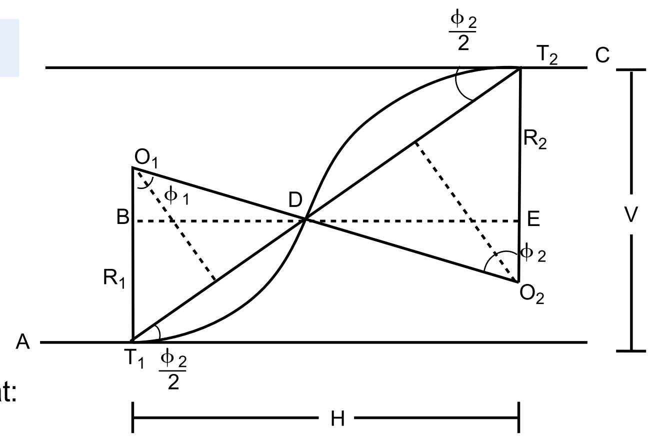
$$L^2 - 2L(R_1\sin\delta_1 + R_2\sin\delta_2) = 4R_1R_2\sin^2\left(\frac{\delta_1 - \delta_2}{2}\right)$$




Substituting the values of $L$, $\delta_1$, $\delta_2$, and $R_1$, the above equation can be used to determine the value of $R_2$. The same equation can be used to determine the value of $R_1$ if the values of $L$, $\delta_1$, $\delta_2$,, and $R_2$ are given.

### Case 4. Parallel straights.

Assumption: $\phi_1 = \phi_2$,
Given $R_1$, $R_2$, and angles $\phi_1$ (= $\phi_2$)
Required: To calculate other elements.
Let $V$ be the distance between the two straights; and $H$ be the horizontal distance between the two centres.
Let $L$ be the distance $T_1T_2$ between the beginning and end of the curves.




It can be deduced from geometry of the above diagram that:

I. $V = 2(R_1 + R_2)\sin^2(\phi_1/2)$

II. $L = 2(R_1 + R_2)\sin\phi_1/2;\ or\ L = \sqrt{2V(R_1 + R_2)}$

III. $H = (R_1 + R_2)\sin\phi_1$

For special case where $R_1 = R_2 = R$, then $V = 2R(1 - \cos\phi_1);\ L = 2\sqrt{VR};\ H = 2R\sin\phi_1 = V\cot(\phi_1/2)$

## Superelevation of curves

Superelevation is applied to circular curves to counteract the centrifugal force exerted on vehicles travelling through the curve. Superelevation is created by tilting (Figure 3-33), the camber slope on the outer half of the roadway thereby preventing vehicles from slipping off the road while negotiating the curve. For safety reasons, superelevation should be created on all roads regardless of traffic volumes. The change from normal cross-section on straights to a superelevated section should be made gradually. The length over which superelevation is developed is known as the superelevation development length $Ld$ as illustrated in Figure 3-34. The minimum superelevation development length can be calculated using the following formulae:

$L_d = \frac{(n_2 - n_1)v_D}{0.126}$ for ($v_D$ < 80km/hr); or $L_d = \frac{(n_2 - n_1)v_D}{0.09}$ for ($v_D$ > 80km/hr);

Where:

$L_d$ = Superelevation development length (m)

$n_2 - n_1$ = crossfall or superelevation at ends of the development length (m/m)

$v_D$ = Design speed (km/hr)

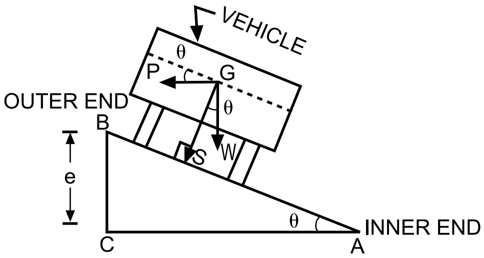



**Figure 3-33: Superelevated curve**

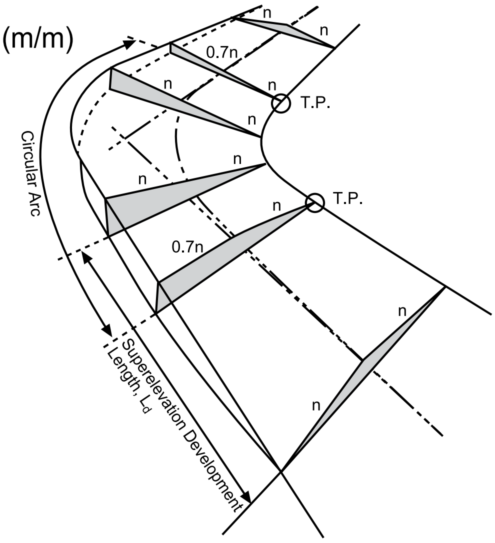



**Figure 3-34: Development of superelevation on curves curve**

The maximum permissible superelevation is 7% which applies to the minimum horizontal radius of curvature, $R_{min}$. A figure of 5% maximum should apply in urban areas where there are more level controls.

For curves with radius of curvature larger than $R_{min}$ the required maximum superelevation is determined directly from the expression:

$$e = \frac{Bv_D^2}{282.8R} \text{ in metres; or as a slope: } s = \frac{v_D{}^2}{282.8R}$$

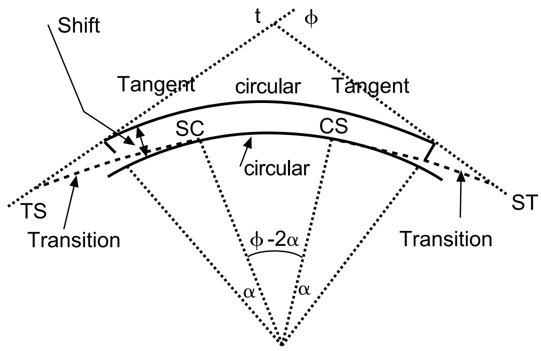
Where $e$ = superelevation (m)

$s$ = superelevation (%)

$v_D$ = design speed (km / h)

$R$ = radius (m)

$B$ = carriageway width




## Transition curves

As mentioned earlier, transition curves provide a smooth change from the tangent (straight) section to the circular curve and vice-versa. It also allows the introduction of superelevation (banking) to counteract the radial centrifugal force exerted on vehicles travelling through the curve thus ensuring safety and comfort to the vehicle occupants.

When a transition curve is used in combination with a superelevated section, the superelevation should be attained within the limits of the alignment transition as shown in Figure 3-34.

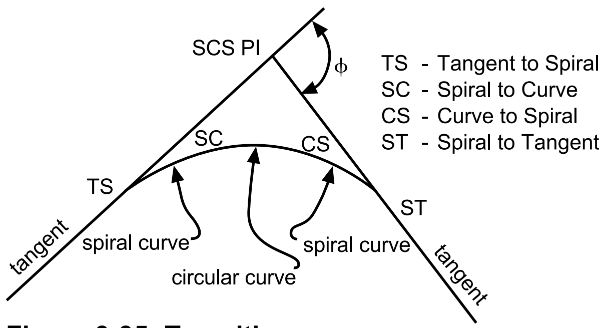



**Figure 3-35: Transition curve**

Definitions used in describing the curve are: $TS$ - Tangent to Spiral; $SC$ - Spiral to Curve; $CS$ - Curve to Spiral; $ST$ - Spiral to Tangent.

To accommodate the transition curve the circular curve is normally shifted inwards towards the centre of the curve as illustrated in Figure 3-35. The shift can be calculated by the formular: $S = \frac{L_T^2}{24R}$ ; where $L_T$ is the length of the transition curve.

**Note: If $S < 0.25m$ then the transition is usually ignored or not required.**

There are two types of transition curves namely, clothoid and cubic spiral.

### Clothoid curve

The Clothoid transition curve has the equation: $K = R.L_T = rl$, where $K$ = Clothoid Parameter, expressed as the rate of change of curvature along the Clothoid; $R$ = Radius of circular arc (m); $r$ = radius of the Clothoid; $L_T$ = Length of the transition Clothoid (m); and $l$ = any length along the Clothoid

### Transition length $L_T$

The length of plan transition ($L_T$) is determined by the rate of change of radial acceleration $q$.

The equation of $L_T$ is given by $L_T = \frac{v_D{}^3}{46.7qR}$ ,

where $L_T$ = length of transition curve (m)
$v_D$ = design speed (km / h)
$q$ = rate of increase of radial accleration (m / sec3)
$R$ = circular curve radius (m)

Note: Typical values for $q$ lie between 0.6 - 0.3 m/sec3 for $v_D$ from 40-140km/hr respectively. The values below are recommended:

| $v_D$ (Km/hr) | 40 - 70 | 80 - 120 | >120 |
|---|---|---|---|
| $q$ (m/s3) | 0.6 | 0.45 | 0.3 |

**Table 3-5: Rates of radial acceleration**

The maximum Transition length is: $L_{T(\max)} = \sqrt{24R}$

It is normally accepted practice to apply higher values of curve radii than the minimum, whereby the requirement for superelevation and/or side-friction is lessened. The minimum desirable radii at given design speeds is as shown below:

**Table 3-6: Desirable Minimum Radius for Transition Curve**

| $v_D$ | km/h | 50 | 60 | 70 | 85 | 100 | 120 |
|---|---|---|---|---|---|---|---|
| $R_{min}$ $(s = 5\%)$ | m | 180 | 255 | 360 | 510 | 720 | 1020 |
| $R_{min}$ $(s = 7\%)$ | m | 127 | 180 | 255 | 360 | 510 | 720 |

### Cubic spiral curve

Another common curve derived from the Clothoid is the Cubic Spiral. In the absence of a theodolite on site, the transition curve can be set out with a tape measure using the cubic Spiral equation: $x = \frac{y^3}{6RL_T}$.

The steps are as follows:

- Choose convenient values of the $y$-distances measured along the initial tangent, and compute the offsets $x$ from the Cubic Parabola equation above.
- Measure the distances $y_1$, $y_2$, $y_3$ etc. along the tangent line and locate the pegs by setting out the respective perpendicular offsets $x_1$, $x_2$, $x_3$ etc.

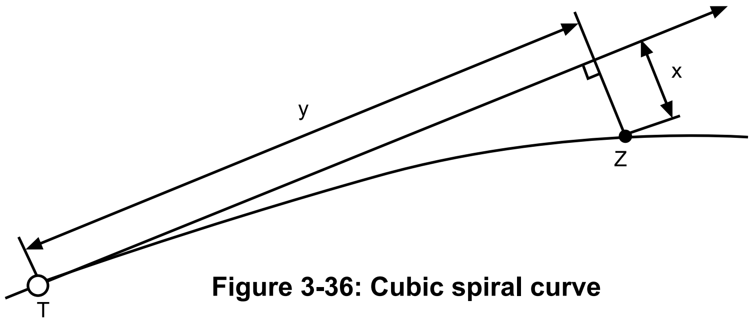



**Figure 3-36: Cubic spiral curve**

**Setting out of a transition curve**

A transition curve is set out following any of the same methods for simple curves described earlier. The following formulae can be used to set out the transition curve:

Total tangent length $L = (R + S)\ tan \left(\phi/2\right)$

The distance from $IP$ to $TS$ (start of transition) = $(R+S)\tan\left(\phi/2\right)+L_T/2$

The length of the circular curve (arc) = $R\times\phi(in\ radians)-L_T$

The chainage of $TS$ = $IP\ chainage = (IP\ to\ TS)$

The chainage of $SC$ = $TS + L_T$

The chainage of $CS$ = $SC + Arc\ length$

The chainage of $ST$ = $CS + L_T$

**Example 3-1**

You have been asked to set out a proposed circular curve connected by two spirals with a minimum curve radius 200m on a rural road which has an intersection angle of 25°, the chainage at the $PI$ being 1208.70. The maximum crossfall for the curve is to be 5% and design speed of 60 km/hr. Compute the chainages for $TS$, $SC$, $CS$ and $ST$ for setting out the curve.

**Solution:**

**(i) Compute the transition length $L_T$**

$$L_T = \frac{V_D^3}{46.7qR} = \frac{60^3}{46.7\times0.60\times200} = 38.54m;$$

**(ii) Compute Shift to See if Transition is required**

The shift can be calculated by: $S = \frac{L_T^2}{24R} = \frac{38.54^2}{24\times200} = 0.31m$

Since $S$ = 0.31 > 0.250, therefore transition is required.

**(iii) Compute Tangent Length and Arc**

Tangent Length $L$ = $(R+S)\tan\left(\phi/2\right)=(200+0.31)\times\tan\left(25/2\right)=39.84m$

Distance from $PI$ to $TS$ (start of transition) : $(R+S)\tan\left(\phi/2\right)+L_T/2 = 39.84+38.54/2 = 59.11m$

Length of circular curve = arc $= R \times \phi(radians) - L_T = \left(200 \times 25 \times \pi/180\right) - 38.54 = 48.73m$

**(iv) Compute Chainages**

Chainage of *TS* = *PI* chainage - (*PI* to *TS*) = *1208.70 - 59.11 = 1149.59*

Chainage of *SC* = *TS* + $L_T$ = *1149.59 + 38.54* = *1188.13*

Chainage of *CS* = *SC* + *Arc* = *1188.13 + 48.73 = 1206.86*

Chainage of *ST* = *CS* + $L_T$ = *1206.86 + 38.54* = *1245.40*

**Example 3-2**

A composite curve consisting of a central circular arc and two transition curves are to be set out as part of a low-volume road alignment to join two straights having a deflection angle of 12°. The carriageway width is 6.3m; designed speed is 60 km/h and a radius of 300m. The rate of change of radial acceleration is 0.6m/s3. The superelevation should be introduced at a rate of no more than 1.5%.

- Calculate the amount of superelevation that should be constructed along the entry transition
- Calculate the length of transition curve and check that the transition curves are long enough for the superelevation to be introduced.
- Calculate the data required to set-out the transition curve by offset taken at 10m intervals along the tangent length.

**Solution:**

Given Data: $q$ =0.6m/s3 $b$=6.3m , $v$ = 60km/h , $R$ = 300m

(i) The amount of superelevation that must be built into the central circular arc

$$e = \frac{Bv_D^2}{282.8R} = \frac{6.30 \times 60^2}{282.8 \times 300} = 0.267\ m$$

Expressed as a % the superelevation slope $S = \frac{v_D^2}{282.8R} \times 100\% = \frac{60^2}{282.8 \times 300} \times 100\% = 4.24\%$

The radius of 300m is greater than the desirable min value of 255m (Table 3-11) for a 60km/h speed.

The superelevation slope of 4.24% is less than the maximum desirable value of 5%. Hence the 0.267m superelevation height should be built into the central circular arc.

**(ii) Calculating length of transition and checking that the transition curves are long enough:**

The length of each transition curve required for comfort and safety is obtained from the equation:

$$L_T = \frac{v_D^3}{46.7qR} = \frac{60^3}{46.7 \times 0.6 \times 300} = 25.7\ m$$

The superelevation value of 0.267 m must be introduced and removed over a distance of 25.7m, which represents a gradient of: $\frac{0.267}{25.7} \times 100\% = 1\%$

Since this is less than the maximum allowable rate of introduction of 1.5%, the transitions are long enough.

**(iii) The data required to set-out the transition curve by offset taken at 10m intervals along the tangent length:**

Using the Cubic Parabola formula: $x = \dfrac{y^3}{6RL_T}$ ;

| $y$ | $x = \dfrac{y^3}{6RL_p}$ |
|---|---|
| 0 | $x_0 = \dfrac{0^3}{6\times300\times25.7} = 0$ |
| 10 | $x_{10} = \dfrac{10^3}{6\times300\times25.7} = 0.022$ |
| 20 | $x_{20} = \dfrac{20^3}{6\times300\times25.7} = 0.173$ |
| 25.7 | $x_{25.7} = \dfrac{25.7^3}{6\times300\times25.7} = 0.367$ |

**Table 3-7: Data to set out transition curve**

## 3.6 VERTICAL CURVES

A Vertical curve is provided at the point where the two straight lines at different gradients intersect in the vertical plane. The vertical curve provides a smooth change in the gradients and is introduced to secure safety and adequate visibility together with comfort to the passengers. The vertical curves are generally parabolic in profile. Vertical curves are classified into two categories:

- Crest curve
- Sag curve

The crest curve having convexity upwards is also called a summit curve. The curve occurs when an ascending gradient meets another ascending segment with a less steep gradient, or an ascending gradient meets a horizontal gradient, or when a descending gradient meets a descending segment with a steeper gradient, or an ascending gradient meets a descending gradient. These are illustrated Figure 3-37:

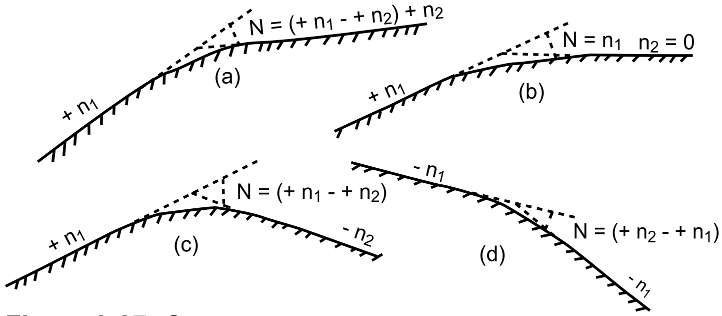



**Figure 3-37: Crest curves**

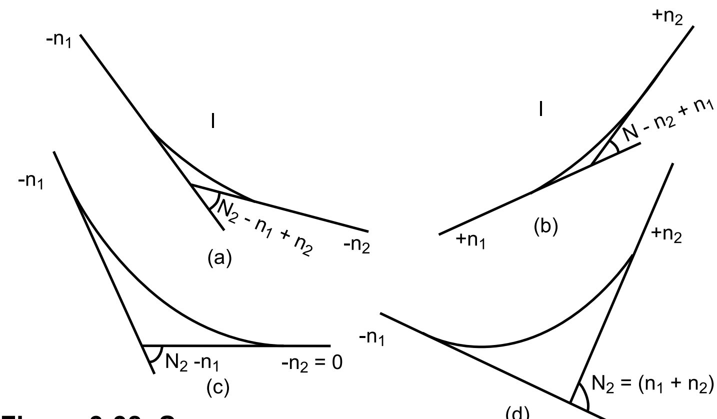



**Figure 3-38: Sag curves**

On the other hand a vertical curve having concavity upwards or convexity downwards is called a sag curve. Examples of sag curves are shown in Figure 3-38:

### 3.6.1 Elements of vertical curves

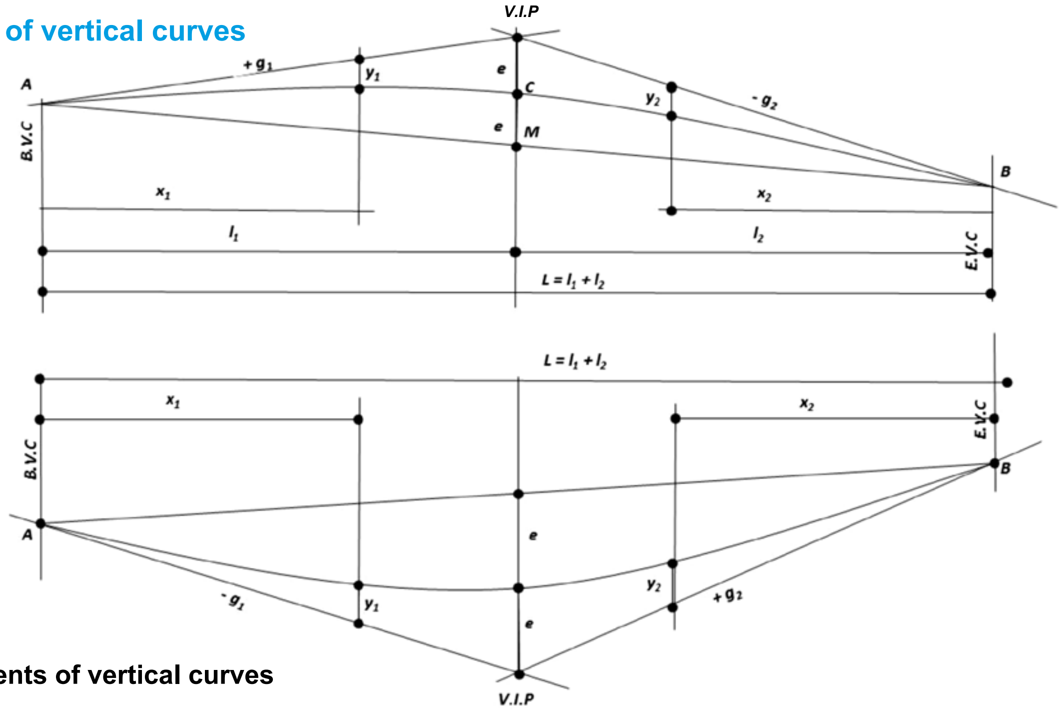



**Figure 3-39: Elements of vertical curves**

The vertical curve could be symmetrical or unsymmetrical.

From Figure 3-39 above, the following are properties of vertical curves:

- $VIP$ = Point of vertical intersection; where the grade tangents intersect.
- $BVC$ = Beginning of Vertical Curve
- $EVC$ = Point of vertical tangency; where the curve ends.
- $g_1$ = Grade of the tangent on which the $BVC$ is located; measured in percent of slope.
- $g_2$ = Grade of the tangent on which the $EVC$ is located; measured in percent of slope.
- $l_1, l_2$ = Length (horizontal) of the curve, i.e. curve $AC$ and $BC$ in metres
- $x_1, x_2$ = The horizontal distance from $BVC$ and $EVC$ respectively in metres

Note: for a symmetrical curve, $x_1 = x_2 = x;\ y_1 = y_2 = y;\ l_1 = l_2 = l$.

Varying vertical curve parameters based on symmetry are as shown below:

**Table 3-8: Vertical Curve Symmetry Parameters**

| Parameter | Symmetrical Curve | Unsymmetrical Curve |
|---|---|---|
| $e$ = the offset from VIP | $e = \frac{l}{4}\frac{(g_2 - g_1)}{100}$ | $e = \frac{l_1 \times l_2}{2L}\left(\frac{g_2 - g_1}{100}\right)$ |
| $y_1$ = The tangent offset at a distance x1 from BVC | $y = \left(\frac{x}{l}\right)^2 e$ | $y_1 = \left(\frac{x_1}{l_1}\right)^2 e$ |
| $y_2$ = The tangent offset at a distance x2 from EVC | $y = \left(\frac{x}{l}\right)^2 e$ | $y_2 = \left(\frac{x_2}{l_2}\right)^2 e$ |
| $x_{max}$ = The horizontal distance to the turning point (highest or lowest point) | $x_{max} = \frac{g_1 L}{g_1 - g_2}$ | $x_{1\max} = \frac{l_1}{l_2}\left(\frac{g_1 L}{g_1 - g_2}\right)$ $x_{2\max} = \frac{l_2}{l_1}\left(\frac{g_2 L}{g_2 - g_1}\right)$ |

### 3.6.2 Setting out of vertical curves

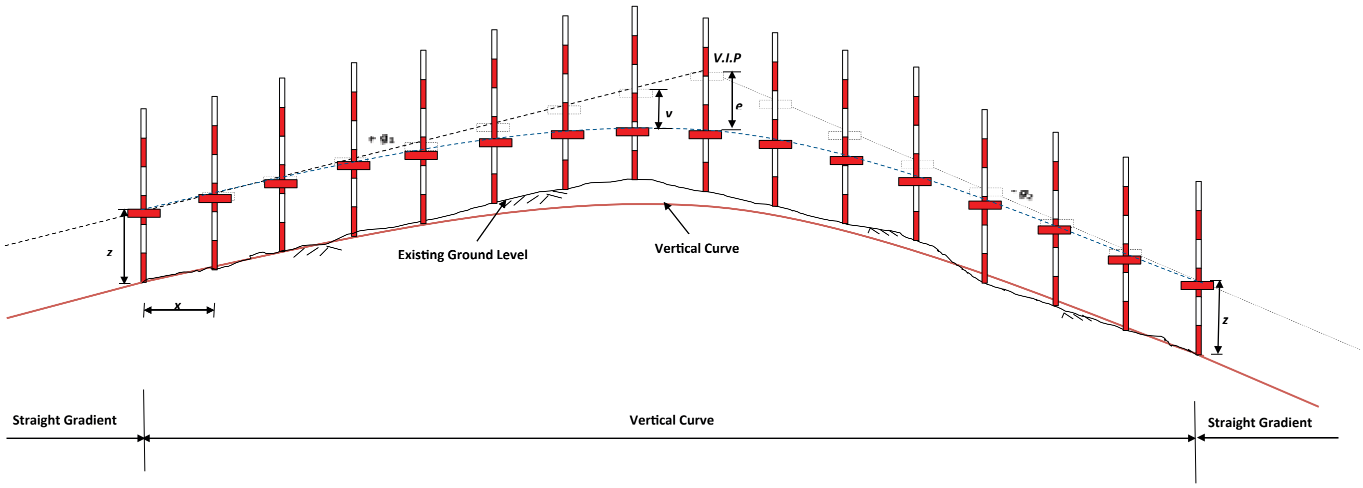



**Figure 3-40: Setting out of vertical curve**

The following steps can be used to set out vertical curves:

i. Using the methods explained in section 3.2.5, measure the longitudinal slopes $g_1$ and $g_2$ of the two intersection gradients.

ii. Calculate the Algebraic difference $A = g_2 - g_1$

iii. Given the Length $L$ of Vertical Curve by the Engineer. ($l = L/2$)

iv. Calculate the offset from VIP $e = \frac{l}{4} \times \frac{(g_2 - g_1)}{100}$

v. Fix ranging rods and profile boards set at levels through the straight section and curve that define the respective measured slopes.

vi. Measure the vertical distance $z$ of the profile board to the ground at the beginning of the curve at each side.

vii. From the beginning of the curve on each leg, drop the profile board at every $x$ = 10m (say) within the curve by the offset,

$y = \left(\frac{x}{l}\right)^2 e$ . The tops of the dropped profile boards will define the vertical curve.

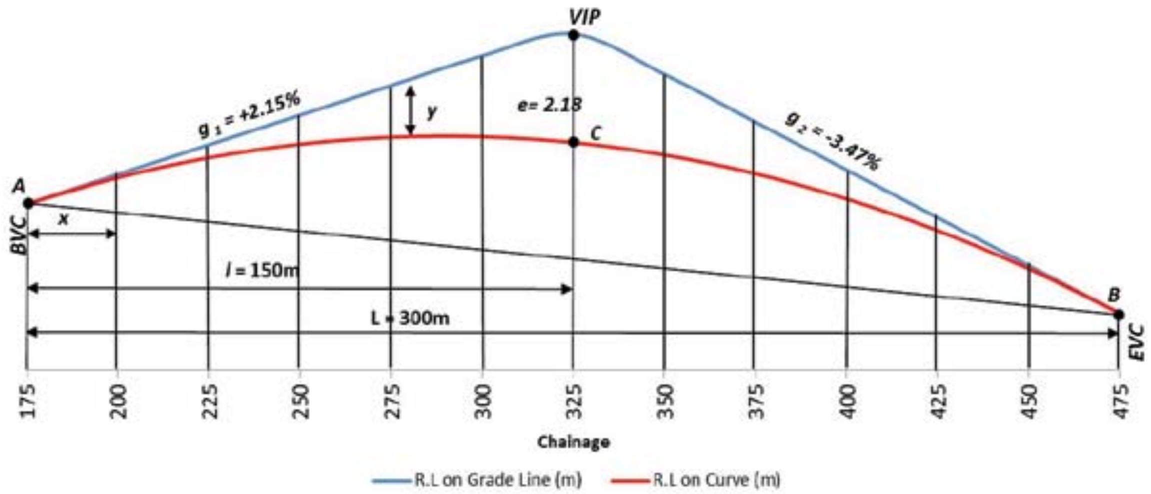
viii. Measuring the vertical distance $z$ down the ranging rod from the level of each lowered profile board will determine the extent of earthwork (cut or fill) at every distance $x$ =10m (say).

The worked example 3-3 below illustrates the above steps in setting out a vertical curve

**Example 3-3**
Set out a Crest Curve with the following data:
$g_1$ = +2.15%; $g_2$ = -3.47%; *VIP* chainage = 3+25.000; *RL* of *VIP* = 45.237; Design speed = 90km/hr; Length of Curve L = 300m.

**Solution:**

1. Calculate the Algebraic difference $A = g_2 - g_1 = -3.47 - 2.15 = \underline{\underline{-5.62\%}}$




2. Calculate the offset from VIP $e = \frac{l}{4} \times \frac{(g_2 - g_1)}{100} = \frac{150 \times 5.62}{4 \times 100} = \underline{\underline{2.108}}$

3. Calculate the off-sets at every 25m using the equation $y = \left(\frac{x}{l}\right)^2 e$

$$\text{For } x = 25m, y = \left(\frac{25}{150}\right)^2 \times 2.108 = \underline{0.058m}$$

$$\text{For } x = 50m, y = \left(\frac{50}{150}\right)^2 \times 2.108 = \underline{0.234m}$$

$$\text{For } x = 75m, y = \left(\frac{75}{150}\right)^2 \times 2.108 = \underline{0.527m}$$

$$\text{For } x = 100m, y = \left(\frac{100}{150}\right)^2 \times 2.108 = \underline{0.937m}$$

$$\text{For } x = 125m, y = \left(\frac{125}{150}\right)^2 \times 2.108 = \underline{1.464m}$$

4. Calculate the Reduced Levels on straight grade line:

$$At\ (A)\ Ch.1+75 = R.L.\ at\ VIP - \left(2.15 \times \frac{150}{100}\right) = 45{,}237 - 3.225 = \underline{42.012}$$

$$At\ Ch.2+00 = R.L.\ at\ VIP - \left(2.15 \times \frac{125}{100}\right) = 45{,}237 - 2.688 = \underline{42.549}$$

$$At\ Ch.2+25 = R.L.\ at\ VIP - \left(2.15 \times \frac{100}{100}\right) = 45{,}237 - 2.150 = \underline{43.087}$$

$$At\ Ch.2+50 = R.L.\ at\ VIP - \left(2.15 \times \frac{75}{100}\right) = 45{,}237 - 1.613 = \underline{43.624}$$

$$At\ Ch.2+75 = R.L.\ at\ VIP - \left(2.15 \times \frac{50}{100}\right) = 45{,}237 - 1.075 = \underline{44.162}$$

$$At\ Ch.3+00 = R.L.\ at\ VIP - \left(2.15 \times \frac{25}{100}\right) = 45{,}237 - 0.538 = \underline{44.699}$$

$$At\ Ch.3+25 = R.L.\ at\ VIP - \left(2.15 \times \frac{0}{100}\right) = 45.237 - 0 \quad = \underline{45.237}$$

$$At\ Ch.3+50 = R.L.\ at\ VIP - \left(3.47 \times \frac{25}{100}\right) = 45.237 - 0.868 = \underline{44.369}$$

$$At\ Ch.3+75 = R.L.\ at\ VIP - \left(3.47 \times \frac{50}{100}\right) = 45.237 - 1.735 = \underline{43.502}$$

$$At\ Ch.4+00 = R.L.\ at\ VIP - \left(3.47 \times \frac{75}{100}\right) = 45.237 - 2.603 = \underline{42.634}$$

$$At\ Ch.4+25 = R.L.\ at\ VIP - \left(3.47 \times \frac{100}{100}\right) = 45.237 - 3.470 = \underline{41.767}$$

$$At\ Ch.4+50 = R.L.\ at\ VIP - \left(3.47 \times \frac{125}{100}\right) = 45.237 - 4.338 = \underline{40.899}$$

$$At\ Ch.4+75 = R.L.\ at\ VIP - \left(3.47 \times \frac{150}{100}\right) = 45.237 - 5.205 = \underline{40.032}$$

The above can be tabulated as shown in Table 3-9 below:

**Table 3-9: Reduced levels solution to Example 3-3**

| Chainage (m) | R.L on Grade Line (m) | Offset y (m) | R.L on Curve (m) |
|---|---|---|---|
| 1 + 75 (A) | 42.012 | 0.000 | 42.012 |
| 2 + 00 | 42.549 | 0.058 | 42.491 |
| 2 + 25 | 43.087 | 0.234 | 42.853 |
| 2 + 50 | 43.624 | 0.527 | 43.097 |
| 2 + 75 | 44.162 | 0.937 | 43.225 |
| 3 + 00 | 44.699 | 1.464 | 43.235 |
| 3 + 25 (C) | 45.237 | 2.108 | 43.129 |
| 3 + 50 | 44.369 | 1.464 | 42.905 |
| 3 + 75 | 43.502 | 0.937 | 42.565 |
| 4 + 00 | 42.634 | 0.527 | 42.107 |
| 4 + 25 | 41.767 | 0.234 | 41.533 |
| 4 + 50 | 40.899 | 0.058 | 40.841 |
| 4 + 75 (B) | 40.032 | 0.000 | 40.032 |

The curve can then be set out as explained in section 3.6.2 above.

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# SECTION 4: SITE CLEARING AND EARTHWORKS

This section focuses on site clearing and earthworks associated with road works.

Site clearing normally involves the digging up and removal of rubbish, debris, vegetation, hedges, shrubs and small trees with a girth of up to 200 mm, bushes including the removal of top soil, roots and other organic matter likely to provide food for termites. The amount of vegetation can differ considerably, from semi-arid areas where the clearing work is negligible, to dense forests where power tools may be necessary to remove extensive tree roots. Redundant buildings and old damaged structures may also need to be demolished and removed.

In labour-based works this operation is broken into common activities such as bush clearing, grubbing, tree and stump removal for ease of work organization and resource management. Grubbing refers to the process of removing and disposing of top soil including roots, stumps (de-stumping), stubs, transverse roots and associated debris.

Clearing and grubbing work can normally be undertaken by hand with appropriate tools. In exceptional cases where massive and difficult areas have to be cleared it may be more effective to introduce some power tools in combination with the labour relying on basic hand tools.

There are several methods which can be applied for boulder removal including moving, burying, breaking using motorized equipment such as compressors with jackhammers and using explosives. Where such equipment is unavailable, fire and water (heating and cooling) and splitting rock using feather and wedges have been used with some degree of success. Some of these are illustrated below:

**Grubbing by hand**

**De-stumping**

**Boulder removal**

**Exposed boulder**

**Heating rock by fire**

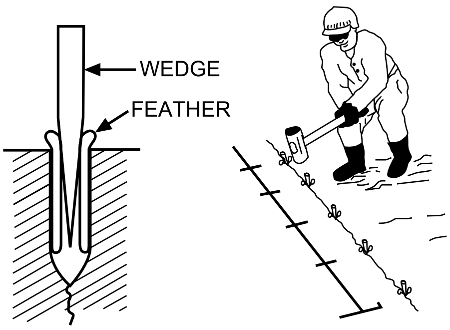



**Figure 4-1: Using feathers and wedges**

**Figure 4-2: Boulder removal using crowbars**

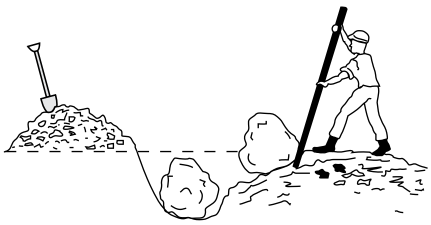


**Figure 4-3: Burying boulders**

Clearing activities are best organized using individual or group tasks. The following are examples of task rates for clearing and grubbing activities. The task rates for most clearing activities depend on the type of vegetation and ease of removal as shown in Table 4-1.

**Table 4-1: Productivities for clearing and grubbing (ILO)**

| **Activity** | **Description** | **Optimum production in** m$^2$ per work day |
|---|---|---|
| Bush clearing | Light bush (using a slasher) | 250 - 350 |
| | Medium bush (using bush knifes or bow saws) | 150 - 250 |
| | Dense bush (bow saw and axe) | 100 - 150 |
| Grass clearing | Removal of vegetation to ground surface | 350 -500 |
| De-stumping | Removal of shrubs | 75 - 125 |
| | Removal of tree stumps with major roots | Daily paid – based on experience (depends on size and difficulty) |
| Grubbing | Top soil and root removal to 250 mm depth in soft loamy soil | 60 - 175 |
| Removal of boulders and other obstructions | Removing loose debris, boulders and other obstructions (fallen trees, dead animals, etc.) | Daily paid or group task – based on experience (depends on size and difficulty) |

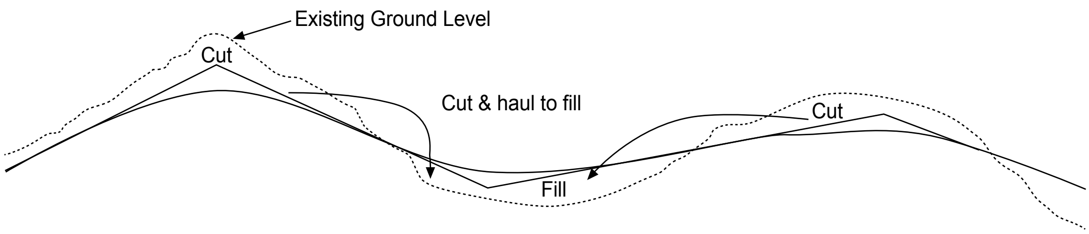
*Source: ILO*

## 4.1 EARTHWORKS

When relying on conventional equipment-based construction methods, earthworks are balanced longitudinally along the road alignment and thus involve long haulages of substantial amounts of material. However, when earthworks are not very extensive, it can be organized relying on manual labour, with the aid of level control equipment and aids such as slots, profile boards, boning rods amongst others, and still achieve the required quality and speed. On low-volume roads long haulage of excavated materials for cuts and fills can be reduced by balancing materials transversely across the road cross-section thus limiting haulage to the use of wheelbarrows and light transport equipment.

**VERTICAL ALIGNMENT DESIGN**

**a) Conventional Equipment-based Methods - by Longitudinal Balancing**




**b) Labour-based Methods - by Transverse Balancing**

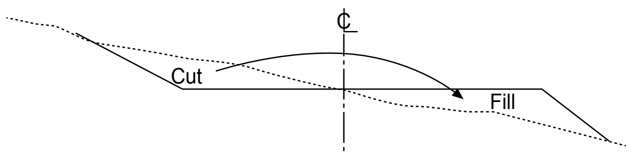



**Figure 4-4: Vertical alignment design**

## 4.2 HAULING BY LABOUR

Hauling by labour has proved to be cost-effective for distances of up to 150 metres using wheelbarrows. Table 4-2 shows the productivity which can be achieved when using wheelbarrows. For longer distances, it becomes necessary to use other appropriate means of transport such as tractors and trailers, tipper trucks and lorries.

When using wheelbarrows it is important to keep the haul route in good condition with a smooth and dry surface. Equally, the wheelbarrows need to be maintained in good operational condition.

Trucks for haulage should not be too large or too high or else they are difficult to load and manoeuver on a worksite where excavation works is carried out using manual labour. Tipping trucks with a capacity of 5 to 7m³ have therefore proved ideal for labour-based work.

**Table 4-2: Wheelbarrow haulage norms (ILO)**

| Haul distance (m) | Productivity in $m^3$/wd |
|---|---|
| 0 - 20 | 8.5 |
| 20 - 40 | 7.0 |
| 40 - 60 | 6.5 |
| 60 - 80 | 5.5 |
| 80 - 100 | 5.0 |
| 100 - 150 | 4.5 |

## 4.3 DITCHING AND SLOPING

When earthworks are organized by balancing materials transversely across the road cross-section, the suitable soils from the drains are used for the build-up of the road subbase/base. The best hydraulic cross-section of a side drain is a trapezoid and this shape open drain can be excavated by hand using the following steps:

1) Set out the middle rectangular section of the trapezium using string lines and pegs and assign workers using the appropriate task rate to excavate to the required dimensions (width and depth);
2) Set out the fore slope using string lines and pegs to the required dimensions and assign workers excavate this slope;
3) Finally, set out the back slope using the same process as the opposite slope and assign workers to excavate.

The steps are illustrated in Figure 4-5 and the photographs below (note that the dimensions vary depending on the chosen design of the road cross-section).

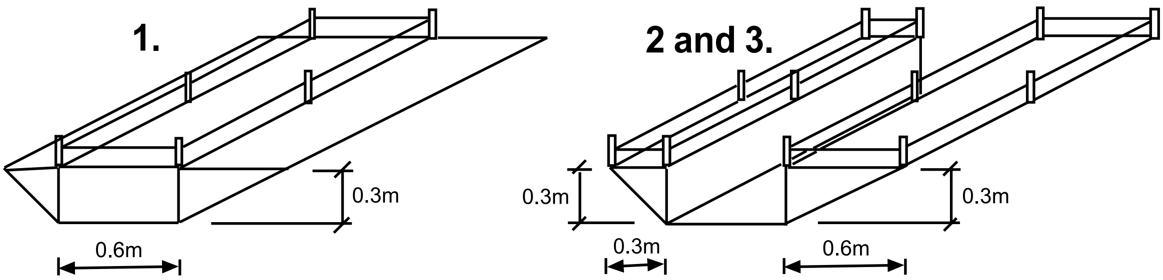



**Figure 4-5 Steps in ditching and sloping**

**Constructing open drains using labour-based work methods**

## 4.4 EXCAVATION REQUIREMENTS

### 4.4.1 Excavating trenches

Generally trenches up to a maximum depth of 1.5m can be excavated by hand without need for shoring[14]. However, in certain difficult geological formations, the Engineer may instruct the Contractor to shore or secure the trench as necessary. It is important that tasks are set fairly so as to encourage work in this activity. Tasks which are unfairly set tend to discourage workers and would lead to chaos on site.

Soil types are generally classified as loose or dense depending on the difficult/ease of their excavation. Different countries or institutions use various classifications. These classifications are often used to set out correct task rates and eliminate ambiguities during implementation. An example from South Africa is given below.

**Table 4-3: Classification of in-situ materials**

| GRANULAR MATERIALS | | COHESIVE MATERIALS | |
|---|---|---|---|
| **Consistency** | **Description** | **Consistency** | **Description** |
| Very loose | Crumbles very easily when scraped with a geological pick. | Very soft | Geological pick head can easily be pushed in as far as the shaft of the handle. |
| Loose | Small resistance to penetration by sharp end of a geological pick. | Soft | Easily dented by thumb; sharp end of a geological pick can be pushed in 30-40 mm; can be moulded by fingers with some pressure. |
| Medium dense | Considerable resistance to penetration by sharp end of a geological pick. | Firm | Indented by thumb with effort; sharp end of geological pick can be pushed in up to 10 mm; very difficult to mould with fingers; can be penetrated with an ordinary hand spade. |
| Dense | Very high resistance to penetration by the sharp end of geological pick; requires many blows for excavation. | Stiff | Can be indented by thumbnail; slight indentation produced by pushing geological pick point into soil; cannot be moulded by fingers. |
| Very dense | High resistance to repeated blows of a geological pick. | Very stiff | Indented by thumbnail with difficulty; slight indentation produced by blow of a geological pick point. |

*Source: Contraction Industry Development Board (CIDB), South Africa*

| Activity definition | Soil description | | Suitable tools |
|---|---|---|---|
| | ***Cohesive*** | ***Non-cohesive*** | |
| Soft | Soft | Very loose | Easily excavated with a shovel or hoe |
| Medium | Firm | Loose | Can be dug with a shovel |
| Hard | Stiff | Compact | Mattock, pick or other swung tool required |
| Very hard | Very stiff or hard | Dense or very dense | Crowbar required in addition to pick |
| Rock | | Rock | Sledge hammer and chisels required |

*Source: World Bank*

[14] Shoring is the term used in construction to describe the process of bracing and supporting the vertical excavated faces from collapse thus ensuring safety..

**Table 4-4: Task rates for earthworks**

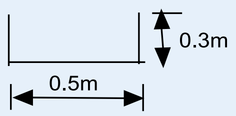
| Activity | | Task rate | Remarks |
|---|---|---|---|
| Bush Clearing | Light bush | 250 - 350 $m^2$/wd | Task length of bush clearing will depend on specified clearing width. |
| Tree & Stump Removal | | 100 – 150 $m^2$/wd | > 20 cm Ø of stump, task rate in $m^2$. < 20 cm Ø, task rate in No. (Use experience) |
| Grubbing | Light ground cover up to 5 cm thick | 150 $m^2$/wd | Task length of Grubbing will depend on specified grubbing width. |
| Boulder Removal | | daily paid | From experience |
| Slotting | | 2-4 slots/wd | Check according to the volume of earthwork. |
| Excavation Only | Soft/loose soil | 3.5 $m^3$/wd | With maximum throwing distance of 4.0 m. |
| | Hard soil | 2.5 $m^3$/wd | |
| | Very hard soil | 1.5 $m^3$/wd | |
| Excavation & Loading | Soft/loose soil | 3.0 $m^3$/wd | |
| | Hard soil | 2.0 $m^3$/wd | |
| | Very hard soil | 1.0 $m^3$/wd | |
| Ditching | Soft/loose soil | 3.5 - 4.0 $m^3$/wd | Throw excavated material to centre of road. Tasks applicable for mitre drain construction and sloping. |
| | Hard soil | 2.5 - 3.0 $m^3$/wd | |
| | Very hard soil | 1.5 - 2.0 $m^3$/wd | |
| Sloping | Soft/loose soil | 3.5 - 4.0 $m^3$/wd | Throw excavated material from fore-slope to centre of road and back-slope material out of the road. * For Rolling/Hilly Terrain where it is rocky the fore-slope may be reduced |
| | Hard soil | 2.5 - 3.0 $m^3$/wd | |
| | Very hard soil | 1.5 - 2.0 $m^3$/wd | |

*Source: ILO*

### 4.4.2 Converting task rates to linear metres

Productivity rates are measured in units of length, area, volume and numbers. Normally, task rates given in area and volume cannot be easily visualized or perceived by the workers. For example if a worker on site is told to excavate $3m^3$ as the task for the day, it is difficult for him/her to determine the actual extent of the task. It is therefore useful to convert the task rates to linear metres which are easy to perceive by the workforce. Table 4-5 below gives some examples of tasks converted to linear metres:

**Table 4-5: Conversion of task rates to linear metres**

| Task rate conversion | Formula | Example |
|---|---|---|
| 1. Area to length (e.g. clearing/grubbing the road reserve to a uniform width) | $Task(Length) = \frac{Task(in\ Area)}{Width}$ | If the grubbing task is $200m^2$ with an average width of 5m, then: $Task\ (Length) = \frac{200\ m^2}{5\ m} = 40m$ |
| 2. Volume to length (e.g. excavating a ditch to uniform width and depth) | $Task(Length) = \frac{Task(in\ Volume)}{Area(of\ Cross\ section)}$ | If the ditching task is $3m^3$ with a ditch cross section of 0.5m width and 0.3m depth, then:   $Task\ (Length) = \frac{3m^3}{(0.5 \times 0.3)} = 20m$ |

### 4.4.3 Measuring earthwork quantities

This section attempts to guide site supervisors through the concepts of accurately measuring earthworks quantities either for payment or reporting purposes. Excavating soils by hand and depositing the material adjacent to the excavated section or away from it, both come under the term earthworks. Soil excavation from the existing ground is known as ‘a cut’ and depositing the earth at some place is commonly referred to as a fill or an embankment.

The cross section of a trench may be rectangular or trapezoidal. In rocky or hard soils the cross-section may be rectangular but in most cases the cross section is almost always trapezoidal. The cross section of an embankment is always trapezoidal, as the filled earth or rock cannot be properly placed with vertical faces. Figure 4-6 shows the trapezoidal sections of earth work in cuts and fills.

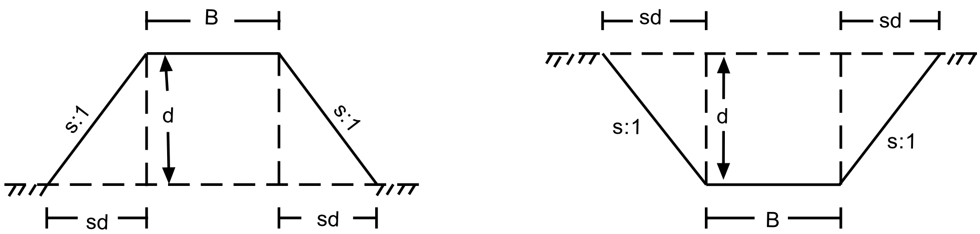



**Figure 4-6: Trapezoidal sections of a fill and cut**

The volume of earthwork is calculated by multiplying the cross-sectional area of the cut or fill with the length of the trench or embankment. As the sides of the trenches or the banked earth always have a slope, the slope is presented as a ratio $s : 1$, s being the horizontal distance in one (1) vertical height or depth. $d$ always represents the depth of cutting or height of embankment. $s : 1$ is the ratio of side slopes as horizontal : vertical. $B$ is the width of the finished trench base or finished top width in case of an embankment. In other words for one vertical height, horizontal distance is ‘$s$’ and for ‘$d$’ vertical height or depth, horizontal distance is $sd$.

Using Figure 4-6, the area of cross-section is calculated from the sum of the central rectangular portion and the areas of the two side triangular portions, given by the formula:

$$A = Bd + 2\left(\frac{1}{2} \times sd \times d\right) = \underline{Bd + sd^2}$$

If L is the length of the trench or earth fill and the cross-section remains unchanged throughout this length, then the quantity or the volume of earthwork can be established by multiplying the cross-sectional area with the length $L$, The total volume of earth work is then given by:

$$V = A \times L = \left(Bd + sd^2\right)L$$

The unit of measurement of earthwork is cubic metres. Different kinds of soils such as sandy, clayey, rocky, etc. are estimated separately. This is done because the respective task rates and unit rates of payment for the different types of soils may vary considerably.

Earthwork is calculated on the basis of longitudinal sections and cross-sections at different lengths from the starting point. First of all formation level of the road is marked on the longitudinal section of the ground keeping in view the principles of the drainage of the road terrain.

When determining the road formation level, emphasis is always given to maintaining a level above the existing ground so that rain and floods do not overtop and damage the road. However, it is not always possible to maintain the formation level above the existing ground. At some locations the ground will be higher than the road and at such points the ground is cut to attain correct vertical alignment. As the road works involves both cutting and filling, effort must be made to balance the cuts and fills. In most cases the road is placed above the existing ground requiring a fill to attain this formation level. The soils used for filling are obtained either from cuts along the road alignment or from borrow pits located in the vicinity of the road.

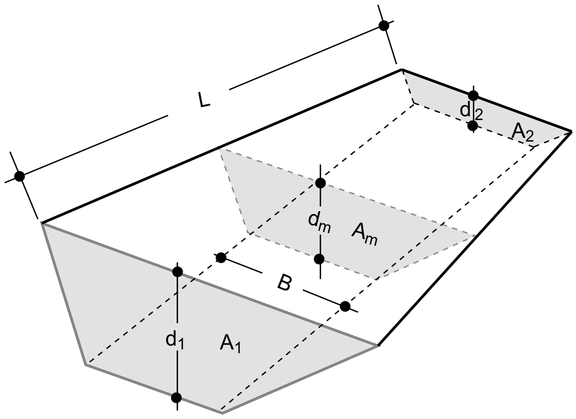
The longitudinal section is usually plotted with a horizontal scale of 1 cm = 10 m to 30 m and vertical scale of 1 cm = 1 m to 5 m, depending upon the slope and undulations in the area.

#### 4.4.3.1 Methods of calculating sectional area and volume of earthwork

Earthworks quantities may be calculated using various approaches. The following describe the most common methods:
- Mid-sectional area method
- Mean sectional area method
- Prismoidal formula method

**1. Mid-sectional area method**

When the ground is sloping longitudinally the height of the embankment or the depth of cutting may not remain the same throughout the length $L$. In this case, the representative cross-sectional area is not measured at the ends but at the mid-length. This section when multiplied by the length $L$ gives the volume of earthwork. As illustrated in Figure 4-7, if $d_1$ and $d_2$ are the fill or cut heights at each of the end sections, $B$ is the formation width, $s$ is the side slope, and $L$ is the total length of the fill or cut, then:




The mean height or depth $d_m$ of the cross-section is thus given by:

$$d_m = \frac{d_1 + d_2}{2}$$

The mean cross-sectional area $A_m$ is given by:

$$A_m = Bd_m + sd_m^2$$

The volume $V$ of the earthwork:

$$V = \left(Bd_m + sd_m^2\right) \times L$$

**Figure 4-7: Mid-sectional Area method**

The table 4-6 below can be used to easily calculate the quantities.

**Table 4-6: Table for computing volumes by mid-sectional area**

| Station or chainage | Depth or Height $d$ | Mean depth or height $d_m$ | Area of central rectangular portion $Bd_m$ | Area of sides $Sd_{m^2}$ | Total Areas $Bd + sd_{m^2}$ | Length between stations $L$ | Volume $V = (Bd_m + sd_{m^2})L$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Embankment | Cutting |
| | | | | | | | | |

**ii. Mean sectional area method**

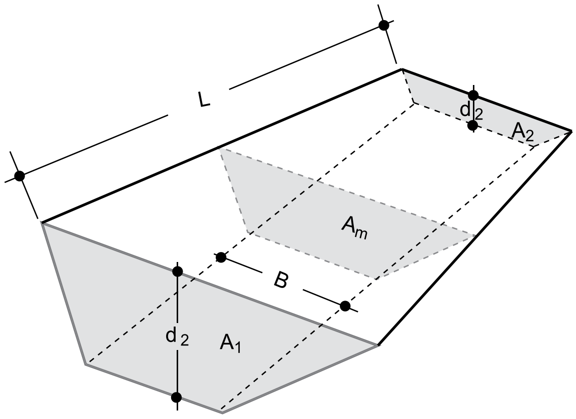



**Figure 4-8: Mean sectional area method**

With this method, the respective cross-sectional areas of the ends are calculated using the respective depths. The mean area is calculated using the calculated end areas. If $A_1$ and $A_2$ are the cross-sectional areas at the two ends where $d_1$ and $d_2$ are the respective depths, then as illustrated in Figure 4-8:

Sectional area of end $A_1$ is: $A_1 = Bd_1 + sd_1^2$

Sectional area of end $A_2$ is: $A_2 = Bd_2 + sd_2^2$

The mean sectional area $A$ is given by: ; $A = \frac{A_1 + A_2}{2}$

Then the volume $V$ is given by: . $V = \left(\frac{A_1 + A_2}{2}\right) \times L$

The quantities can be easily calculated in a tabular form as shown in table 4-7 below:

**Table 4-7: Table for computing volumes by mean sectional area**

| Station or chainage | Depth or Height $d$ | Area of central rectangular portion $Bd$ | Area of sides $Sd^2$ | Total Areas $Bd + sd^2$ | Mean sectional area | Length between stations $L$ | Volume $V = (Bd + sd^2)L$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Embankment | Cutting |
| | | | | | | | | |

### iii. Prismoidal Formula Method

Still using Figure 4-8, if $A_1$ and $A_2$ are the cross-sectional areas at the two ends where $d_1$ and $d_2$ are the respective depths, then:

Sectional area of end $A_1$ is: $A_1 = Bd_1 + sd_1^2$

Sectional area of end $A_2$ is: $A_2 = Bd_2 + sd_2^2$

Mean Sectional area $A_m$ is: $A_m = Bd_m + sd_m^2$ ; where $d_m = \frac{d_1 + d_2}{2}$ ;

Then the volume of earthworks $V$ by Prismoidal method is given by: $V = \frac{L}{6} \times (A_1 + 4A_m + A_2)$.

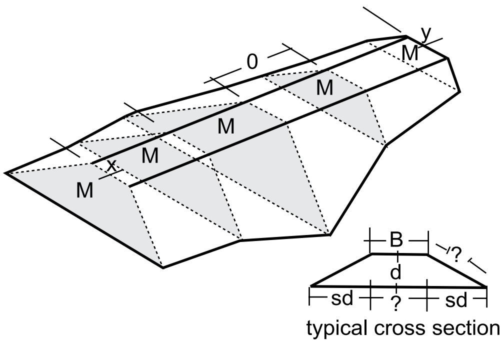



**Figure 4-9: Prismoidal method**

In the case of series of cross-sections (say 5) at equal intervals $D$ as shown as an example in Figure 4-9, then the volume calculated using the Prismoidal formula becomes: $V = \frac{D}{3}\left[(A_1 + A_5) + 4(A_2 + A_4) + 2A_3\right]$

In general, for n cross sections at equal intervals $D$, the equation is given as:

$$V = \frac{D}{3}\left[(A_1 + A_n) + 4\{(A_2 + A_4) + (A_6 + A_8) + ....\} + 2\{(A_3 + A_5) + (A_7 + A_9) + ....\}\right]$$

In words, the equation becomes:

$$V = \frac{D}{3}\{(\textit{First area} + \textit{last area}) + 4 \times (\textit{even areas}) + 2 \times (\textit{odd areas})\}$$

***Note:***

1. *All the three methods are applicable for both cuts and embankments even though the first two methods are commonly used as they are simpler and easier to apply. However, the Prismoidal method is most accurate and should be applied in cases with extensive earthworks and high unit rates requiring greater accuracy.*
2. *In the case of using the Prismoidal formula, the number of cross-sections from which the volume is to be calculated must be odd. If there are even numbers of cross-sections, then the volume of the last section should be calculated separately and added to the volume of the odd number of sections.*

Other methods that can be used for calculating earthwork quantities which are not covered in this guideline include:

a) Method of spot levels
b) Method of contour lines

## 4.5 EARTHWORK IN HILLY TERRAIN

In hilly terrain the ground is irregular and besides the longitudinal slope there could be cross slopes as well. For new road construction, levels are taken at regular intervals along the centreline of the road alignment. Cross-slopes may be measured as the ratio of the horizontal distance to the vertical height. It is generally written as $r{:}1$ which means in $r$ horizontal distance, vertical rise or fall is one (1). The cross slope may also be determined using a line level or placing a light wooden bar of about 3 to 4m in length horizontally and checking the vertical rise using a spirit level.

When estimating the volume of earthwork it is assumed that the cross-slope remains same between two consecutive cross-sections. The cross-sectional areas can be worked out using Figure 4-10 and formulae shown below whilst the volumes are calculated using one of the three methods described earlier. The following describes how to calculate the quantities of earthworks with a cross-slope of *r:1*.

**Case 1: Cross-section partly in cut and partly in fill**

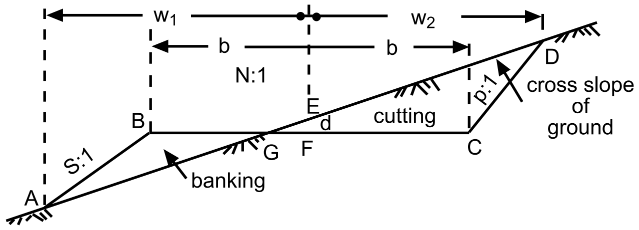



**Figure 4-10: Cross-section in part-cut, part fill**

The area ABG describes the fill section and the area DCG represents the cut.

Side slope of banking = s : 1

Side slope of cutting = p : 1

Finished formation width = 2b

It can be proved that:

$$\text{Area of banking } ABG = \frac{1}{2}\frac{(b-rd)^2}{r-s}$$

$$\text{Area of Cutting } DCG = \frac{1}{2}\frac{(b+rd)^2}{r-p}$$

$$\text{Side width } w_1 = \frac{(b+sd)r}{r-s}$$

$$\text{Side width } w_2 = \frac{(b+pd)r}{r-p}$$

Similarly it can be proved that:

$$\text{Side slope } AB = \frac{(b-rd)}{r-s}\sqrt{s^2+1}$$

$$\text{Side slope } CD = \frac{(b-rd)}{r-s}\sqrt{p^2+1}$$

Note that if point *G* on the right side of the centre *F* then areas can be found by the same formula but with the signs interchanged in the numerator only i.e.:

$$\text{Area of banking } ABG = \frac{1}{2}\frac{(b+rd)^2}{r-s}$$

$$\text{Area of Cutting } DCG = \frac{1}{2}\frac{(b-rd)^2}{r-p}$$

Case 1 is mostly used in labour-based earthworks as the cut and fill are mostly balanced at each cross-section to minimize longitudinal haulage of material.

**Example 4-1: Earthworks with cross-sections partly in cut and partly in fill**

A road is to be constructed in a sidelong ground in cutting and partly in embankment. The formation width of the road is 8m, the cross-slope of the existing ground is 8:1, the embankment has a slope of 2:1 and the back slope of the cut is 1.5:1. The depth of the cut at the centre is 0.2m all through. Calculate the quantity of earthwork in the fill and the cut for a length of 250m.

**Solution:**

Side slope of fill = $s : 1 = 2{:}1$
Side slope of cut = $p : 1 = 1.5{:}1$
Ground slope = $r : 1 = 8{:}1$
Finished formation width = $2b = 8;\ b = 4$
Height at the centre of cut & fill $h = 0.2m$

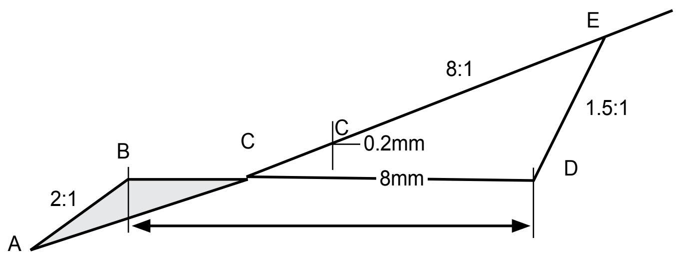



**Figure 4-11: Cut and fill cross section**

**Table 4-8: Earthworks calculation in part cut and part fill**

| Cross-section Part | Height of bank or Depth of cut (m) | Cross slope of ground | Sectional Area | Length between stations $L$ | Volume $V\ (m^3)$ | |
|---|---|---|---|---|---|---|
| | | | | | Cutting | Banking |
| Cut | 0.2 | 8.00 | $\text{Cut Area} = \frac{1}{2}\frac{(b+rd)^2}{r-p} = \frac{1}{2}\times\frac{(4+8\times0.2)^2}{8-1.5} = 2.41m^2$ | 250.0 | 603.08 | - |
| Fill | 0.2 | 8.00 | $\text{Fill Area} = \frac{1}{2}\frac{(b-rd)^2}{r-s} = \frac{1}{2}\times\frac{(4-8\times0.2)^2}{8-2} = 0.48\ m^2$ | 250.0 | - | 120.00 |
| | | | | **Total Quantities** | **603.08** | **120.00** |

**Case 2: Sectional area fully in embankment or fully in cut**

Sections of the road may be placed either in a full embankment (low-lying areas) or fully in a cut (through a hill). In such terrain, it is obviously not possible to balance the cut and fill at each cross-section. Instead the material needs to be transported from a cut to a location where the road is on an embankment or to spoil. The following example of Figure 4-12 illustrates the method of calculating the earthworks.

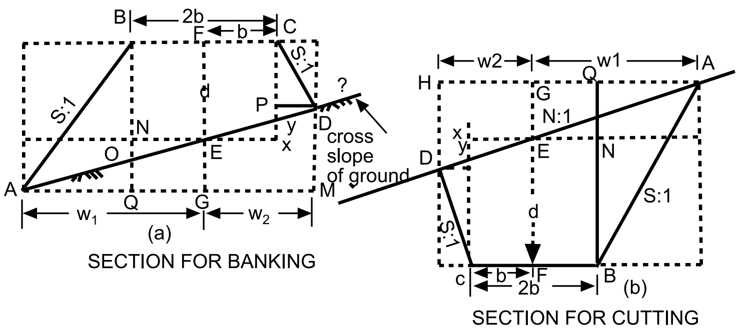



**Figure 4-12: Full embankment or cut area**

The land has a cross slope of $r{:}1$
Side slope of fill = $s : 1$
Height of fill = $d$
Finished formation width = $2b$
It can be proved that:

$$\text{Area } ABCD = \frac{sb^2 + r^2\left(2bd + sd^2\right)}{r^2 - s^2}$$

$$\text{Side width } w_1 = b + \frac{rs}{r-s}\left(d + \frac{b}{r}\right)$$

$$\text{Side width } w_2 = b + \frac{rs}{r+s}\left(d - \frac{b}{r}\right)$$

Similarly it can be proved that:

$$\text{Side slope } AB = \frac{w_1 - b}{s}\sqrt{s^2+1}$$

$$\text{Side slope } CD = \frac{w_2 - b}{s}\sqrt{s^2+1}$$

$$\text{Length } AE = \frac{w_1}{r}\sqrt{r^2+1}$$

$$\text{Length } DE = \frac{w_2}{r}\sqrt{r^2+1}$$

$$\text{Final mean slope } r = \frac{2r_1r_2}{r_1 + r_2}$$

Where $r_1$ and $r_2$ are the cross-slopes of the ground at the two ends. Generally, the ground is considered to have the same cross-slope at the two ends and therefore $r_1$ and $r_2$ have the same value

### Example 5 2: On full embankment and cut

A proposed road to be constructed has a section from Chainage 0+120 to 0+360 with a formation width of 10m. Side slopes are 1.5:1 for cutting and 2:1 for filling. The road formation has a uniform falling gradient of 1:200. At chainage 0+120, the formation is at ground level. Reduced levels (RLs) of the ground at different locations are as given in Table 4-9 below:

**Table 4-9: Reduced levels of ground**

| Chainage | 0+120 | 0+150 | 0+180 | 0+210 | 0+240 | 0+270 | 0+300 | 0+330 | 0+360 |
|---|---|---|---|---|---|---|---|---|---|
| RL of Ground | 118.60 | 119.25 | 119.40 | 118.85 | 118.50 | 117.25 | 116.80 | 117.15 | 117.20 |

1. Work out the earthwork quantities for this section.
2. Draw the longitudinal section and cross-section for both cuts and fills.

**Solution:**
Formation width $B = 10m$; cut side slope $s = 1.5$, and embankment side slope $s = 2$
The road formation level is falling uniformly with a gradient of 1/200 starting from Chainage 0+120.
Using the tabular format of the Mid-sectional Area Method, the solution is given as below:

**(i) Earthwork quantities for the section**

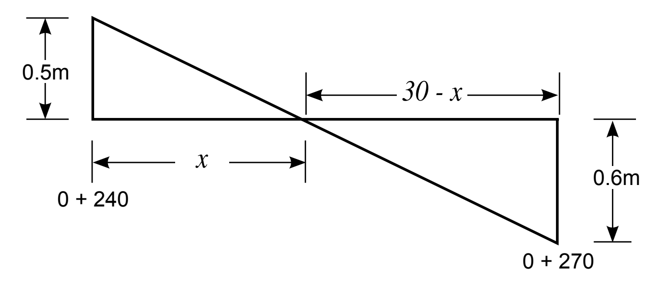
**Table 4-10: Table for computing quantities (Example 4-9)**

| Chainage | Ground Level *(a)* | Formation Level *(b)* | Depth or Height $d$ *(c) = (a) - (b)* | Mean depth or height $d_m$ *(d)* | Area of central portion $Bd_m$ *(e) = 10 x (d)* | Areas of sides $sd_m^2$ *(f) = s x (e)* | Total areas $Bd + sd_m^2$ *(g) =(e) + (f)* | Lenth between stations $L$ *(h)* | Volume V = $(Bd_m + sd_m^2)\,L$ *(i) = (g) + (h)* | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0+120 | 118.6 | 118.60 | - | - | - | - | - | - | - | - |
| 0+150 | 119.25 | 118.45 | -0.80 | -0.40 | 4.00 | 0.24 | 4.24 | 30 | | 127.20 |
| 0+180 | 119.4 | 118.30 | -1.10 | -0.95 | 9.50 | 1.35 | 10.85 | 30 | | 325.61 |
| 0+210 | 118.85 | 118.15 | -0.70 | -0.90 | 9.00 | 1.22 | 10.22 | 30 | | 306.45 |
| 0+240 | 118.5 | 118.00 | -0.50 | -0.60 | 6.00 | 0.54 | 6.54 | 30 | | 196.20 |
| change | 118.6 | 118.60 | 0.00 | -0.25 | 2.50 | 0.09 | 2.59 | 13.64 | | 35.38 |
| 0+270 | 117.25 | 117.85 | 0.60 | 0.30 | 3.00 | 0.18 | 3.18 | 16.36 | 52.02 | |
| 0+300 | 116.8 | 117.70 | 0.90 | 0.75 | 7.50 | 1.12 | 8.62 | 30 | 258.75 | |
| 0+330 | 117.15 | 117.55 | 0.40 | 0.65 | 6.50 | 0.84 | 7.34 | 30 | 220.35 | |
| 0+360 | 117.2 | 117.40 | 0.20 | 0.30 | 3.00 | 0.18 | 3.18 | 30 | 95.40 | |
| | | | | | | | | **Total Volume** | **626.52** | **990.84** |

***Note:***

a. *The calculated volumes show longitudinal cut to fill and not cut to fill within a cross-section.*
b. *The negative(-ve) depth shows that it is a cut, whilst positive (+ve) depth means a fill*
c. *Since the depth/height sign changes between Chainages 0+240 and 0+270, that means that within that section the earthworks changes from cut to fill.*
d. *The exact point where the change from cut to fill occurs is calculated as follows:*

**Table 4-11: Point of change from cut to fill**




Let $x$ be the cut length within the section
The fill length is then ; $30 - x$
From the two similar triangles:

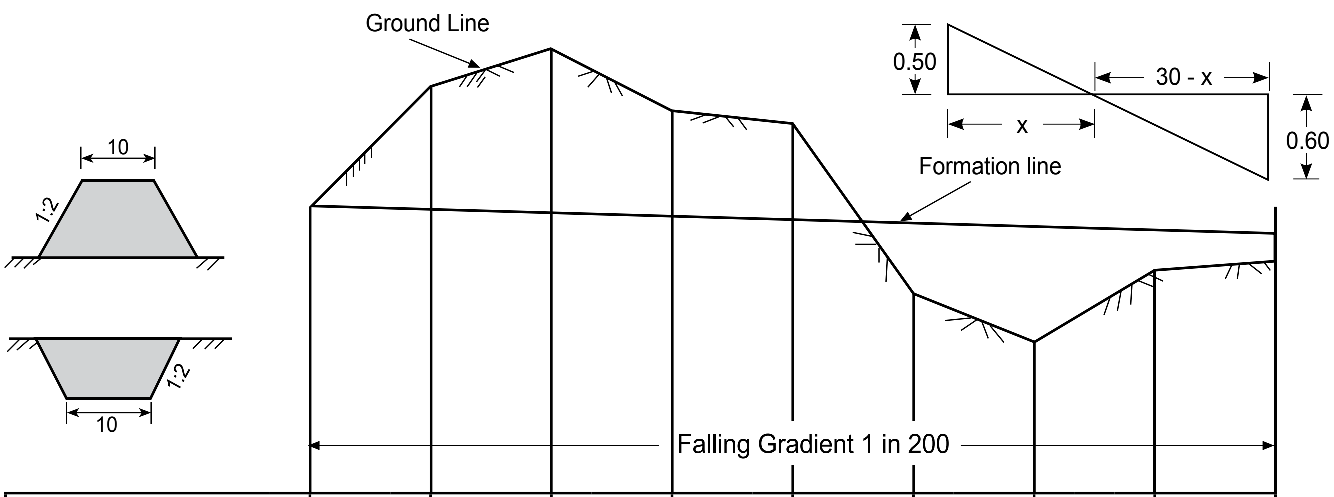
$$\frac{x}{0.5} = \frac{(30 - x)}{0.6}$$

By cross-multiplying and solving for $x$ gives:

$$\underline{x = 13.64m}$$

$$\therefore \text{ Cut Length} = \underline{13.64m}$$

$$\text{Fill length } = \underline{16.36\text{m}}$$




| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Datum Line | | | | | | | | | |
| Depth of Cutting | 0.00 | 0.80 | 1.10 | 0.70 | 0.50 | | | | |
| Height of Embankment | | | | | | 0.60 | 0.90 | 0.40 | 0.20 |
| Reduced Level of Formation | 118.60 | 118.45 | 118,30 | 118.15 | 118.00 | 117.85 | 117.70 | 117.55 | 117.40 |
| Reduced Level of Ground | 118.60 | 119.25 | 119.40 | 118.85 | 118.50 | 117.25 | 116.80 | 117.15 | 117.20 |
| Distance (m) | 120 | 150 | 180 | 2.10 | 2.40 | 2.70 | 3.00 | 3.30 | 3.60 |

**Figure 4-13: Longitudinal profile showing work example cut and fill quantities**

**Case 3: When the cross-slope is not uniform at a section**

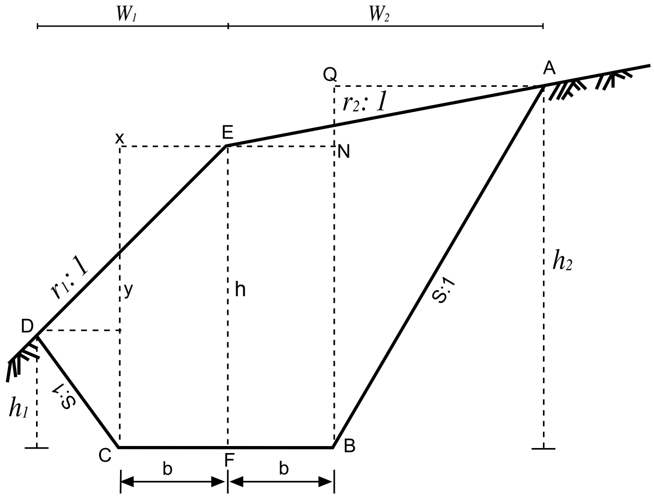



**Figure 4-14: Area non-uniform cross-slope**

When the cross-slope is not uniform at a section at least three points are required to define the ground slope. Using Figure 4-14,
Let the ground slopes be = $r_1 : 1$, and $r_2 : 1$
Side slope of cut = $s : 1$
Finished formation width = $2b$
It can be proved that:

$$\text{Area of ABCD} = \frac{1}{2s}\left[(b+sh)(w_1+w_2)-2b^2\right]$$

$$\text{Side width } w_1 = \frac{r_1}{r_1+s}(b+sh)$$

$$\text{Side width } w_2 = \frac{r_2}{r_2-s}(b+sh)$$

Similarly it can be proved that the heights in the cut are: $\text{Height } h_1 = h - \frac{w_1}{r_1}$

$$\text{Height } h_2 = h + \frac{w_2}{r_2}$$

In fill, the heights are respectively:

$$\text{Height } h_1 = h + \frac{w_1}{r_1}$$

$$\text{Height } h_2 = h - \frac{w_2}{r_2}$$

**Example 5-3: Earthworks in cut and fill sections**

A road is to be built in hilly terrain with formation widths of 10m in embankment and 8m in cuts. The side slope of the embankment is 2:1 and that of the cuts is 1.5:1. The heights of embankment and the depths of cuts at the centre of the road and the cross slopes of the ground at intervals of 50m are as given below. Calculate the quantities of earthwork.

**Table 4-12: Cut and fill sections**

| Distance (m) | Depth of cutting (m) | Height of embankment (m) | Cross slope of the ground |
|---|---|---|---|
| 0 | 0.5 | - | 8:1 |
| 50 | 0.7 | - | 10:1 |
| 100 | 0.4 | - | 12:1 |
| 150 | 0.3 | - | 8:1 |
| 200 | - | 0.6 | 12:1 |
| 250 | | 0.4 | 8:1 |
| 300 | - | 0.3 | 12:1 |
| 350 | - | 0.6 | 10:1 |

**Solution:**

The road passes from cut to fill between Chainage 150m and 200m. The distance $x$ from the zero point of Chainage 150m is as follows: $\frac{x}{0.3} = \frac{(50-x)}{0.6}$; solving for $x$ gives $x = 16.67m$

The distance of zero point from Chainage 150 is: 150 + 16.67 = 166.67m
Mean harmonic cross-slope of ground at zero point is:

$$r = \frac{2r_1r_2}{r_1 + r_2} = \frac{2\times8\times12}{8+12} = \frac{192}{20} = 9.6 = 10 \ (\text{approx})$$

At zero point one half of the road will be in cutting and one-half will be in banking; $d = 0$ and formation width may be taken 10m i.e. $b = 5m$.

At the zero point, the sectional area of the cut portion = $\frac{1}{2}\frac{b^2}{(r-p)} = \frac{1}{2}\frac{5^2}{(10-1.5)} = 1.47m^2$

At the zero point, the sectional area of the fill portion = $\frac{1}{2}\frac{b^2}{(r-p)} = \frac{1}{2}\frac{5^2}{(10-2.0)} = 1.1.56m^2$

$b = 4m$ in cutting, and $b = 5m$ for banking. $s = 2$, and $p = 1.5$. The volume of earthworks is calculated in tabular form as follows:

**Table 4-13: Calculation of volume of cut and fill earthworks**

| Chainage | Height of bank or Depth of cut (m) $d$ | Cross slope of ground $r$ | $Sectional\ Area = \frac{sb^2 + r^2\left(2bd + sd^2\right)}{r^2 - s^2}$ (m²) | Mean Sectional Area | Length between stations $L$ | Volume $V\ (m^3)$ | |
|---|---|---|---|---|---|---|---|
| | | | | | | Cutting | Banking |
| 0 | 0.5 | 8.00 | $\frac{1.5\times(4)^2+8^2\left(2\times4\times0.5+1.5(0.5)^2\right)}{8^2-1.5^2}=4.92$ | - | - | - | |
| 50 | 0.7 | 10.00 | $\frac{1.5\times(4)^2+10^2\left(2\times4\times0.7+1.5(0.7)^2\right)}{10^2-1.5^2}=6.73$ | 5.82 | 50 | 291.24 | |
| 100 | 0.4 | 12.00 | $\frac{1.5\times(4)^2+12^2\left(2\times4\times0.4+1.5(0.4)^2\right)}{12^2-1.5^2}=3.66$ | 5.20 | 50 | 259.76 | |
| 150 | 0.3 | 8.00 | $\frac{1.5\times(4)^2+8^2\left(2\times4\times0.3+1.5(0.3)^2\right)}{8^2-1.5^2}=3.02$ | 3.34 | 50 | 167.00 | |
| 166.67 | 0 | 10.00 | $\frac{1}{2}\frac{b^2}{(r-p)}=\frac{1}{2}\frac{5^2}{(10-1.5)}=\frac{25}{17}=1.47\ m^2$ <br> $\frac{1}{2}\frac{b^2}{(r-s)}=\frac{1}{2}\frac{5^2}{(10-2)}=\frac{25}{16}=1.56\ m^2$ | 3.02 | 16.67 | 50.39 | |
| 200 | 0.6 | 12.00 | $\frac{2\times(5)^2+12^2\left(2\times5\times0.6+2(0.6)^2\right)}{12^2-2^2}=7.27$ | 5.15 | 33.33 | | 171.64 |
| 250 | 0.4 | 8.00 | $\frac{2\times(5)^2+8^2\left(2\times5\times0.4+2(0.4)^2\right)}{8^2-2^2}=5.44$ | 6.36 | 50 | | 317.76 |
| 300 | 0.3 | 12.00 | $\frac{2\times(5)^2+12^2\left(2\times5\times0.3+2(0.3)^2\right)}{12^2-2^2}=3.63$ | 4.53 | 50 | | 226.73 |
| 350 | 0.6 | 10.00 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.6+2(0.6)^2\right)}{10^2-2^2}=7.52$ | 5.57 | 50 | | 278.72 |
| | | | | | **Total Volume** | **768.38** | **994.85** |

**Example 4-4: Earthworks in fill-only section**

A road section is to be constructed having a land slope tangent of 0.1. The Reduced Level (RL) and ground level for the chainages are given in the table below. Calculate the quantity of earthworks if the formation width is 10m with an embankment slope of 2:1. The length of each chainage interval is 30m.

**Table 4-14: Reduced ground and formation levels**

| Chainage | Distance | R.L. of Ground | R.L. of Formation |
|---|---|---|---|
| 0 | 0 | 100.80 | 101.20 |
| 1 | 30 | 101.25 | 101.80 |
| 2 | 60 | 101.90 | 102.40 |
| 3 | 90 | 102.60 | 103.00 |
| 4 | 120 | 102.90 | 103.60 |
| 5 | 150 | 103.60 | 104.20 |

**Solution:** $\tan\theta = 0.1 = \frac{1}{10} \quad r:1 = 10:1$

Note that all the sections are in fill as the formation level is higher than the ground level at all given chainage points. The height of the embankment at each Chainage is calculated by subtracting the reduced level of the ground from the reduced level of the formation. The quantities are calculated in tabular form as shown below:

**Table 4-15: Calculation of embankment (fill) volumes**

| Chainage | Ground Level | Formation Level | Depth of bank (m) $d$ | $Sectional\ Area = \frac{sb^2 + r^2\left(2bd + sd^2\right)}{r^2 - s^2}$ (m2) | Mean Sectional Area | Length between stations $L$ | Volume $V\,(m^3)$ |
|---|---|---|---|---|---|---|---|
| 0 | 100.8 | 101.20 | 0.40 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.4+2(0.4)^2\right)}{10^2-2^2}=5.02$ | - | - | - |
| 1 | 101.25 | 101.80 | 0.55 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.55+2(0.55)^2\right)}{10^2-2^2}=6.88$ | 5.95 | 30 | 178.52 |
| 2 | 101.9 | 102.40 | 0.50 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.5+2(0.5)^2\right)}{10^2-2^2}=6.25$ | 6.57 | 30 | 196.95 |
| 3 | 102.6 | 103.00 | 0.40 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.4+2(0.4)^2\right)}{10^2-2^2}=5.05$ | 5.64 | 30 | 169.06 |
| 4 | 102.9 | 103.60 | 0.70 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.7+2(0.7)^2\right)}{10^2-2^2}=8.83$ | 6.93 | 30 | 207.81 |
| 5 | 103.6 | 104.20 | 0.60 | $\frac{2\times(5)^2+10^2\left(2\times5\times0.6+2(0.6)^2\right)}{10^2-2^2}=7.52$ | 8.18 | 30 | 245.31 |
| | | | | | | **Total Volume** | **997.66** |

### 4.5.1 Curvature correction

The earthwork quantities calculated in the sections above have assumed that the various sections are parallel to each other and the cross sections are set normal(perpendicular) to the centre line of the route. It should be noted that when the centre line is on a curve, the cross-sections are set out in the radial directions as shown in Figure 4-15, and are therefore not parallel to each other.

The mid- or mean sectional areas and Prismoidal methods discussed in earlier sections above have been derived on the assumption that the sections are in parallel planes. Hence the volumes computed by these formulae needs to be adjusted when the centre line is curved and the sections are not parallel. A correction[15] factor, known as the curvature correction, is applied to the computed areas to obtain the correct volumes.

The area correction factor C is given by $C = \pm \frac{Ae}{R}$, *where*

$A$ = the calculated area; $e$ = is the eccentricity (the distance of the centroid of the area to the centreline; and $R$ = radius of the curve.

The adjusted volume for an earthwork sectional area $A$, and length $L$ within a curve is given by: $V = LA\left(1 \pm \frac{e}{R}\right)$

**Note:** $e$ is negative when the centroid is inside the curve (i.e. on the same side of the centreline as the centre of curvature; and positive when the centroid lies outside the centreline of the curve).

The eccentricity e of a particular cross-section can be determined by locating its centroid. The centroid is determined by dividing the cross-section into small regular shapes (i.e. rectangles, triangles, etc.) and taking the moments of these small areas about the centre line.

[15] This is obtained by using Pappus' Theorem which states that the volume swept out by an area revolving around an axis is equal to the product of the area and the length of the path traced by the centroid of the area. i.e. V = area x distance traced by the centroid.

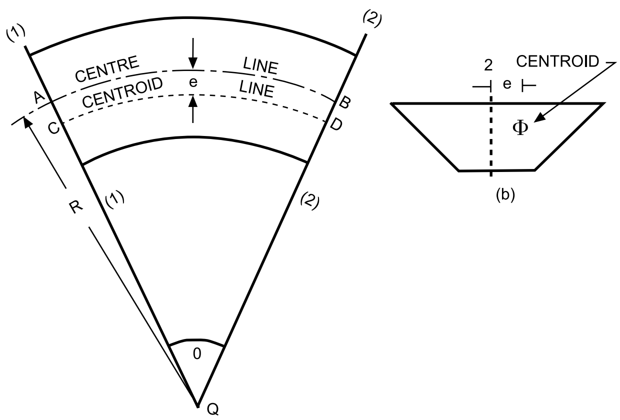



**Figure 4-15: Curvature correction**

(i) The value of C depends on the type of section:
For Level Section, $C = 0.0$

(ii) For two-level section,

$$C = \pm\frac{Ae}{R}; where\ e = \pm\frac{w_1 w_2 (w_1 + w_2)}{3As}$$

$w_1$, $w_2$ are the side widths, and s is the side slopes.

(iii) For Side-Hill two level section,

$$e = \frac{1}{3}\left(w_1 + \frac{b}{2} - sh\right); for\ small\ area.$$

$$e = \frac{1}{3}\left(w_1 + \frac{b}{2} + sh\right); for\ large\ area.$$

The correction is quite significant when the radius $R$ of the curve is relatively small. The correction is also important in the case of widening at the curves and in the case of side-hill sections.

### 4.5.2 Bulking and shrinkage

When hard soils are excavated, it increases its volume. It is therefore necessary to use a bulking factor to determine the volume of material resulting from the excavation works. The bulking factor is defined as:

$$\text{Bulking Factor} = \frac{\text{Volume after Excavation}}{\text{Volume before Excavation}}$$

Similarly a shrinkage factor is defined when compacting a soil at its final destination:

$$\text{Shrinkage Factor} = \frac{\text{Volume after Compaction}}{\text{Volume before Compaction}}$$

Table 4-16 gives a guide to bulking and shrinkage factors for different soil types.

**Table 4-16: Bulking and Shrinkage Factors**

| Material | Bulk density (kg/m$^3$) | Bulking factor | Shrinkage factor |
|---|---|---|---|
| Clay (Low PI) | 1.650 | 1.3 | 1.0 |
| Clay (High PI) | 2.100 | 1.4 | 0.9 |
| Clay and Gravel | 1.800 | 1.35 | 1.0 |
| Sand | 2.000 | 1.05 | 0.89 |
| Sand & Gravel | 1.950 | 1.15 | 1.0 |
| Gravel | 2.100 | 1.05 | 0.97 |
| Chalk | 1.850 | 1.5 | 0.97 |
| Shales | 2.350 | 1.5 | 1.33 |
| Limestone | 2.600 | 1.63 | 1.36 |
| Sandstone (Porous) | 2.500 | 1.6 | 1.0 |
| Sandstone (cemented) | 2.650 | 1.61 | 1.34 |
| Basalt | 2.950 | 1.64 | 1.36 |
| Granite | 2.410 | 1.72 | 1.33 |

*Source: ILO - LIC Guidelines for water provision, sanitation, solid waste and building works*

## 4.6 QUARRY (BORROW PIT) OPERATIONS

### 4.6.1 Borrow pit identification

If there is insufficient material within the road alignment, one has to borrow suitable material from elsewhere for fills and the construction of road layer works. Borrow pits are normally identified by the Client and it is advisable that before the contractor starts work in opening any quarry, a proper investigation is undertaken by the Engineer, comprising:

- The establishment of possible sites from geological knowledge of the area, and/or a study of the local vegetation, cutting faces and also conducting discussions with locals;
- Excavating trial pits to examine the extent of the deposits of suitable material as well as overburden to be removed;
- A plan of the area identifying the location and systematic establishment of further trial pits and showing these on the plan with test results. Samples of the material need to be tested in a laboratory to prove that they meet the minimum quality requirements. Samples should be taken by digging test pits in a 10x10m grid pattern throughout the entire area of the borrow pit. Concrete beacons can be placed at the perimeters of the area for ease of identification and direction for working of the quarry. The findings of the material testing should be presented in a standard format documenting:
- The location and extent of the source;
- The thickness and properties (hardness, stone content) of the overburden;
- The thickness and properties of the seam (hardness, stone content, standard test results) and total volume to be extracted from the quarry;
- Recommendations on methods for working the quarry including feasibility for excavation by hand.
- Proposed road access

***Note:***
*If the work is to be let out on contract, it is essential that this information concerning the quarry is readily available - including estimated material quantity.*

*Before commencing any material tests, the land owner must be consulted and permission obtained to use the land. Compensation is normally covered in the relevant road ordinances.*

Careful assessment must be made to determine the most economic approach in the use of the identified quarries. Even if one source has sufficient material to cover a very long road section, it might be more economical to open another quarry with a shorter haul route. Costs have to be carefully assessed including comparing costs of long haulages vis-à-vis the expenses involved in opening new quarries.

### 4.6.2 Borrow pit layout and access road

While conditions vary from site to site, there are some general principles for proper layout which are useful to observe.

The quarry layout should allow the tipper trucks or tractor and trailers to enter and leave the quarry without being on each other's way. Possible quarry layouts are as shown in Figures 4-16 and 4-17.

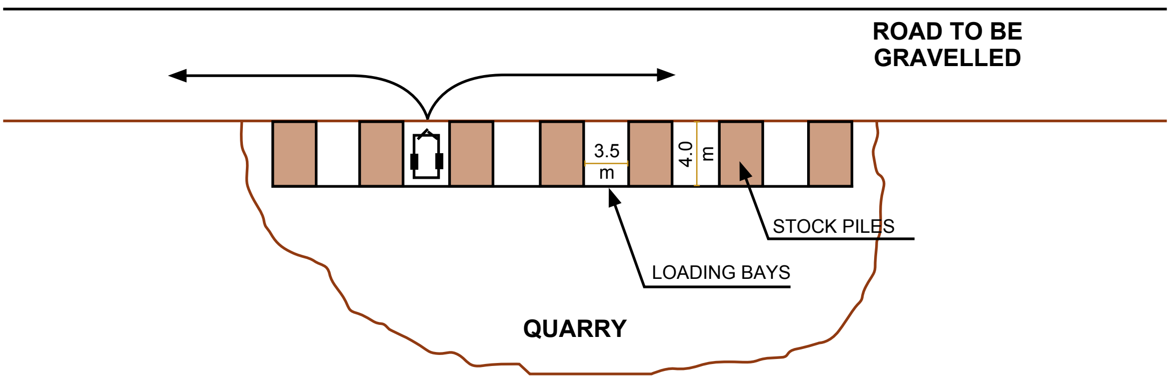



**Figure 4-16: Quarry by the road side**

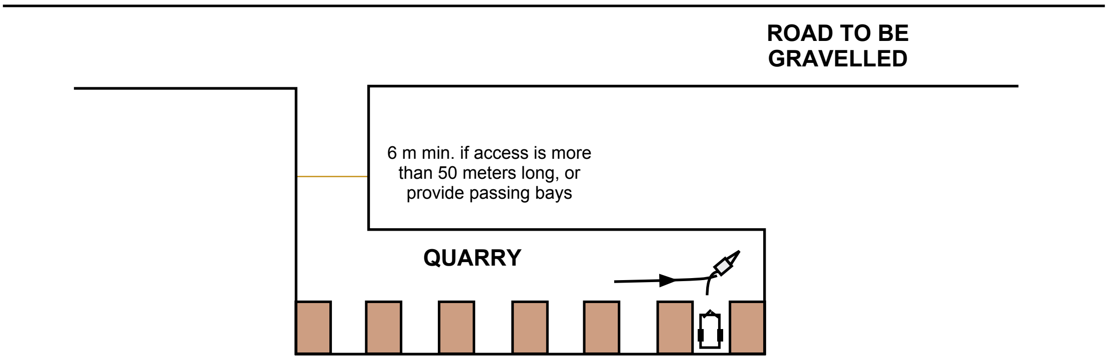



**Figure 4-17 Quarry with Access Road**

Where the quarry is not within the road reserve or located close to an existing road, an access road needs to be constructed. The access road must allow the vehicles to easily reach the quarry, pass each other and turn in front of the quarry. When work is tendered out, the cost of such work should be included in the bid price. Remember that transport equipment and its operation is expensive, so it is better to spend money once to have a good access road than lose money repeatedly every time a tipper truck or a tractor is held up or stuck on the access road. The small team of workers located at the quarry can be assigned to maintain the access road. It may also be necessary to provide some gravel to sections of the access road once the quarry is established and the equipment is brought to site.

Road signs and flagmen should be used for controlling traffic at the junction of the quarry access road and the main road.

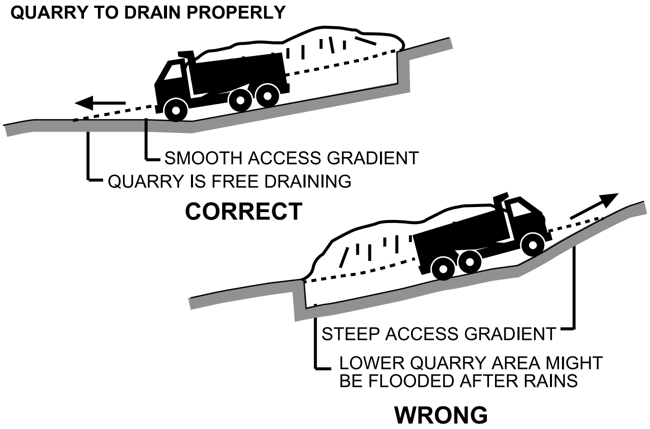



**Figure 4-18: Quarry drainage** **Un-drained quarry**

The quarry must be properly drained to prevent water accumulating in ponds in the pit during rains which can sometimes render the pit inoperative.

It should also be drained for health and safety reasons – especially in malaria-prone areas, and also preventing children from nearby villages from accidentally falling into the ponds created.

### 4.6.3 Excavation of overburden

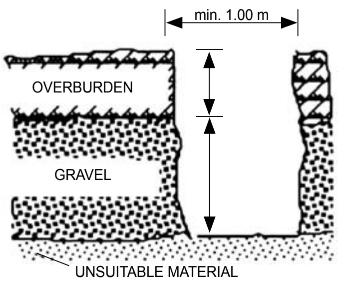



**Figure 4-19: Test pit showing soil profile**

It is necessary to strip the surface from vegetation and organic material as well as some soil (overburden) located on top of the 'good material' before working the quarry for the following reasons:

- The overburden is not suitable for the road layer works for which the borrow material is required. This can be assessed from the test results;
- Grass and roots in the overburden are not suitable for road construction works;
- Reinstatement of the quarry is very important - top soil, seeds and grass roots should be stockpiled for this purpose.

### 4.6.4 Excavating, stockpiling, and loading from borrow material

Where soil is not too rocky and conditions permit, excavation, stockpiling, and loading of borrow materials can be executed by hand. Excavation works in a hill-side quarry should follow the steps as indicated in Figure 4-20, to prevent landslide accidents and ensure the safety of workers.


**Figure 4-20: Hill-side quarry excavation**

Careful planning of the quarry work is needed to achieve the efficient operation of the road pavement works. The quarry preparation work should commence well before the formation and base layer works start on the road. It is useful to stockpile sufficient material so that once the haulage plant arrives, it can be fully utilised without waiting until enough material is excavated.

Each day, new material needs to be excavated and stockpiled at the quarry. The quantity stockpiled during a day should match or exceed the amount expected to be transported the following day. Excavation works in a quarry is suitable for gang/team tasks. A gang/team task, compared to individual tasks, reduces the amount of setting out and monitoring work required by the foreperson.

Particular attention should be given as to how the quarry develops so that work continues to proceed efficiently. Where possible, bays should be excavated and the material stockpiled on top of the bays as illustrated in Figure 4-21 for ease of loading into trucks by hand. In this way the material is always cast down into or from the same level as the trailers or trucks.

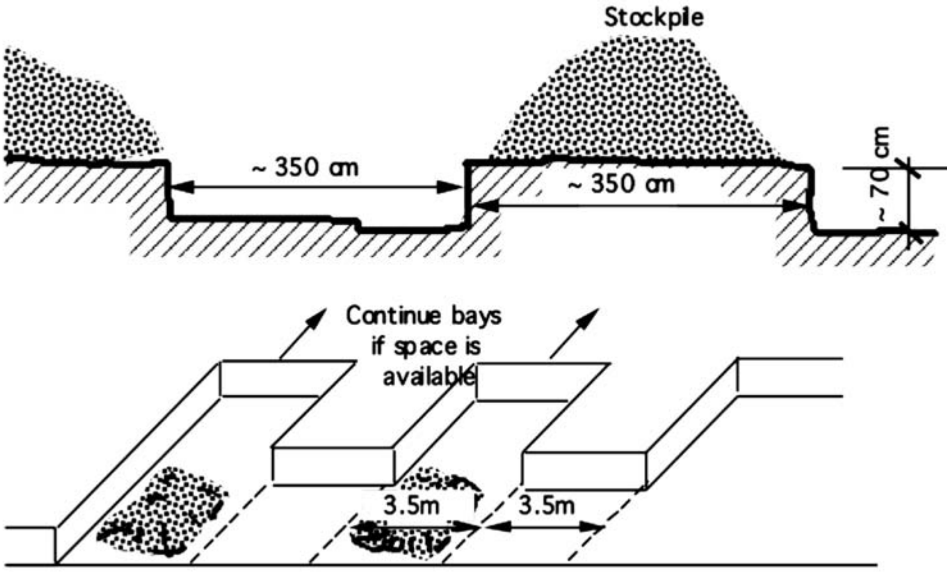



**Figure 4-21: Construction of loading bays**

**Excavation and stockpiling to create a loading bay**

**Loading a truck**

### 4.6.5 Rocky quarries

Where borrow pits are too rocky and the soils are difficult to excavate by hand, the use of explosives can be an effective method to loosen certain types of material prior to breaking and stockpiling by hand. The alternative is to break the stockpiled material using machines, for loading by manual labour. This approach can be advantageous especially for road pavement works where the harder materials are desired since they often have a higher CBR (strength). The use of machines in quarries:

- Speeds up the process of stockpiling hard material for later loading by hand.
- If the material consists of large quantities of coarse and over-size material, e.g. weathered dolerite or quartzitic boulder material, it is recommended to crush the material using a mobile crushing plant.

The excavation and stockpiling of material can be carried out as a separate works contract. The heavy equipment can complete its work at a specific quarry and move on to the next quarry for later loading of the material by labour as required in the road works. (This reduces the cost of keeping the idle equipment on site for extended periods)

### 4.6.6 Re-instating borrow pits

**Partially reinstated quarry**

**Fully reinstated quarry**

Quarries must be reinstated at the end of the pavement works by sloping the vertical excavated faces to stable slopes, returning the vegetation and topsoil to neatly cover the area. This can be undertaken by manual labour. Stockpiled organic material should be spread on the final surfaces. If possible, the reinstated area should be watered to encourage the growth of vegetation.

### 4.6.7 Quarry productivities

From experience, a well organised borrow pit, which is prepared, excavated and loaded using manual labour can alone employ as many as 50 - 80 workers. Table 4-17 below provides recommended productivities for quarry works:

**Table 4-17 Proposed Task Rates for Quarry Activities**

| Activity | Task Rate | |
|---|---|---|
| Preparation of access road | 20-60 m/worker-day | |
| Clearing bush | 200-600 m²/worker-day | |
| Excavating overburden + loading on wheelbarrow | 2-4 m³/worker-day | |
| Excavation loose gravel | 2.5-3.5 m³/worker-day | |
| Excavation hard gravel | 1.5-2.0 m³/worker-day | |
| Excavation gravel with oversize | 1-1.2.0 m³/worker-day | |
| Excavation very hard gravel with much oversize | 1.0 m³/worker-day | |
| Loading gravel to tractor trailer (3m³ capacity) | 8-10 m³/worker-day | |
| Loading gravel to truck (5m³ capacity ) | 5-8 m³/worker-day | |
| Spreading of gravel | 12 – 15m³/worker-day | |
| Reshaping road | 50-60 m/worker-day | |
| **Hauling by wheelbarrow** | **Quantity** | **No. of trips/day** |
| 0-40 m | 10.5 m³/worker-day | 210 |
| 40-60 m | 8.0 m³/worker-day | 160 |
| 60-80 m | 6.5 m³/worker-day | 130 |
| 80-100 m | 5.5 m³/worker-day | 110 |

*Source: ILO, Road construction and upgrading (ROCAU)*

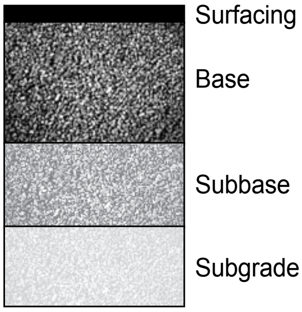
***Note:*** *Use the rates as a guideline only and develop your own set of rates.*

# SECTION 5: PAVEMENT LAYERS

## 5.1 PAVEMENT TYPES

When discussing road pavements, it is common to distinguish between flexible and rigid pavements. The pavements of engineered gravel roads and bituminous roads are commonly referred to as "flexible" while concrete pavements are referred to as "rigid". This section focuses on flexible pavements, as they represent the dominant pavement type for low-volume roads.

The following terms are used for the components of a flexible pavement:




**Surfacing:** The uppermost layer of the pavement is termed surfacing. The main purpose of the surface course is to provide a watertight seal which protects the layers below and is strong enough to resist the abrasive wear caused by traffic. It normally consists of a bituminous surface dressing or a layer of premixed bituminous material as shown in Figure 5-1.

**Road base:** This constitutes the main load-bearing layer of the pavement. It normally consists of crushed stone or gravel, or of gravelly soils, decomposed rock, sands, and sand-clays stabilised with cement, lime or bitumen.

**Figure 5-1: Structure of a flexible pavement**

**Sub-base:** The layer immediately underlying the road base is called the sub-base which acts as a secondary load-spreading layer. It normally consists of a material of lower quality than that used in the road base such as unprocessed natural gravel, gravel-sand, or a gravel-sand-clay mix. From design considerations, this layer may not be required for low-volume roads especially where good subgrades exist. Otherwise, it may serve as a separating layer preventing contamination of the road base by a low strength subgrade material and, under wet conditions; it has an important role to play in protecting the subgrade from damage by construction traffic.

**Subgrade:** This is the upper layer of the natural soil, normally consisting of undisturbed local material, or soils excavated elsewhere and placed as a fill. In both cases it is compacted during construction to give added strength.

## 5.2 PAVEMENT MATERIAL SELECTION

The design[17] of the sub-base and base courses on low-volume roads have traditionally been done on the basis of importing materials from identified borrow pits without any serious consideration of the suitability of the in-situ materials within the immediate road reserve.

### 5.2.1 Minimum specifications

The base course in the road pavement needs to be built of material of a certain minimum strength. For low volume sealed roads with traffic levels up to 500 vehicles per day, the appropriate range for the CBR strength for a base course is from 15% to 45% and above (soaked CBR), with a (P.I) between 6 to 12, provided that appropriate drainage is provided. Experience shows that the grading[18] of the base material is of minor importance in relation to its strength.

### 5.2.2 In-situ material

On most low volume sealed road construction sites, materials hauled over long distances from borrow pits for base/sub-base formation are often almost of the same (if not inferior) quality to spoiled in-situ material within

[17] Other pavement design analyses including traffic, climatic, and material characteristics are not covered in this guideline.

[18] Grading is a way of classifying a soil by determining its grain size distribution. This is done through sieving the soil sample through a set of sieves kept one over the other, the largest size sieve being kept at the top and the smallest size at the bottom. The soil retained on each sieve is weighed and expressed as a percentage of the total weight of the sample.

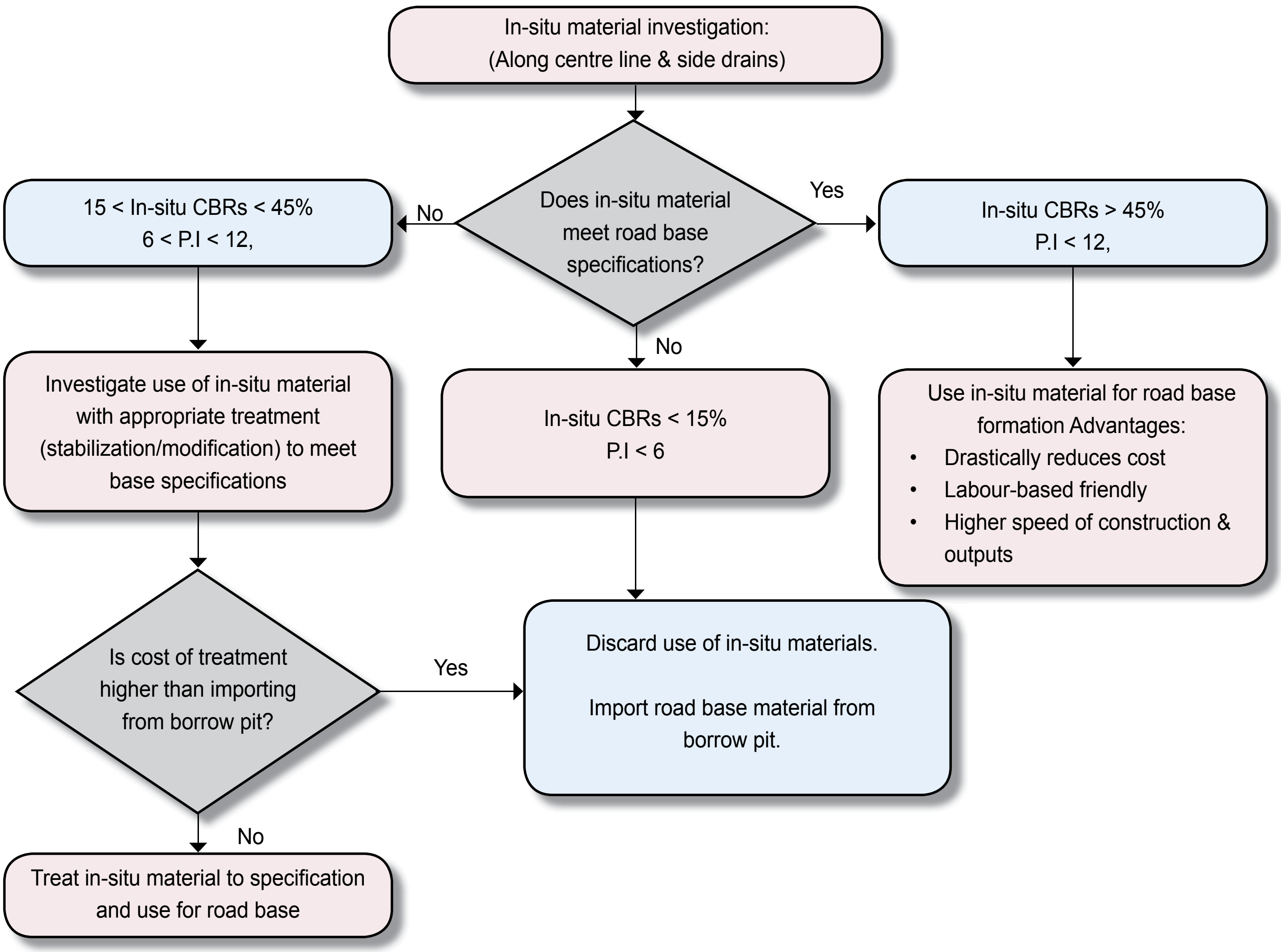
some sections of the road formation. This happens when design engineers do not take the pains to prospect for new suitable material along the alignment but rely on existing borrow pits with sometimes very long haulage distances. This unnecessarily increases the cost of the road due to the excessive material haulage. Pavement costs can be significantly reduced when more efforts are made during design to investigate the use of locally available materials.

It is therefore useful to start pavement material investigations and design of low-volume roads by determining the strength and other characteristics of the in-situ soils. If by chance the local soils are of insufficient strength it is worthwhile considering possible improving the material through mechanical or chemical stabilization to meet the minimum design specifications thus reducing the need to import foreign material with the benefits of:

- Significant project cost savings (up to 20%) on transport cost, depending on the haul distance.
- Avoiding potentially useful material being excavated to spoil and thereby reducing project costs.
- Increased progress as adequate road-building material is found next to the road, leading to earlier works completion and additional savings.
- Feasibility of using labour-based work methods for the excavation and placing of sub-base/base thus increasing the labour content of the project.
- Limiting environmental degradation caused by opening large borrow pits

The flow chart below illustrates the steps to be followed for cost-efficient pavement material selection for low-volume sealed roads.

**Chart 5-1: flowchart for pavement materials selection and design**



### 5.2.3 Imported material

It is only in cases with very poor in-situ materials (CBR < 15%) and where treatment of such soils is very expensive, that materials need to be imported. The final design decision to import material or improve in-situ soils should therefore be informed by a detailed cost assessment of the in-situ treatment as against the cost of borrow in terms of haulage distances, material quantities, extent of overburden to be removed and the feasibility of excavating materials using labour-based work methods.

## 5.3 CENTRE LINE SURVEY

The quickest and most economical means of establishing the bearing capacity of the in-situ material along the road alignment is by means of the Dynamic Cone Penetration (DCP) test.

DCP tests should be carried out in the middle of the wet season or just at the end of the wet season. This will give a safety factor in the design.

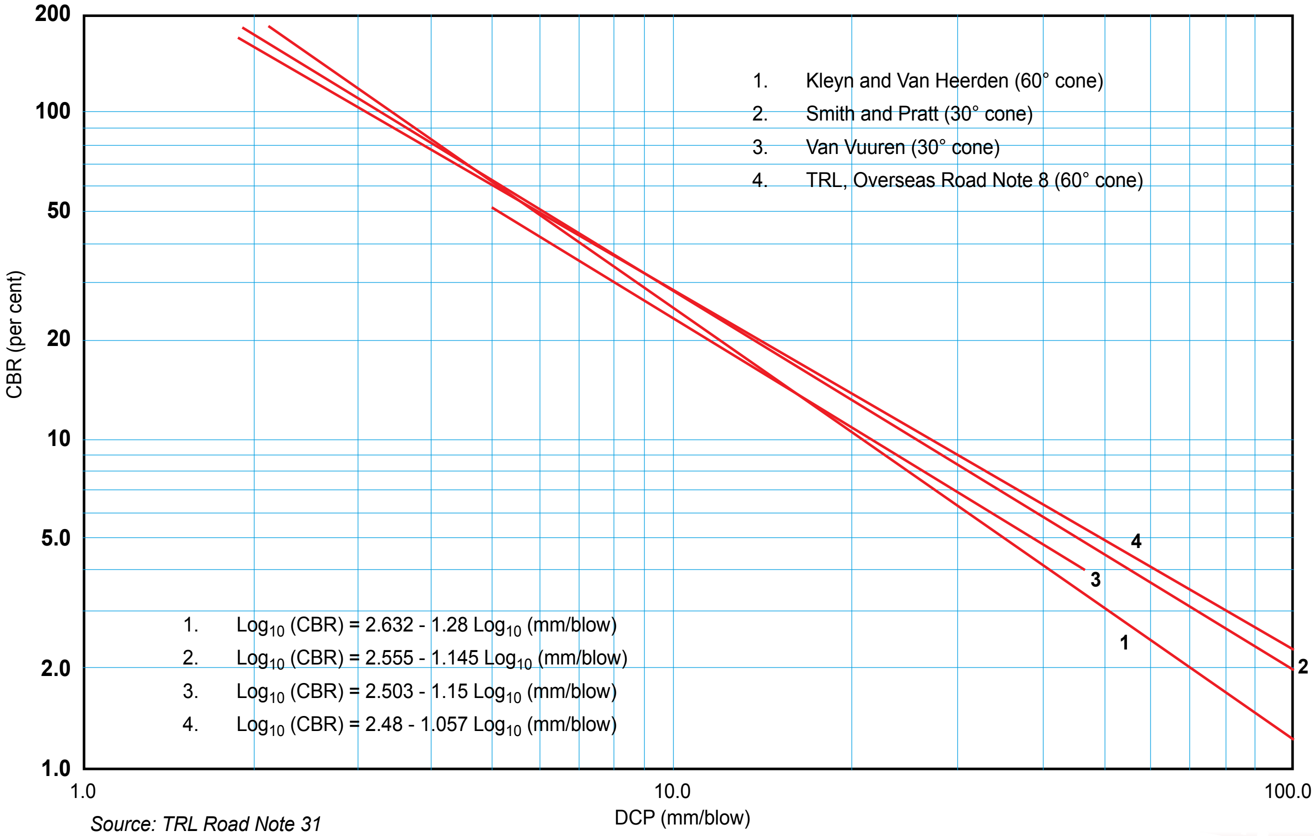
It is recommended that DCP tests are carried out at 50 metres intervals along the route at three points, the centreline, and at each of the road shoulders. In the case of short lengths of road/street it is useful to perform at least three tests on every 80 – 100 metres. Continuous DCP measurements can be made to a depth of 800 mm or to 1200 mm when an extension rod is fitted.

It is recommended that other field tests, such as soil plasticity and grading are also done at the selected points.

**DCP Testing**

The DCP tests can be used to establish the CBR for in-situ materials along the alignment of either an existing or new road. Chart 5-2 below can be used to determine the CBRs.

**Chart 5-2: Correlation between DCP and CBR**




*Source: TRL Road Note 31*

It is however, advisable to do full laboratory CBR tests on selected samples from the test points to verify the results of the DCP tests.

## 5.4 CONSTRUCTION OF BASE LAYER USING IN-SITU MATERIALS

### 5.4.1 Subgrade formation to camber

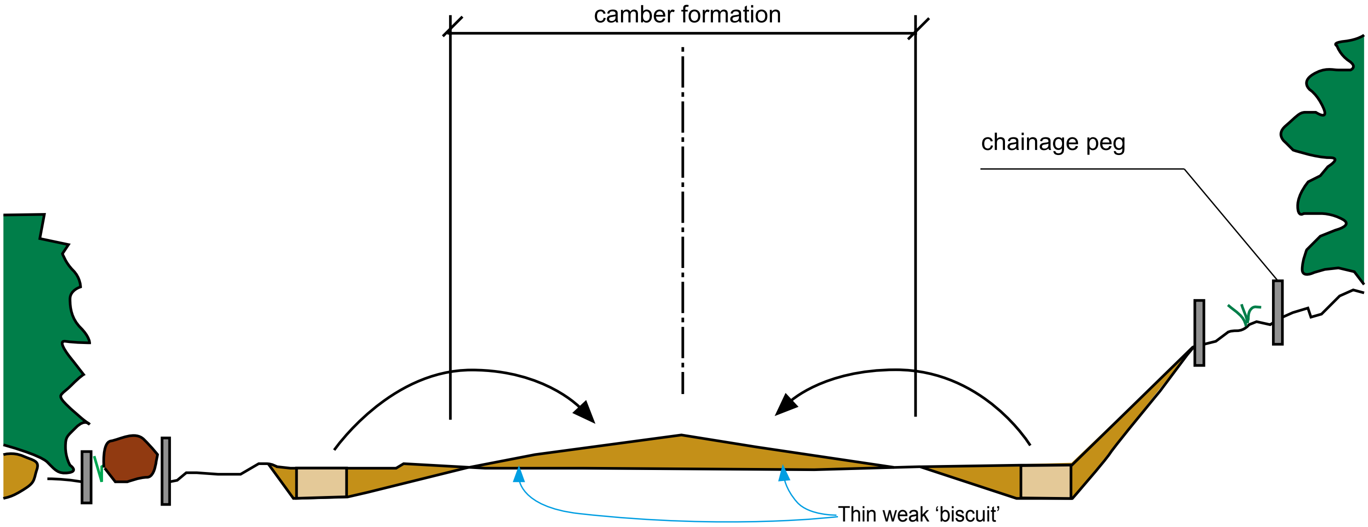



**Figure 5-2: Unpaved road camber formation**

Unlike the steps involved in constructing the camber on unpaved gravel roads, as shown in Figure 5-2, where excavation is done to a level platform before constructing a triangular "roof-shape" camber, for sealed roads, the subgrade should be constructed in one-go to the required camber slopes. This eliminates the creation of a thin 'biscuit' at the edges of the formed camber. The steps for subgrade formation on sealed roads are illustrated below:

i. Select control points over a given section of the road alignment and establish the correct levels that result in a balance of materials within each cross section.
ii. Set the centre line profile level to a height difference (based on the camber slope) from the profile levels on the left and right side shoulders to create an excavated finished subgrade bed with the desired camber over the formation width from the centre line. For low-volume sealed roads, the recommended camber should be in the range of 2.5 – 3.5%.
iii. Ensure that spreading to the required level is achieved by first cutting humps to fill all depressions. and compacting in uniform layers.
iv. Excavate approved material from the sides and place it on each side of the centre line. Increase the width of the cut if more material is required. If the material is dry, make a hole at the top of the heap and add water. Let the water seep in overnight.
v. Carefully add additional water if necessary in order to achieve optimal moisture content (OMC) while spreading and levelling the material to the required camber slope. Once levelled, the surface is compacted to refusal while still maintaining the correct shape of the camber

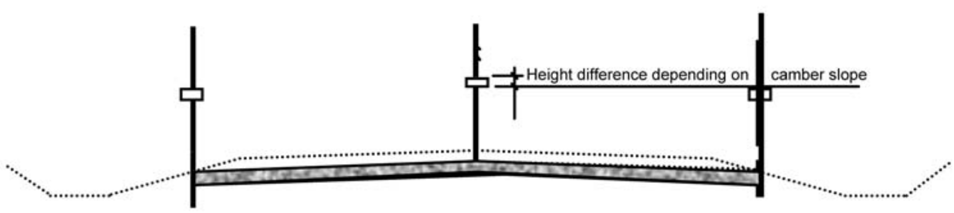
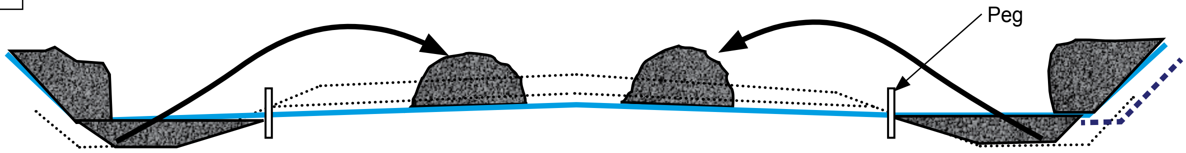



**Figure 5-3: Paved road camber formation**

### 5.4.2 Steps in in-situ base layer construction

If the in-situ soils are found to meet the specifications for base layer construction, the following steps can be followed in constructing the un-stabilized base layer using excavated material from the side drains.

1



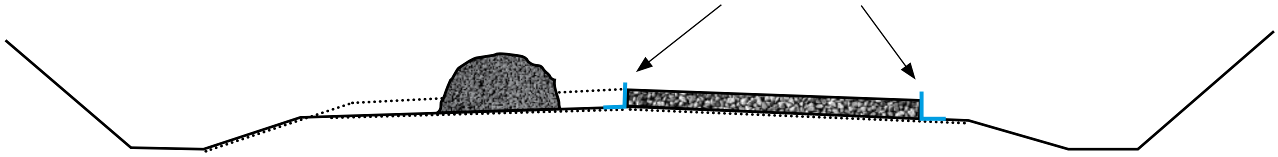

vi. Excavate approved material from side drains and windrow or heap it between the shoulder pegs. Increase the width of the cut if more material is required
vii. If the material is dry, make a hole at top of windrow or heap and add water. Let water seep in overnight.

***Note:*** *If the material from the side drains is not good (unapproved), it can be stabilized before use. If it cannot be stabilized, it should be thrown to spoil at a safe location and replaced with approved material imported from elsewhere.*

viii. Place shutters in the longitudinal direction, the first set along the centreline and another set along one edge of the base width, with the top of the shutters high enough to allow for the bulking of the base layer to attain the desired compacted thickness layer (say 150mm). It is advisable to construct one half of the width of the base at the time.
ix. Add additional water if necessary and mix at the optimal moisture content. Then spread the material between the shutters, screed off and compact to refusal.

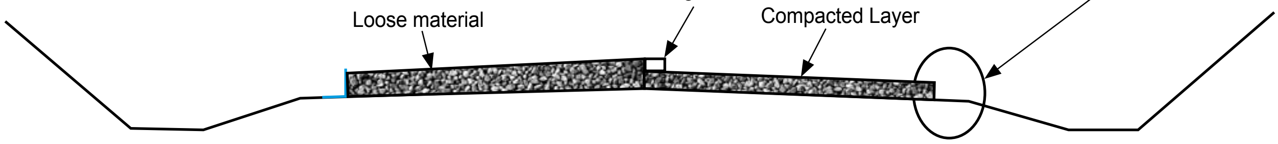
Ensure that the workers do not walk/step on the loose base layer to prevent differential compaction.

2



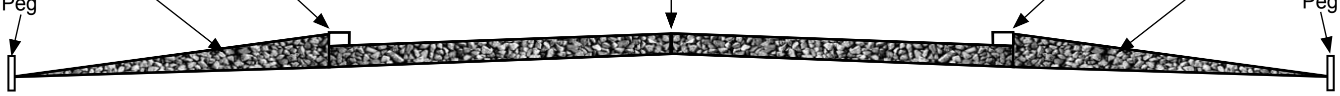

x. Remove the centre line shutters, place shutters on the edge of the other half width, and spread material to a height of 50mm above the compacted section (use a 50mm guard rail ). Then compact to refusal which will compress this section to the same level as the first compacted width.

3




xi. For cladding of the edge of the compacted base layer, place pegs and string line at shoulder breakpoint.
xii. Place loose material to a height of 50mm above the compacted layer (using a 50mm guard rail) and compact to the required slope.

4



The photos below further illustrate all the above steps.

**Setting out of Steel Shutters to retain Base Layer**

**Use of screed board to level spread Base Layer**

**Spread and Compacted Base layer**

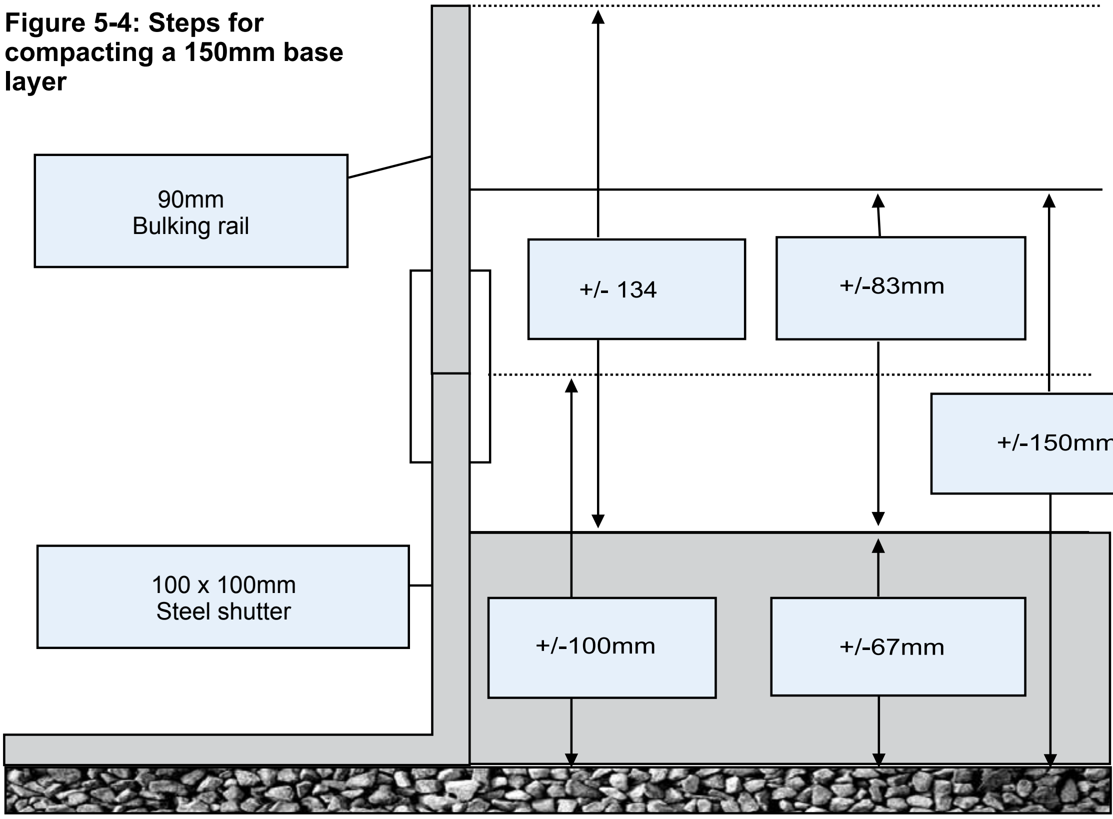
**Edge Cladding of Based Layer**

### 5.4.3 Constructing a 150mm base course layer

If the pavement is designed with a 150mm thick compacted base course, the layer is too thick to be compacted in a single layer using a 900 kg pedestrian vibratory roller as described above. Still using shutters and bulking rails, the base course should then be constructed in a two-step procedure, as follows:

1) Correct the sub-base/subgrade to within an accuracy of +/-10mm of the design levels.
2) Moisten and scarify using rakes, the surface of the sub-base/subgrade to obtain good bonding with the base course.
3) Mix base course material to OMC, fill loose material and screed off to the top of the 100mm x 100mm steel shutter base section. Compact the material to refusal. This will produce a first layer with a compacted thickness of approximately 67mm.
4) Scarify the surface to obtain good bonding with the next layer.
5) Place a 90mm bulking rail on top of the 100mm x 100mm base section. Mix the second layer of base course material to OMC, place the loose material and screed off to the top of the bulking rail. Once again, compact the material to refusal. This will give a second compacted layer of roughly 83 mm thickness and a total thickness of the two compacted layers at 150mm. Figure 5-4 below illustrates the steps described above.

**Figure 5-4: Steps for compacting a 150mm base layer**



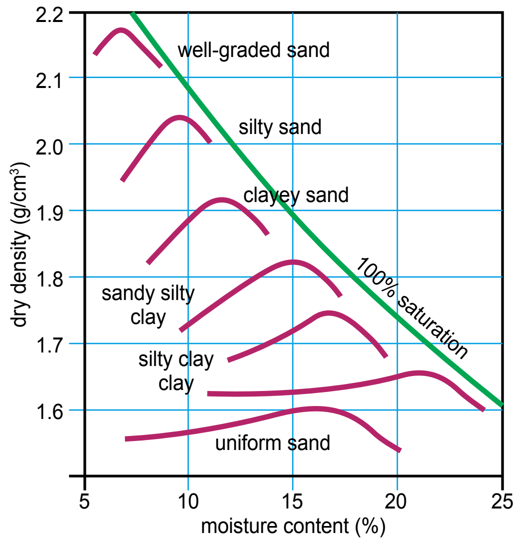

### 5.4.4 Constructing 120 mm base course layers

This layer is also too thick to be compacted in one single operation. Instead, follow the steps above, but replace the 90mm bulking rail with a 50mm rail.

## 5.5 COMPACTION OF LAYERS

### 5.5.1 Moisture density relationships

**Chart 5-3: Moisture content – dry density**




When subjected to dynamic compaction, practically all soils exhibit a similar relationship between moisture content and density (dry unit weight). Every soil has an optimum moisture content at which point the soil attains the maximum density under a given compactive effort. This fact as depicted in Chart 5-3 forms the basis for the modern construction process commonly used in the formation of road pavements and embankments, earth dams, levees and similar structures.

In the laboratory, the compaction is simulated by the use of a freely falling weight impinging on a confined soil mass. In road construction, compaction is secured through the use of rollers or vibratory compactors applied to relatively thin layers of soil. In the field an attempt is usually made to maintain the soil at an optimum moisture and bring the soil to maximum density or some specified percentage thereof. In the laboratory, compaction tests are usually performed using the "standard Proctor" or "standard AASHTO" methods (T99). The optimum moisture and maximum density are usually found in the laboratory by a series of determinations of wet unit weight and the corresponding moisture content. After the moisture content determinations are completed, the dry unit weights may be calculated and plotted. Different soils react differently to compaction at moisture contents that are less than optimum. The moisture content is less critical for heavy clays than for the less plastic sandy and silty soils. Clays may be compacted through a relatively wide range of moisture contents below optimum with comparatively small changes in dry density. On the other hand, the granular soils that have better grading and higher densities under the same compactive effort react sharply to small changes in moisture content, with significant changes in dry density. Relatively clean, poorly graded and non-plastic sands are also relatively insensitive to changes in moisture. Other factors such as the content of coarse aggregate also influence the results of compaction tests.

Compaction rollers are classified by weight and commonly used ones are smoothed- wheeled rollers for compacting earthworks and surfacing. Sheep's foot rollers are used for compacting cohesive soils of large fills. Pneumatic-tyred rollers are useful for compacting sandy soils and the final rolling of bituminous road surfacing. Vibratory rollers are useful for deep compaction of granular soils whilst tamping equipment like hand rammers, drop hammers, pneumatic tampers and vibratory compacting units are used for non-cohesive soils in locations which are in-accessible to conventional rollers.

## 5.6 IMPROVING IN-SITU MATERIALS FOR BASE COURSES

### 5.6.1 Mechanics of soil stabilization

Soil stabilization is a process which brings about the improvement in the performance of a soil for its use as a building material. The purpose is to improve the stability and load bearing capacity of the soil. These changes are brought about through controlled proportioning, compaction and/or the addition of a suitable stabilizer or admixture. The following processes describe the basic principles of soil-stabilization:

a) Evaluation of the properties of the available soil;
b) Assessing the lacking properties of the soil;
c) Devising a suitable method of adding the lacking properties through economical methods of stabilization;
d) Compacting the improved soil.

Soil stabilization may bring any one or more of the following changes:

- Chemical properties may get modified (Stabilization);
- Physical properties such as density, expansion, shrinkage and stability may be changed (Modification);
- Retention of some minimum strength properties due to water proofing measures.

The three most common ways of improving the strength of in-situ materials are mechanical stabilization, chemical stabilization and bitumen stabilization. Each of these is briefly described below.

### 5.6.2 Mechanical stabilization

This is the process of carefully proportioning and mixing two or more soil types and compacting the resulting mixture to obtain a stable layer. For example, properties of granular soils having negligible fines are improved if mixed with fine soils like clay, resulting in increased stability and strength. Similarly, the stability and strength of clayey soil can be improved by adding a proportion of granular material. The following are the factors which affect stability of mechanically stabilized layers:

- Proper proportioning of the mix, i.e. gradation;
- Strength of the aggregates;
- Properties of the soils to be mixed;
- Presence of harmful ingredients in the soil or aggregates;
- Quality of compaction.

### 5.6.3 Chemical stabilization

The use of chemical stabilizers to improve in-situ or imported materials is a possible alternative. The main objective of chemical stabilisation is to enhance the suitability of locally available natural gravels for pavement construction, thereby avoiding the need to import other materials. This can often lead to more cost-effective use of available materials with the following beneficial properties by comparison with the untreated parent material:

- increased strength or stability
- improved load-spreading capability
- increased resistance to erosion
- reduced sensitivity to moisture changes
- improved workability of clayey materials

The choice of chemical stabiliser[19] depends on the material to be stabilised and the position it is to occupy in the road pavement. These stabilisers are generally applied at relatively low dosages, typically between 3 and 6 per cent. However, if problems are to be avoided, they must be subjected to careful and well-controlled processing and construction. The suitability of any particular stabilizer to treat the materials available on a specific road works project needs to be assessed through laboratory tests.

The optimal application depends on the type of soils with obvious cost variations. Each material needs to be assessed individually and the need for and appropriate type of surfacing would also need to be investigated.

**Cement and Lime Stabilization**

While cement is particularly effective in stabilizing medium to low plasticity materials, lime is more effective for materials with sufficient amount of clay with a P.I in excess of 10. Both actions reduce the P.I and increase the material strength. For example, the addition of 2 to 10 percent cement to an in-situ soil can increase its Unconfined Compressive Strength (UCS) from 0.5 to 3.5MPa at 100% Mod. AASHTO. It is not unusual for the swell to be reduced from 7 or 8 per cent to 0.1 per cent by the addition of lime. The ion exchange reaction occurs quickly and can increase the CBR of clayey materials by a factor of two or three.

**Criteria for Chemical Selection**

When chemical stabilization or modification of in-situ soils is considered as the most economical or feasible alternate, the selection of the stabiliser is based on the plasticity and particle size distribution of the material to be treated. The appropriate stabiliser can be selected according to the criteria shown in Table 5-1.

**Table 5-1: Criteria for determining the type of stabilizer**

| Stabilizer Type | Type of Stabilization | | | | | |
|---|---|---|---|---|---|---|
| | More than 25% passing 0.075mm sieve | | | Less than 25% passing 0.075mm sieve | | |
| | PI ≤ 10 | 10 < PI ≤ 20 | PI > 20 | PI ≤ 6 PP[20] ≤ 60 | PI ≤ 10 | PI > 10 |
| Cement | Yes | Yes | 0 | Yes | Yes | Yes |
| Lime[21] | 0 | Yes | Yes | No | 0 | Yes |

*Source: TRL Road Note 31*

Table 5.2 provides the desirable properties of soil materials before and after stabilization.

[19] Chemical stabilizers in this context include both proprietary soil stabilizers and conventional lime or cement-based materials.

[20] Plastic Product (P.P) = plasticity index (P.I) x percentage passing the 0.425mm sieve.

[21] Lime in the form of quicklime (calcium oxide), hydrated lime (calcium hydroxide), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix.

**Table 5-2: Desirable properties of material before and after stabilization**

| Desirable Properties of Material before Stabilization | | | |
|---|---|---|---|
| **BS Test sieve (mm)** | **Percentage by Mass of Total Aggregate passing test sieve** | | |
| | **Crushed stone** | **Crushed stone or gravel** | **Gravel subbase** |
| 53 | 100 | 100 | - |
| 37.5 | 85-100 | 80-100 | - |
| 20 | 60-90 | 55-90 | - |
| 5 | 30-65 | 25-65 | - |
| 2 | 20-50 | 15-50 | - |
| 0.425 | 10-30 | 10-30 | - |
| 0.075 | 5-15 | 5-15 | - |
| Liquid Limit (LL) | 25 | 30 | - |
| Plasticity Index (P.I) | 6 | 5 | 20 |
| Limit of Shrinkage (LS) | 3 | 5 | - |
| **Recommend Properties after Stabilization** | | | |
| Unconfined Compressive Stress (UCS) (MPa) at 7 days; 100% Mod. AASHTO density | 3.0 - 6.0 | 1.5 - 3.0 | 0.75 - 1.5 |
| Unconfined Compressive Stress (UCS) (MPa) at 7 days; 97% Mod. AASHTO density | 2.0 -4.0 | 1.0 - 2.0 | 0.5 - 1.0 |
| Plasticity Index (P.I) | 4 | 4 | 6 |

*Source: Technical Recommendation for Highways (TRH 13); South Africa*

**Construction - Mixing and placing**
The required amount of lime or cement should be thoroughly mixed with the dry soil in small batches, ensuring a uniform consistency before adding the required water. The mixture should then be laid using shutters to ensure that the required base thickness (loose) is achieved. Walking/stepping on the loose base layer should be avoided to prevent uneven compaction. Hand gloves, nose masks, gum boots, and other protective clothing should be provided to workers.

**Curing**
Proper curing is important for three reasons:
- It ensures that sufficient moisture is retained in the layer so that the stabiliser can continue to hydrate.
- It reduces shrinkage.
- It reduces the risk of carbonation from the top of the layer.

In a hot and dry climate the prevention of moisture loss is difficult so the curing process needs careful attention. If the surface is sprayed constantly and kept damp day and night, the moisture content in the main portion of the layer will remain stable but the operation is likely to leach stabiliser from the top portion of the layer. Also if the spraying operation is intermittent, the surface dries up (a common occurrence when this method is used), resulting in the curing becoming completely ineffective. Therefore it is very important to always cover the un-compacted layer with plastic polythene to prevent moisture loss before compaction.
*(**Caution:** It is also advisable to immediately prime the finished compacted section to prevent moisture loss).*

**Compaction**
A stabilised layer should be compacted as soon as possible after mixing has been completed in order that the full strength potential can be realised and the density can be achieved without over-stressing the material. If the layer is over-stressed, shear planes are formed near the top of the layer and premature failure along this plane is likely, particularly when the layer is only covered by a surface dressing.

**Control of shrinkage and deflection cracks**

There is no simple method of preventing shrinkage cracks occurring in stabilised layers. However, design and construction techniques can be adopted which go some way to alleviating the problem. Shrinkage, particularly in cement-stabilised materials, has been known to be influenced by:

- Loss of water, particularly during the initial curing period.
- Cement content.
- Density of the compacted material.
- Method of compaction.
- Pre-treatment moisture content of the material to be stabilised.

Proper curing is essential not only for maintaining the hydration action but also to reduce volume changes within the layer. A longer initial period of moist curing will result in less shrinkage when the layer subsequently dries. When the layer eventually dries, the increased strength associated with high stabiliser content will cause the shrinkage cracks to form at increased spacing and have substantial width. With lower cement contents, the shrinkage cracks occur at reduced spacing and the material will crack more readily under traffic because of its reduced strength. The probability of these finer cracks reflecting through the surfacing is reduced, but the stabilised layer itself will be both weaker and less durable. In order to maximise both the strength and durability of the pavement layer the material is compacted to the maximum density possible. However, for some stabilised materials it is sometimes difficult to achieve normal compaction standards and any increase in compactive effort to achieve this may have the adverse effect of causing shear planes in the surface of the layer or increasing the subsequent shrinkage of the material as its density is increased. If it proves difficult to achieve the target density, higher stabiliser content should be considered in order to produce an adequately strong and durable layer at a lower density.

**Effects of carbonation**

Lime- and, to a lesser degree, cement-stabilized soils, can lose strength through carbonation. This effect is particularly evident in lime-stabilised fine-grained, relatively weak soils (especially calcretes). When used as base course material, prolonged exposure of these stabilised soils to the air before sealing can also result in a weak upper layer being produced prior to surfacing. Subsequent crushing of the aggregate as well as poor bonding between the surface and the base can occur, leading to pavement failure.

Measures that ameliorate the effects of carbonation during the stabilisation process include:

- Immediate covering with the next layer of material
- Immediate application of a bitumen prime coat
- Full moist curing (with no drying of the surface)
- Constructing a layer with a sacrificial thickness to be bladed off

**Opening to traffic.**

Insufficient research has been carried out to determine the precise effects of opening a road base to traffic before the completion of the curing period but it is considered that allowing traffic on the pavement during the first two days can be beneficial for some stabilised layers provided the traffic does not mark the surface and all traffic is kept off the pavement from the end of the second day until one week has elapsed (Williams (1986)). Early trafficking has a similar effect to that of pre-cracking the layer by rolling within a day or two of its construction but rolling is preferred because it ensures even coverage of the full width of the carriageway.

The photos below illustrate lime stabilization carried out using labour-based methods.

**Lime stabilization in practice**

**Use of plastic cover to prevent moisture loss**

**Compacted stabilized base**

## 5.6.4 Bitumen stabilization of in-situ materials

Another effective stabilization method is to treat in-situ materials with bitumen and surface the base layer with a low-volume seal (Otta, cold mix asphalt, etc.) described in later sections of this Guideline. An appropriate means of preparing such a base layer using labour-based work methods would be to use bitumen emulsion, mixed alongside the road, typically in concrete mixers, tray pans or on a clean platform.

It is important, however, that the treated material achieves the required structural properties for a base course (minimum CBR of 45 to 80 per cent) with an economical quantity of emulsion. For this reason, the locally available soils intended for this use should first be tested in a laboratory.

A wide range of materials can be treated with bitumen emulsion. The optimum binder content depends on the actual properties of the base material and needs to be investigated individually.

Bitumen stabilization trials have shown that the application of 1 – 2% bitumen emulsion can improve natural soils with 15% CBR and 140kPa Unconfined Compressive Strength (UCS) to above 45% and 2000kPa respectively. High strength sandy materials may only require a surface spray of diluted emulsion to provide the necessary strength. In these cases no prime would be necessary and a seal can be placed directly on the treated surface. However it is recommended that where laboratory facilities exist, tests and trials are conducted on the local soils to verify the appropriate bitumen content in order to achieve the desired minimum strength.

### 5.6.5 Emulsion Treated Base (ETB)

Emulsion Treated Bases are commonly made from in-situ or reclaimed gravels (often of insufficient quality for use as a base course) treated with a small percentage of bitumen emulsion[22] to increase the strength of the base course. Usually, less than 2.5% of emulsion is added to the material but again this depends on the quality of the parent material.

#### 5.6.5.1 Advantages of ETB

The addition of bitumen emulsion to in-situ or reclaimed gravels offers the following advantages:

- The use of local material obviates the need to import suitable base course material from quarries located far away from the construction site. Adding small percentages of emulsion to locally available soils can be an effective alternative solution from the point of view of costs.
- ETBs are particularly suitable for labour-based road works, not only because the technique lends itself to the construction of a quality base using labour and light equipment, but the completed base course can be opened to traffic for an extended period without untoward damage to the surface. This is an advantage as pavement works using labour-based methods normally proceed more slowly than is the case with conventional methods often resulting in the need to manage traffic away from partially finished road sections for longer periods of time. This is also a common feature for bases stabilised with cement or lime.
- Emulsion reduces the internal friction of the gravel materials during construction, thus improving its compacted density and workability.
- It reduces water susceptibility and improves cohesion by binding fine aggregate,
- The addition of a fairly small amount of emulsion can significantly increase the CBR and Unconfined Compressive Strength (UCS) of the material,
- The strength and stiffness of ETBs are similar to those of lightly cemented materials,
- Rutting of the base course can be reduced significantly when opened to traffic prior to sealing,
- The cohesiveness of an ETB limits the development of potholes in the base when the surfacing is damaged,
- By enriching the upper layer of the ETB during construction, usually eliminates the need for priming,
- When using crushed stone aggregate as a base, the risk of segregation of the aggregate matrix is reduced during construction,
- It allows the layer to be trafficked sooner than most other base layers – as soon as the emulsion has broken and no pick-up is evident under traffic,
- The use of emulsions results in savings in fuel consumption required for heating as emulsions are applied at ambient temperatures (cold mix),
- Gravels do not need to be dried, as emulsions adhere readily to damp aggregate,
- It is usually possible to core ETBs and to recover complete cores, which facilitates easy and speedy testing for quality control purposes.

#### 5.6.5.2 Material components

As a guideline the following materials may be considered for use in an ETB:

**Cement**
A small percentage of cement (1 - 1.5%) is added to assist with the breaking of the emulsion as it acts as a catalyst. Cement increases early strength of the ETB when the layer needs to be opened to traffic.

**Lime**
If the soils have a high plasticity (P.I > 6), it is advisable to add lime to the material to reduce the P.I. The effect of the lime on the material must be established, with emulsion added.

[22] Bitumen emulsion is made up of minute droplets of bitumen suspended in water. The bitumen, in emulsified form, can be easily mixed with aggregates after which the bitumen adheres to the aggregates, and the water evaporates.

### Emulsion

The emulsion to be used must be an anionic[23] stable grade 60% emulsion. Normally the emulsion will be supplied in 210 litre drums.

### Natural gravel

ETBs can be produced from a variety of natural gravels, including:
- Decomposed granites (may require lime)
- Decomposed dolerites (may require lime)
- Decomposed basalts
- Quartzitic gravels
- Laterite/ferricrete gravels
- Chert gravels
- Sandstone gravels
- Calcretes

Sometimes only fine grained sands are available. By adding 15% to 20% of 6.7 or 9.5mm crushed aggregate to this fine material, substantial improvement of bearing qualities can be obtained.

The following sections describe the preparatory work, materials, plant and equipment and construction process for the construction of an emulsion stabilised base course.

It comprises:
- Emulsion treated base course (ETB), 100mm thick
- Composite gravel and ETB base course, 100mm thick

### Design Process

The design process for materials treated with small percentages of emulsion (less than 3%) is based on the following procedure:
- Characterisation of materials to be used in ETBs;
- Determination of the optimum fluid[24] content;
- Preparation of test samples, in which the amount of residual bitumen varies from 0 - 2% in increments of 0.5%, but where the optimum fluid content (hydroscopic water, emulsion and compaction water) remains unchanged;
- Compaction in accordance with the standard modified AASHTO method at room temperature;
- Curing of samples (24 hours at ambient temperature followed by 48 hours' oven curing at 40°C if the optimum moisture content is less than 8%, or 45 hours at 60°C if the optimum moisture content is greater than 8%);
- Determination of CBR and UCS after 4 days and 6 hours soaking, respectively; and
- Determination of optimum residual bitumen content.

For some materials such as dolerites with a P.I of, say, 3 to 4, but which may contain clays, it is recommended that lime be added to the material. In order to quantify the presence of such clays, the P.I test should be conducted on material passing the 0.075mm sieve.

***Note:*** *Before any local soil materials are used, it is recommended that a reputable materials laboratory carries out tests based on standard methods for testing ETB.*[25]

Chart 5-4 below can also be used to check if a 100mm Emulsion Treated Base (ETB) will be adequate as a base layer on a well-shaped and compacted subgrade. From Chart 5-4, the in-situ field CBR of the subgrade/sub-base must not be less than 40 to be able to place the 100mm ETB on a shaped subgrade/sub-base, otherwise the appropriate imported soil cover layer as per the chart must be provided.

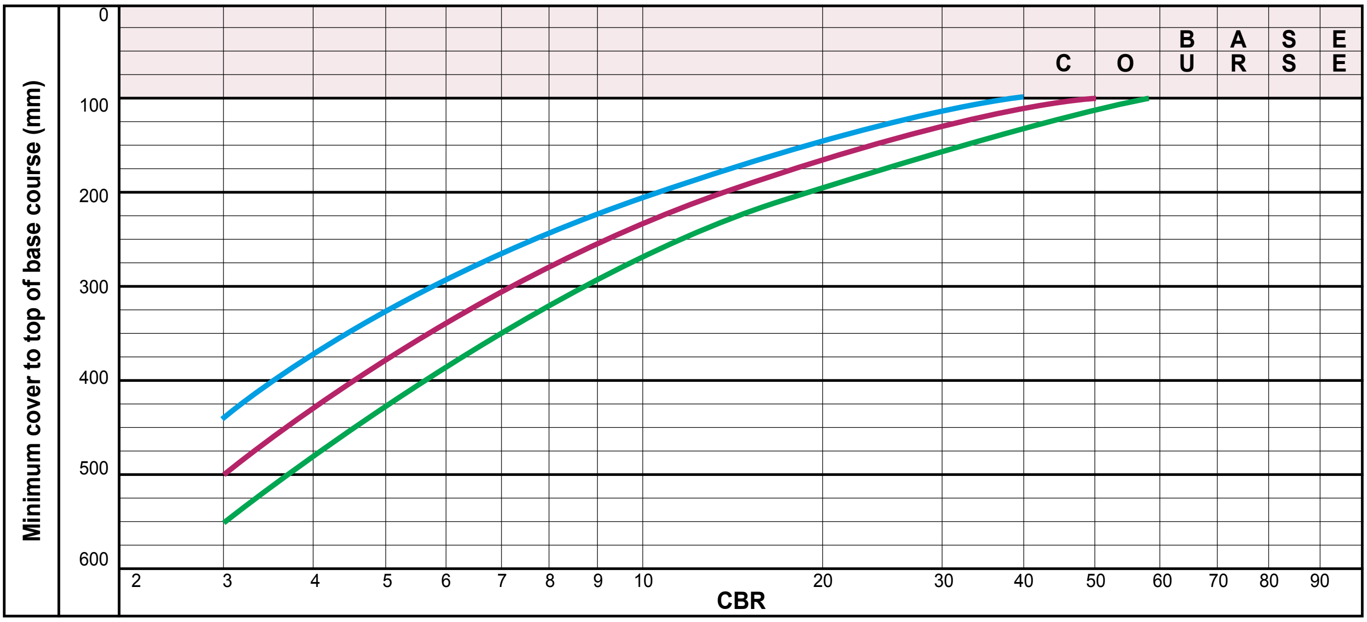
---

[23] An anionic emulsion is more appropriate and very absorptive for dusty aggregates as compared to cationic emulsions.

[24] Fluid content is the total quantity of fluid in the mix, including hygroscopic moisture, the bitumen and water within the emulsion and moisture added for compaction. The optimum fluid content for a specific compactive effort is the fluid content at which the maximum density is obtained.

[25] In South Africa, an appropriate testing method is provided in the South African Bitumen Association (SABITA) Manual 21, 1999.

**Chart 5-4: CBR curves for Emulsion Treated Base**




**Legend:** 7000 pound wheel load — 9000 pound wheel load — 12 000 pound wheel load

## 5.6.6 Construction of ETB

### 5.6.6.1 Specification

The specification may be for the construction of a 100mm Emulsion treated base (say) constructed in accordance with the Specifications as modified to suite labour based construction methods.

### 5.6.6.2 Materials

Materials required for the construction of the ETB are:

- Gravel – approved from in-situ source or gravel pit (quarry)
- 60% Anionic stable grade emulsion (Vinzyl resin emulsifier) decanted from 210 litre drums (Emulsion made with Vinzyl resin as emulsifier has less tendency to settle than other emulsifiers)
- Cement
- Lime (if required to adjust the P.I.)

### 5.6.6.3 Plant, equipment and tools

The following plant and equipment is recommended for the construction of the ETB using labour-based methods:

- Steel framed stand for emulsion drums
- Steel or timber ramps
- Ball valve (75 mm diameter.)
- Measuring containers – 25, 20 and 5 litre (for dry and wet materials) and dipsticks
- Suitably sized concrete mixer (14/10 or 400/300) or steel pans or any clean hard surface.
- Suitably sized vibratory pedestrian roller (750kg to 1.2 tonnes)
- 150 x 100 mm x 6mm thick steel angle formwork (shutters) (3m, 2m and 1m lengths);

**Steel frame stand for decanting emulsion**

- 50 x 2 mm steel spacer plates (3m, 2m and 1 m lengths)
- Steel pegs (cut from 10mm diameter reinforcement bars) for securing formwork
- Steel squeegees
- Screeding boards
- Plastic sheeting
- 1000 litre water tank on pick-up truck or mounted on trailer – with pump
- 210 litre drums for storing water
- 25 litre container with clip-on lid to store left over cement from cement bags

### 5.6.6.4 Construction

The emulsion should be anionic stable grade 60% emulsion (vinzyl resin emulsifier) decanted from 210 litre drums. Before using the drums of emulsion they should be rolled backwards and forwards to ensure that the emulsion is properly mixed, as when stockpiled for any length of time the bitumen in the emulsion tends to settle. Full drums should be stored flat and empty drums upright.

For neat and accurate workmanship place the drums on a steel frame and fit a ball valve to the drum. The ball valve should be soaked and cleaned in paraffin at the end of each shift. Measuring containers with calibrated dipsticks should be available for accurately measuring the required amount of emulsion in each mix.

Formwork for the placing of the ETB should be 150 x 100mm x 6mm thick angle steel and be available in 3, 2, and 1 metre lengths. The shorter lengths should be used for small curves.

It is recommended that the steel formwork conforms to the dimensions and thickness shown in Figure 5-5.

Sufficient quantities of formwork should be available for a full day of work.

(One 400/300 concrete mixer or steel pans or any clean hard surface and approximately 30m length of formwork is required for one construction unit).

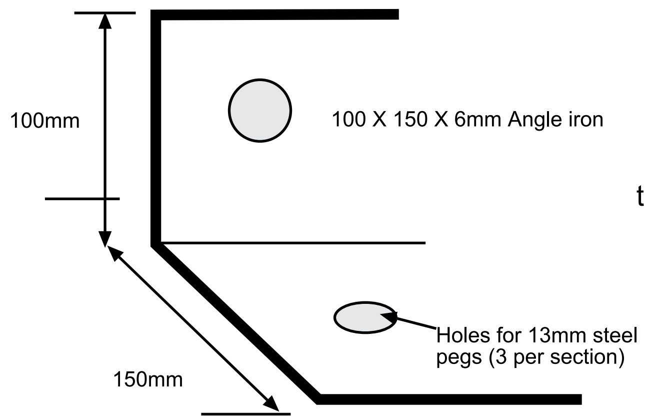



**Figure 5-5: Steel Shutter formwork**

### 5.6.6.5 Construction process

**Tolerances**

In view of the relatively thin surfacing being placed, the ETB base should be constructed to levels to accommodate the surface within 6mm of designed level.

**Placing steel side forms**

In placing and fixing the formwork, care must be taken to ensure that no bumps are built into the surface and that a smooth vertical and horizontal alignment is obtained.

The vertical and horizontal alignment should be carefully checked to ensure that the formwork is firmly and correctly placed before placing the ETB material.

Once the side forms have been placed, the levels must be checked again (using a straight edge and spirit level across the top of the side forms) and the surface trimmed to ensure that the correct thickness of ETB (100mm) is placed. Slacks or depressions in the sub-base will not only result in an increase in the amount of ETB required but also cause differential settlement.

**Work site planning**
It is essential that the delivery and stockpiling of gravel is carefully planned and controlled.
Assume:
- Material is delivered in $5m^3$ trucks
- The base course is being constructed in half width (2.75 meters)
- Layer thickness is 100mm compacted (150mm loose/un-compacted). Then:

Spacing of stockpiles is:
Volume = length x width x thickness (un-compacted/loose)

$$5m^3 = Length \times 2.75m \times 0.150m$$
$$Length\ (Spacing\ of\ Stockpiles) = \frac{5m^3}{2.75 \times 0.15m} = 12m$$

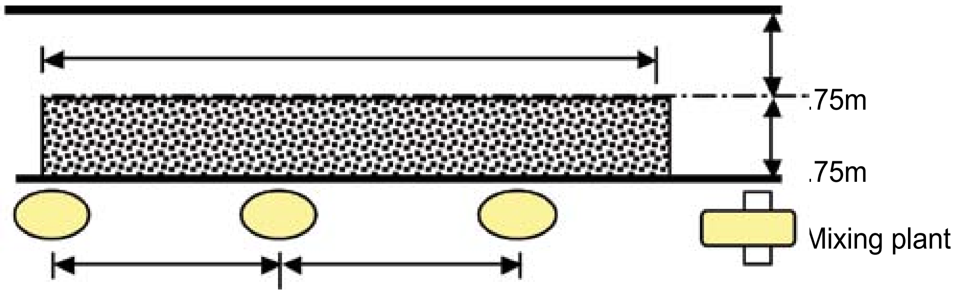



**Figure 5-6 Placing of mixer (work site)**

**Placing the mixing plant**
The mixing plant is placed at a location equivalent to one day's production ahead of the gravel stockpiles (**Figure 5-6**) so that it only needs to be moved every second day.

The following precautions must be observed when handling bitumen emulsion:
- When unloading the drums it is important to avoid dropping them from the delivery truck but instead roll the drums off the truck using steel or timber ramps. This process avoids damaging the drums and prevents premature breaking of the emulsion in the drum.
- When drums are stockpiled for any length of time the bitumen in the emulsion tends to settle to the bottom of the drum. Before emulsion is used, the drums need to be rolled backwards and forwards to ensure that the emulsion is properly mixed. .Note: Full drums must be stored flat and empty drums vertically.
- It is essential for accurate and neat workmanship that the drums are placed on a steel frame and a hand operated ball valve fitted to the drum. Measuring containers and calibrated steel dip sticks are used to accurately measure the required amount of emulsion for each mix.

### 5.6.6.6 Batching and mixing

The material can be mixed either by hand in steel pans or with a concrete mixer. Ensure that the appropriate mix[26] is correct as established by the laboratory, i.e. the percentage of emulsion, cement and/or lime to be added to the gravel or aggregate.
Assuming that the laboratory has determined that the ETB will consist of the following:
a) 2% of 60% Anionic Stable grade Emulsion/$m^3$
b) 1% of Cement/$m^3$
c) 1.5% of Lime/$m^3$
d) Optimum Moisture Content (OMC) of the gravel is 6%
e) Dry density of the gravel is 2000kg/$m^3$

***Note:** The above percentages of emulsion, cement, lime, and water are based on the compacted mass of gravel.*

[26] Note: For planning/tender purposes the following proportions may be used per cubic metre of compacted material:
- Cement: 7 litres (22 kg)
- Emulsion: 45 litres
- Water: 120 litres (approx.)

(The amount of liquid to be added should be approximately 1 to 1.5% over the optimum moisture content required for Mod. AASHTO density).

**The equivalent compacted mass of gravel**

As the materials measured in 20 litre cans or wheelbarrows will be loose, an allowance is made for the bulking of the material. If the material is completely dry, a factor of 1.37 can be used (this condition is unlikely). If the material is at optimum moisture content, a factor of 1.5 can be used (this condition is also unlikely). Therefore it is recommended that an average factor of (1.37+1.5)/2 = 1.43 is used.

The equivalent mass of gravel material in the 20litre can or wheelbarrow is calculated as shown in Table 5-3.

**Table 5-3 : Equivalent mass of gravel material in a 20 litre can or a wheelbarrow**

| 20 litre can | Wheelbarrows (69 litre capacity) |
|---|---|
| $Equivalent\ compacted\ volume = \frac{20}{1.43} = 13.99\ litres$<br>The density of gravel is 2000kg/m$^3$ and the compacted mass of the gravel material per 20litre can is:<br>$Mass = \frac{13.99}{1000} \times 2000 = 27.97kg$<br>Assume 6 cans are used, then total mass of gravel will be:<br>$Total\ Mass\ per\ batch = 27.97 \times 6 = 167.82kg$ | $Equivalent\ compacted\ volume = \frac{69}{1.43} = 48.25\ litres$<br>The density of gravel is 2000kg/m3 and the compacted mass of the gravel material per wheelbarrow is:<br>$Mass = \frac{48.25}{1000} \times 2000 = 96.50kg$<br>Assume 4 wheelbarrows are used, then total mass of gravel will be:<br>$Total\ Mass\ per\ batch = 96.50 \times 4 = 386.0kg$ |

**Quantities of emulsion, cement and lime**

The quantities of emulsion, cement, and lime required are determined as shown in the Table 5-4 below:

**Table 5-4: Quantities of emulsion. cement, and lime**

| 20 litre can | Wheelbarrows (69 litre capacity) |
|---|---|
| Using the mass of gravel of 167.82kg per mix:<br>$1)\ Mass\ of\ \ Cement = 1\% \times 167.82 = 1.68kg / mix$<br>$But\ mass\ of\ Cement\ per\ litre = 1.50kg / litre$<br>$\therefore Cement\ per\ batch = \frac{1.68}{1.50} = 1.12\ litres/mix$<br>$2)\ Mass\ of\ \ Lime = 1.5\% \times 167.82 = 2.52kg / mix$<br>$But\ mass\ of\ Lime\ per\ litre = 1.065kg / litre$<br>$\therefore Lime\ per\ batch = \frac{2.52}{1.065} = 2.4\ litres/mix$<br>$3) Mass\ of\ \ Emulsion = 2\% \times 167.82 = 3.36kg / mix$<br>$But\ mass\ of\ Emulsion\ per\ litre = 1.00kg / litre$<br>$\therefore Emulsion\ per\ batch = \frac{3.36}{1.00} = 3.36\ litres/mix$<br>$= 3.40\ litres/mix\ (say)$ | Using the mass of gravel of 386.0kg per mix:<br>$1)\ Mass\ of\ \ Cement = 1\% \times 386.0 = 3.86kg / mix$<br>$But\ mass\ of\ Cement\ per\ litre = 1.50kg / litre$<br>$\therefore Cement\ per\ batch = \frac{3.86}{1.50} = 2.6\ litres/mix$<br>$2)\ Mass\ of\ \ Lime = 1.5\% \times 386.0 = 5.79kg / mix$<br>$But\ mass\ of\ Lime\ per\ litre = 1.065kg / litre$<br>$\therefore Lime\ per\ batch = \frac{5.79}{1.065} = 5.43\ litres/mix$<br>$3) Mass\ of\ \ Emulsion = 2\% \times 386.0 = 7.72kg / mix$<br>$But\ mass\ of\ Emulsion\ per\ litre = 1.00kg / litre$<br>$\therefore Emulsion\ per\ batch = \frac{7.72}{1.00} = 7.72\ litres/mix$<br>$= 7.7\ litres/mix\ (say)$ |

**Quantity of water**

The required Optimum Moisture Content (OMC) = 6%

The required 60% Anionic Stable Grade Emulsion = 2%

It should be noted that the 60% emulsion contains a mixture of 60% emulsion and 40% water.

Therefore the 2% emulsion contains $\frac{60}{100} \times 2 = 1.2\%\ Emulsion, and\ \frac{40}{100} \times 2 = 0.8\%\ Water$ .

Therefore the actual water content to be added = 6.0 – 0.8 = 5.2%.

This amount of water can be added in two stages:
i. First add 2.2% of water to the dry mixture of gravel, cement and lime.
ii. Then add the remaining 3.0% to dilute the emulsion, which is later added to the mixed gravel, cement and lime.

The required volume of water as per the batching is shown in Table 5-5:

**Table 5-5: Quantities of water required per batch**

| 20 litre can | Wheelbarrows (69 litre capacity) |
|---|---|
| Using the mass of gravel of 167.82kg per mix | Using the mass of gravel of 386.0kg per mix: |
| 1) $Mass\ of\ initial\ 2.2\%\ Water = 2.2\% \times 167.82 = 3.69kg$ | 1) $Mass\ of\ initial\ 2.2\%\ Water = 2.2\% \times 386.0 = 4.49kg$ |
| $But\ mass\ of\ Water\ per\ litre = 1.00kg\ /\ litre$ | $But\ mass\ of\ Water\ per\ litre = 1.00kg\ /\ litre$ |
| $\therefore Water\ per\ batch = \frac{3.69}{1.00} = 3.69\ litres/mix$ | $\therefore Water\ per\ batch = \frac{4.49}{1.00} = 4.49\ litres/mix$ |
| 2) $Mass\ of\ extra\ Water = 3.0\% \times 167.82 = 6.3kg$ | 2) $Mass\ of\ extra\ Water = 3.0\% \times 386.0 = 11.6kg$ |
| $But\ mass\ of\ Water\ per\ litre = 1.0kg\ /\ litre$ | $But\ mass\ of\ Water\ per\ litre = 1.0kg\ /\ litre$ |
| $\therefore ExtraWater\ per\ batch = \frac{6.3}{1.0} = 6.3\ litres/mix$ | $\therefore ExtraWater\ per\ batch = \frac{11.6}{1.0} = 11.6\ litres/mix$ |
| Therefore mix the 4.2 litres of Emulsion (from Table 5-3) with the extra 6.3 litres of water:<br>Emulsion plus water = 4.2 +6.3 = 10.5 litres mix | Therefore mix the 7.7 litres of Emulsion (from Table 5-3) with the extra 11.6 litres of water:<br>Emulsion plus water = 7.7 +11.6 = 19.3 litres mix |

**Notes:**
- The amount of water is not critical but it should not be less than the amount calculated to obtain the optimum liquid content as shown above.
- From the first and second trial mixes it should be established what little, if any, extra water may be added to obtain a workable, easily 'screedable' mix.
- Depending on the climatic conditions, 1 - 2% may be added to the above OMC to accommodate for moisture loss during handling.

**Mixing ETB**

Mixing the ETB should be done in appropriately sized concrete mixers or steel trays.

The material used in the ETB should be stockpiled as closely as possible to the work area, as described above.

The mixing of materials should take place in the following order:

- The dry materials, aggregate, cement and lime (if required) is added first and mixed well;
- Followed by adding one third of the water and mixing well;
- Lastly the emulsion diluted with the remaining two thirds of the water is added and mixed to a uniform consistency.

The photos below illustrate the steps explained above. Similarly, the mixing can be done by hand in tray pans as explained in Section 8.5.3

**Batching aggregate, lime and cement**

**Feeding aggregate, lime and cement into mixer**

**Add 1/3 portion of water**

**Mix remaining water and emulsion and add**

**Mixed ETB**

**Discharging the mixed ETB**

**5.6.6.8 Placing the ETB**

If the sub-base is dry, it is important that the surface is lightly watered to dampen and break the surface tension before placing the ETB.

The ETB should be placed as uniformly as possible by dumping the wheelbarrow loads at a uniform spacing, between the side forms, to achieve the minimum amount of movement when levelling the loose material as shown in Figure 5-7.

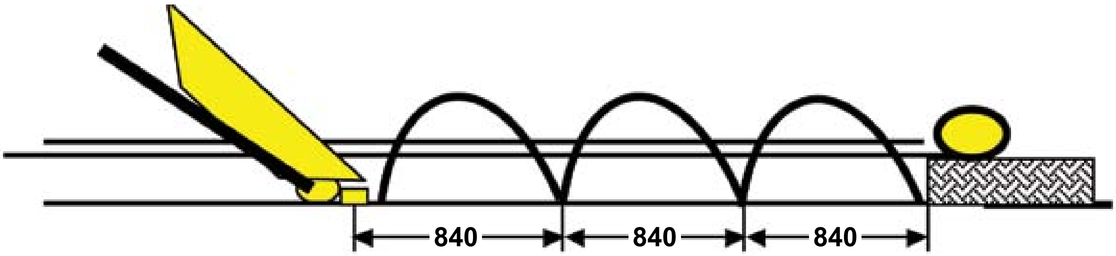



**Figure 5-7: Placing the ETB wheelbarrow loads**

**Calculating the spacing for a 150mm loose layer for half width of 2.75m**

A width of 2.75 metres allows 5 wheelbarrow loads to be placed at a spacing of 0.84 metres.
Assuming the capacity of the wheelbarrow is 0.69 m$^3$, the spacing between rows of wheelbarrows to obtain a loose depth of 150mm (0.15m) is: $\frac{5 \times 0.069m^3}{2.75m \times 0.15m} = 0.84m = 840mm\ (Figure\ 5-7)$

Place the 50mm x 6mm thick steel spacer plate, as shown in Figure 5-9, on top of the 100mm leg of the side forms and using the steel squeegees and steel screed bar spread the ETB to obtain a 150mm loose layer. Less segregation of the material is attained by using steel squeegees in place of rakes.

Where the layer is being constructed adjacent to previously constructed work (e.g. half width construction) a 50mm x 50mm spacer must be placed on top of the existing work to obtain the correct loose thickness for the new work (Figure 5-8).

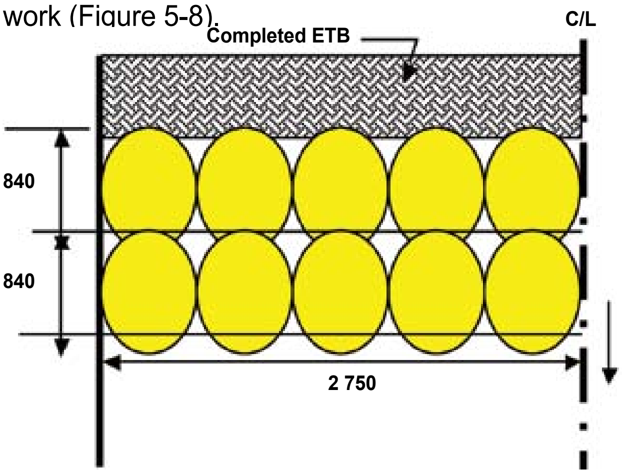



**Figure 5-8: Construction adjacent to compacted layer**

When using a coarse material the judicious removal of the large fractions from the surface and their replacement with finer material will result in a smoother finish. The large fractions can be placed on the floor of the advancing work.

As the work progresses a black plastic sheet should be rolled out over the work to inhibit the emulsion breaking prematurely. Once some 8 – 10 metres of ETB has been placed the cover can be rolled up, the spacer plates removed and rolling commenced.

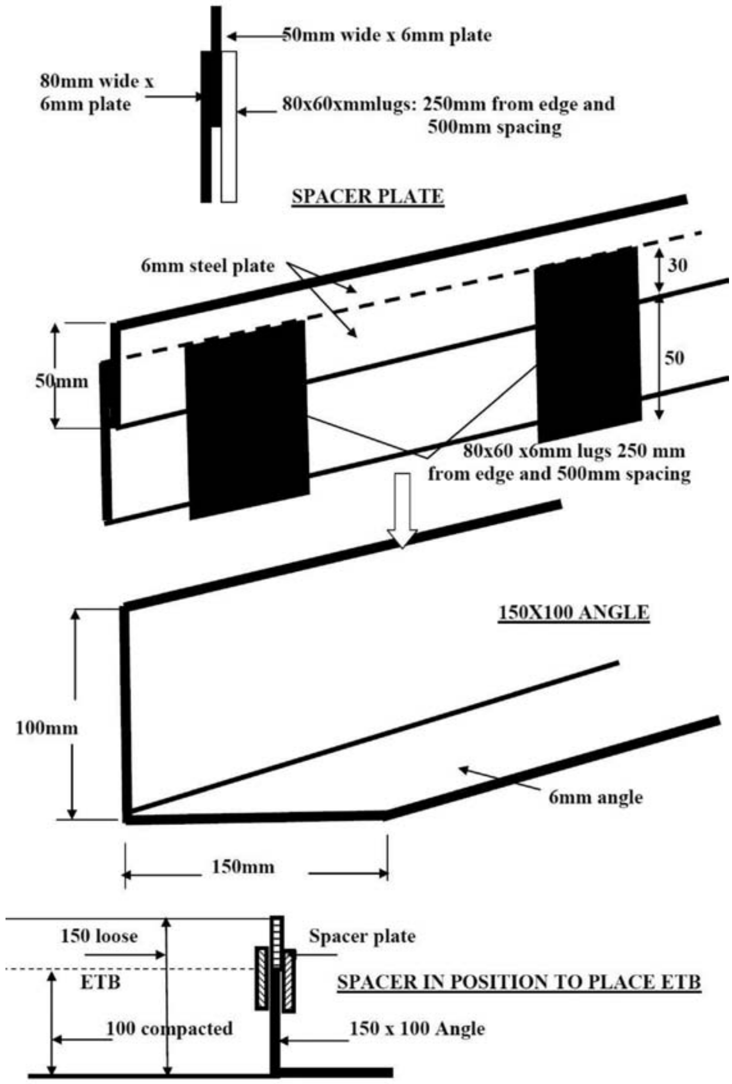



**Figure 5-9: Shutter arrangement for ETB**

**Compacting the ETB**

Rolling, with the roller in vibratory mode, is continued until the 150 mm loose layer has been compacted to the top edge of the 100 mm leg of the side form. Wrong rolling can result in the building of undulations in the surface. Rolling should commence from the edge line of the shutters and thereafter be undertaken parallel with the shutter lines, moving from both sides towards the middle of the layer in a little less than half the width of the roller after each pass of the roller. Continue to roll the section until the layer is level with the shutters.

Always roll in vibratory mode, parallel with the shutter lines, moving from both sides towards the middle of the layer in a little less than half the width of the roller after each pass of the roller. Continue to roll the section until the layer is level with the shutters.

**Compaction of ETB layer**

**Compacted ETB layer**

Sufficient time should be allowed for the emulsion to fully break before commencing the construction of the surface layer.

All loose material is removed from the surface before applying a diluted emulsion (1:8) neatly and uniformly to the surface before commencing surfacing works. A coarse broom can be used to evenly distribute the diluted emulsion.

**Composite base of gravel with emulsion treated upper layer**

On roads with limited levels of traffic and which has a subgrade/sub-base course of natural materials of high strength, it is often cost-effective to construct a partially emulsion stabilised base course consisting of a 67mm thick natural gravel base and a 33mm emulsion treated gravel top - applying the same construction methods as described above.

***Note:*** *The passage of the barrows must be outside the traffic lane and no walking should take place on the spread but un-compacted gravel, as this will result in differential compaction and an uneven final surface.*

With a 50mm x 6mm thick steel spacer plate placed on top of the 100mm leg of the side forms and using the steel squeegees and steel screed bar spread the ETB to obtain a 50mm loose layer.

Where the layer is constructed adjacent to previously constructed work (e.g. half width construction) a 50mm x 50mm spacer is placed on top of the existing work to obtain the full loose thickness for the new work.

### 5.6.7 Alternative base treatments

Other labour-friendly base treatments not covered in this guide are slurry-bound and water-bound macadam bases.

### 5.6.8 Summary of base layer treatments and productivities

Table 5-5 provides a summary of advantages, disadvantages, and productivities for various base layer soil treatments which are suitable for labour based works:

**Table 5-6: Summary of pavement soil treatment types**

| Pavement soil treatment type | Advantages | Disadvantages | Daily Productivity |
|---|---|---|---|
| Untreated in-situ natural soil | • Give good quality finished base with use of shuttering and quality control.<br>• Obviates the need to import suitable base course material from distant quarries thus could result in project costs reduction.<br>• Avoids potentially useful material being excavated to spoil and thereby reducing project costs.<br>• Increased progress as adequate road-building material is found next to the road, leading to earlier works completion and additional savings.<br>• Limiting environmental degradation caused by opening large borrow pit. | • Applicable only in sections of road where in-situ material meets base specifications.<br>• Needs very intense and good supervision to achieve specification standards.<br>• Team balancing critical to ensure that all operations (watering/mixing, spreading, screeding, and rolling) proceed at a uniform sequence. | • 3.5m³/wd (Group task with team of 15 completing 350m² in batching, watering, mixing soil, spreading, and screeding 150mm thick base layer) |
| Lime stabilization | • Allows use of marginal/high P.I soils.<br>• Lowers P.I, improves workability, bearing capacity and water resistance of gravel.<br>• Low stabilisation crack forming potential.<br>• Works best with reasonably well graded soil materials with low grading modulus. | • Traffic must be kept off until suitably sealed.<br>• Damage by traffic relatively time consuming to repair compared to natural gravel.<br>• Proper curing can be problematic especially with basic crystalline material | • 3m³/wd (Group task with team of 15 completing 300m², in batching, dry-mixing soil-lime, watering, re-mixing, spreading, and screeding 150mm thick base layer) |
| Cement stabilization | • Allows use of soils with marginal base properties.<br>• Improves bearing capacity and water resistance of gravel.<br>• Only works best with reasonably well graded soil material. | • High propensity for the formation of closely spaced stabilisation cracks.<br>• Traffic must be kept off until suitably sealed.<br>• Proper curing can be problematic especially with basic crystalline material | • 3m³/wd (Group task with team of 15 completing 300m², batching, dry-mixing soil-cement, watering, re-mixing, spreading, and screeding 150mm thick base layer) |
| Emulsion Treatment Base | • Emulsion reduces the internal friction of the soil materials thus improving its compacted density and workability.<br>• Significantly increase the CBR and UCS of the material,<br>• Limits the development of potholes in the base when the surfacing is damaged,<br>• Eliminates the need for priming,<br>• Allows the layer to be trafficked sooner than most other base layers – as soon as the emulsion has broken<br>• Soils do not need to be dried, as emulsions adhere readily to damp aggregate,<br>• Possible to core ETBs and to recover complete cores, which facilitates easy and speedy testing for quality control purposes. | • Requires sound and reasonably well graded soil material.<br>• Requires availability of bitumen emulsion and necessary mixing equipment. | • 2m³/wd (Group task with team of 15 completing 300m², in batching, dry-mixing soil-lime-cement, watering, re-mixing, spreading, and screeding 150mm thick base layer) |

## Notes

# SECTION 6: DRAINAGE

Various drainage measures are necessary in order to satisfactorily deal with rainwater falling on or near a road. Rainwater is the main cause of damage to low-volume roads and a good drainage system significantly reduces the detrimental effects of water and minimise future road maintenance requirements.

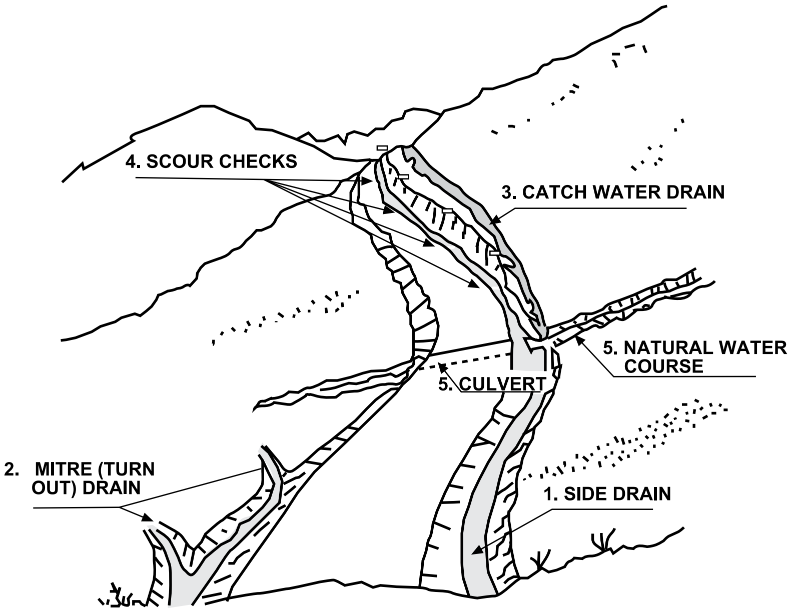



**Figure 6-1: Road drainage system**

Water can damage the road in two principal ways:

- By weakening the soil in the pavement and thus reducing the traffic bearing capacity.
- By erosion and silting (damaging the road and reducing the effectiveness of the drainage system).

The drainage system with all its components as illustrated by Figure 6-1 must therefore collect all rainwater and dispose of it quickly and freely so that it does not penetrate the road body and thereby reduce the bearing capacity. A well functioning drainage system actually keeps the pavement dry through rainy weather. It should enable the road with all its components to rapidly dry out after rain and regain its full strength.

The drainage system will normally require most of the following components to function effectively. It is important to make sure that they are provided at the necessary locations.

- **Road Surface Camber:** sheds water from the road surface (covered in the previous section).
- **Side Drains:** collect water from the road surface and adjoining land (covered in the previous section).
- **Mitre Drains:** lead water out of the side drains and safely disperse it on adjoining land.
- **Catchwater Drains:** intercept surface water flowing towards the road from adjacent land, and lead it away.
- **Scour Checks:** prevent erosion in side drains by slowing down the speed of the runoff water.
- **Culverts/Drifts:** allow water to pass from one side of the road to the other.

In isolated cases ground water/springs will require some **sub-surface drainage** measures.

## 6.1 MITRE DRAINS

Mitre drains (or turn out drains) lead water away from the side drains to the adjoining land.

This must be achieved in a manner to avoid causing erosion at the discharge point. Therefore mitre drains should be provided as often as possible so that the accumulated water volume in each drain is not high. There should be at least one outlet either using a mitre drain or culvert every 200 metres of side drain.

The discharge water should be channelled to field boundaries where possible. Care should be taken to ensure that mitre drains discharge without causing nuisance or damage to farmland. The minimum width of the mitre drains is 0.60 metres and the cross section should have at least the same capacity as the side drain. Mitre drains should have a gradient of 2 - 5%. Gradients should be carefully checked to ensure that they drain properly within these limits.

Some of the excavated soil is used to block the downhill end of the side drain to ensure that the water flows into the mitre drain. Figure 6-2 shows the principal features of a mitre drain.

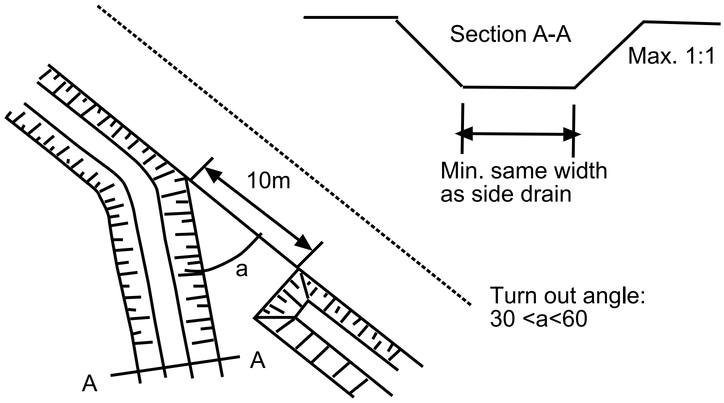



**Figure 6-2: Mitre drain layout**

**Setting out a mitre drain**

**Excavating a mitre drain**

**A functioning mitre drain**

### 6.1.1 Determining the length of a mitre and outer drain

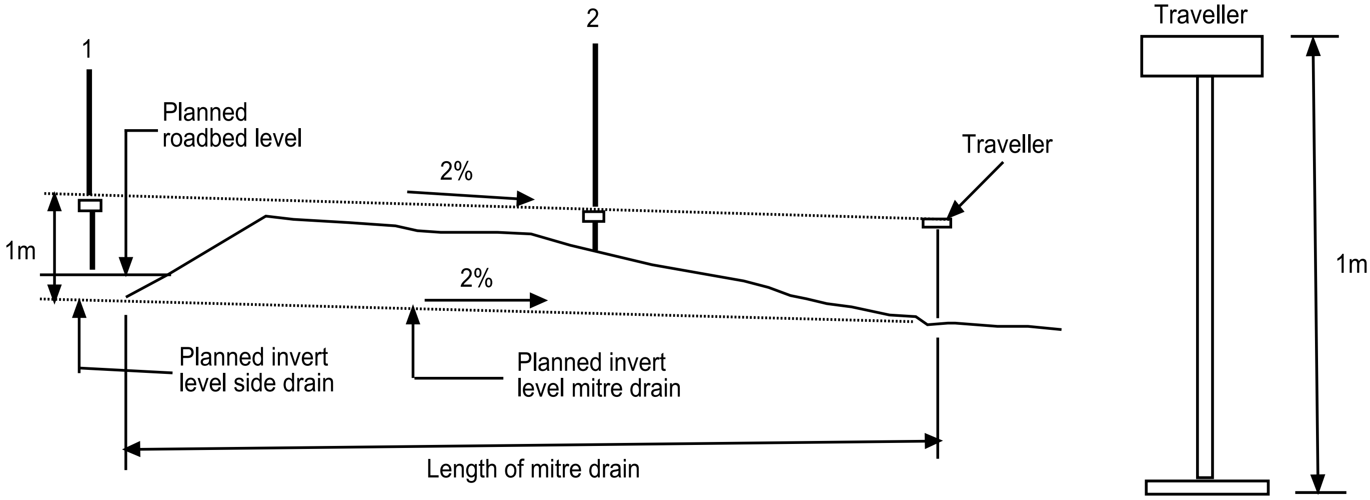



**Figure 6-3: Checking the length of a mitre drain**

Mitre drains should be positioned such that the length is not longer than 30m beyond which it becomes uneconomical and may also be prone to siltation.

Using Figure 6-3, the following procedure can be used to check the length of a mitre- or outer drain of a culvert:

1. Place bonning rod 1 in the centre of the ditch at the turnout point of the mitre drain and rod 2 at a distance 10m (say) down on the centreline of the proposed mitre drain.
2. Adjust the profile board on rod 1 to 1m above drain invert level and set out on rod 2, to the specified gradient for invert of the mitre drain, say 2% (by transfering the height on rod 1 to rod 2 and dropping the profile board down by 0.2m).
3. Sight over the two profiles while an assistant moves a 1m height traveller on the ground along the centreline away from rod 2.
4. The end of the mitre drain is found where the top of the traveller flushes with the two profile boards.
5. Measure the distance beteen rod 1 and the traveller as the length of the mitre drain.

It should be noted that if the length of the mitre drain becomes more than 30m, then a more economical solution should be found to shorten the length to 30m or less. This could be done by applying any of the following measures:
(i) Dividing the measured length in two and apply a less steep gradient (say 1%) for the latter half,
(ii) Changing the turnout angle, or the turnout point;
(iii) Raising the roadbed and hence the drain invert level.

*Caution: All outlet- and mitre drains should be determined before the final roadbed level is decided. It should not be an after-thought once earthwork is in progress.*

## 6.2 CATCHWATER DRAINS

Where the road is situated on a hillside a significant amount of rainwater may flow down the hill towards the road. This may cause damage to the cut face of the road and even cause land slips. Where this danger exists a catchwater drain should be installed uphill and parallel to the road to intercept this surface water and carry it to a safe point of discharge, usually a natural watercourse.

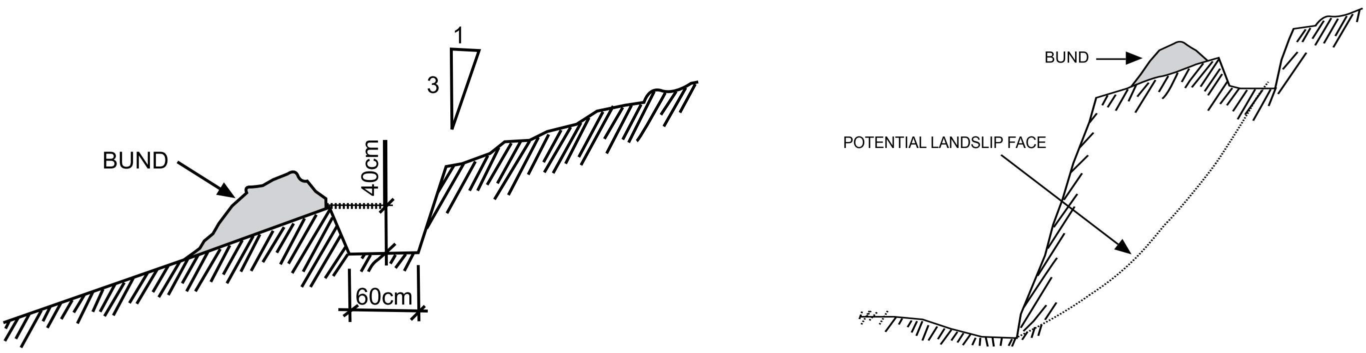
The catchwater drain should be carefully located[27] so that:
i. It drains at a satisfactory gradient throughout its length (>2%).
ii. It is not too close to a cut face thereby increasing the danger of a land slip (see Figure 6-4b).

If steep gradients are unavoidable then scour checks should be installed (refer to Table 6-1).

Normally the material excavated to form the drain is placed on the downhill side to form a bund. Vegetation cover should be established as soon as possible in the invert and sloping sides of the catchwater drain and bund to prevent erosion.

The catchwater drain should normally be 0.60m wide, 0.40m (minimum) deep with sides back sloped at 3:1 (See Figure 6-4).

In view of the potential to increase risk of erosion due to incorrectly installed catchwater drains, and the problems of maintenance, consideration should also be given to alternative slope erosion control measures.




**(a) Correctly designed catchwater drain** **(b) Wrongly designed catchwater drain**

**Figure 6-4: Catchwater Drain**

27 In cases where the catchwater drain has to be constructed on private land, permission from the owner must be sought it

## 6.3 SCOUR CHECKS

Where longitudinal open and unlined drain gradients are steeper than about 4%, water flows at high speed. Therefore, if no protective measures are taken, scouring in side drains is likely to occur on erodible soils. The simplest way of dealing with scouring is by reducing the volume of water (by installing mitre drains at frequent intervals). In addition scour checks can be constructed to reduce the velocity of the water. They hold back the silt carried by the flow and provide a series of stretches with gentle gradients interrupted by small "waterfalls". (ref. Figure 6-5)

**A functioning scour check**

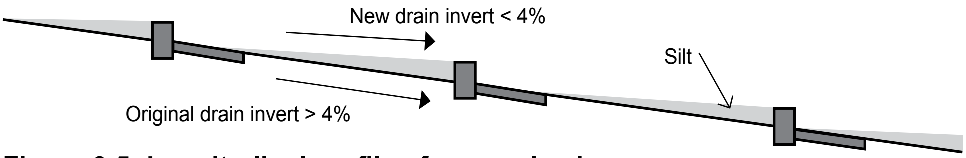
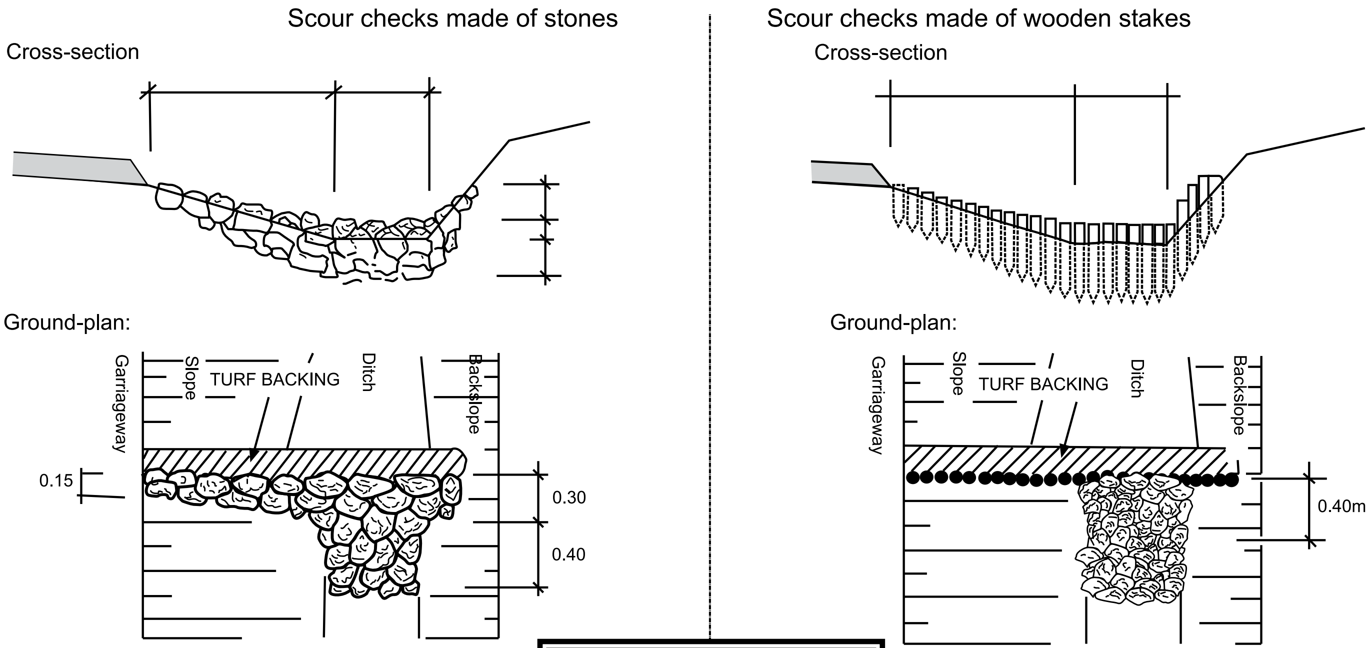



**Figure 6-5: Longitudinal profile of scour checks**

Scour checks are usually constructed of natural stones or with wooden stakes. The level of the scour check must be a minimum of 0.2m below the edge of the carriageway in order to avoid the water flow being diverted out of the side drains (see Figure 6-6). The constructed scour checks therefore have to be controlled with a template (which is part of the ditch and slope template - see Figure 6-7). The interval at which scour checks are constructed depends on the gradient as shown in Table 6-1. The gradient of the side drain should be checked using a spirit level and tape, Abney level or string line and level.

**Table 6-1: Scour check spacing**

| Gradient of Road | Scour Check Spacing According to Soil Conditions | | Gradient of Road | Scour Check Spacing According to Soil Conditions | |
|---|---|---|---|---|---|
| | Good | Poor | | Good | Poor |
| 2% | None | None | 8% | 7.5m | 4m |
| 3% | None | 20m | 9% | 6m | 3m |
| 4% | None | 15m | 10% | 5m | 2.5m |
| 5% | 20m | 10m | 12% | 4m | Lining with masonry |
| 6% | 15m | 7.5m | 14% | Lining with masonry | |
| 7% | 10m | 5m | 15% | | |




STONE WEIGHT: MIN. 20 kg
STAKE DIAMETER: MIN. 0.15m

**Figure 6-6: Dimensions of scour checks for standard drain**

Scour checks should not be constructed on roads with gradients of less than 3% - 4%. This would encourage too much silting of the side drain and lead to road damage.

After the basic scour check has been constructed an apron should be built immediately downstream either using stones or grass turf pinned to the ditch invert with wooden pegs. The apron helps to diminish the impact of the waterfall. Grass sods should be placed against the upstream face of the scour check to prevent water seeping through the scour check and to encourage the silting behind the scour check. The long term objective is to establish complete grass cover over the silted scour checks to stabilise them.

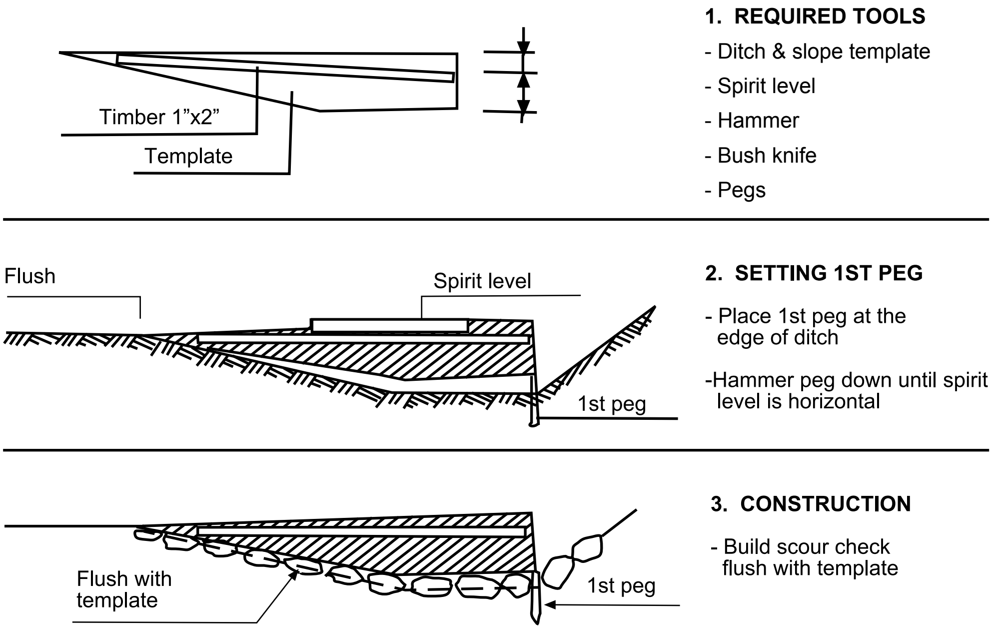



**Figure 6-7: Scour Check Installation Procedure**

## 6.4 CULVERTS

This section covers the construction of standard precast concrete pipe culverts and simple drift, gabion and masonry structures for use on low-volume roads. These are small structures suitable for construction by local contractors or, in the case of force account under the relevant road authority, by a road superviser or superintendent. Small bridges or vented drifts may also be constructed under similar site arrangements. For more complex structures requiring specialist supervisory and technical skills (such as multiple culverts involving pipe diameters in excess of 2.0m, box culverts, bridges, retaining walls and large vented drifts over wide rivers) the head offices of the respective road agency should be consulted to provide guidance on the design and construction.

Culverts can be placed in two categories according to their functions:

- A relief culvert is an integral part of the road drainage system, and conveys water under the road from the upper (uphill) side of the road to the lower (downhill) side. It discharges runoff during and after rainfall from the road surface and adjacent roadside areas. Relief culverts carry water seasonally only.
- A stream culvert is required at the intersection point between an existing water course and the road alignment. The volume of water to be discharged through the crossing includes the flood carried by the stream or river and the runoff from the road drainage system. Flood levels will be largest after heavy rains, but a minimum flow can normally be expected throughout the year.

Relief culverts are placed perpendicular to the (horizontal) road alignment. Stream culverts must be set out in the direction causing the lowest possible disruption to the natural flow of the water course. Figure 6-8 depicts the alignment of relief and stream culverts.

Structures may already exist on some unpaved rural roads, and these may only require minor repairs or improvement. These activities may include replacement of sections such as installation of broken pipes, headwalls, protection of aprons, installation of cut-off walls among others.

New structures should be carefully designed for the type of crossing and traffic, and should be built using locally available materials. Due to the difficulties in treating timber and its rapid deterioration, structures are normally not constructed using this material. These days concrete is the most commnly used material used for the structural components of cross-drainage structures. Major structures to be installed on any road are determined during the road evaluation, and their estimated cost is indicated in the design. Construction of structures should, where possible, be undertaken ahead of the road works activities in order to facilitate transport of materials during the remaining construction period.

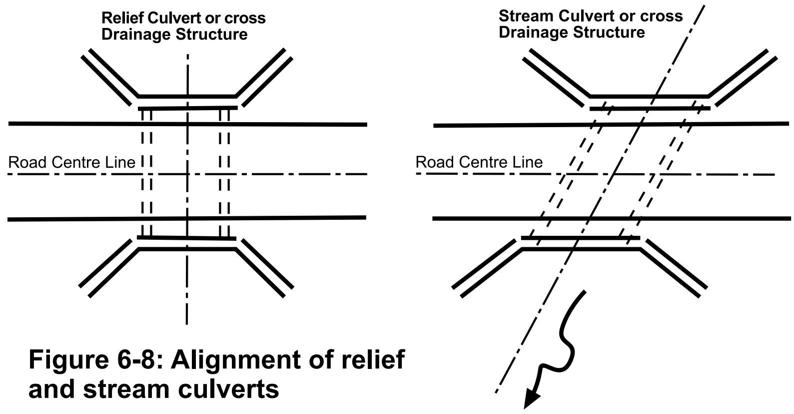



**Figure 6-8: Alignment of relief and stream culverts**

Procedures for setting out a 600mm diameter culvert in rolling or mountaneous terrain

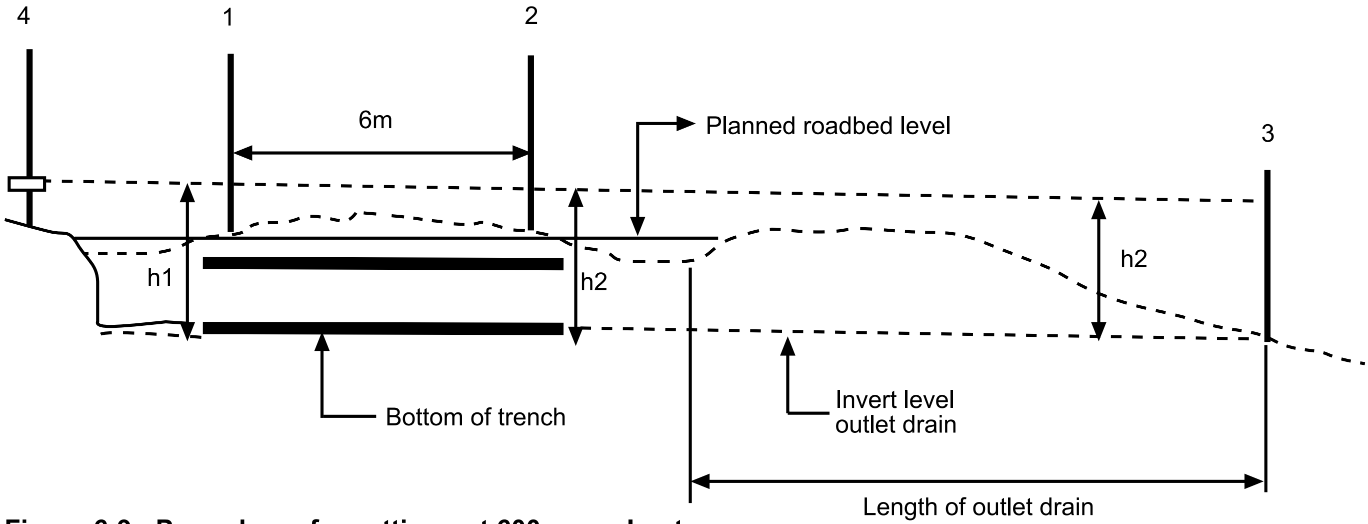



**Figure 6-9 : Procedures for setting out 600mm culvert**

As illustrated with Figure 6-9, the following procedure may be used to set out a 600mm diameter culvert in a rolling or hilly terrain:

**Procedure:**

1. Place bonning rods 1 and 2 on the intended centre line for the culvert at the edge of the shoulder 3.15m
2. Adjust the profile on rod 1 to 0.5m above roadbed level and calculate h1 like in the table below.
3. Set out the culvert invert gradient, say 4%, to rod2 (by dropping it 3.15 x 4% = 0.126m) and adjust the profile.
4. Take rod 3 and adjust the profile to h2 (h1 minus thickness of bottom slab) above the bottom end (the 1m traveller will be too short) Walk rod 3 along the centre line of the outlet until profiles 1, 2 and 3 are flush. Drive down rod 3 at this ponit and adjust the profile board again to flush with 1 and 2.
5. Measure the length of the outlet drain from the edge of the side drain. If the drain is longer than 30m, try with a slightly lower invert gradient (say 2 or 3 %). Repeat steps 1 to 5 or consider raising the roadbed.
6. When the levels are correct, secure rod 4 outside of the working areaa where it will not be disturbed and adjust the profile board to be flush with 1, 2, and 3.

| | | |
|---|---|---|
| Profile height above roadbed | = | 0.50m |
| Minimum earth cover | = | 0.30m (subgrade and base layers) |
| Outside dimension of culvert | | |
| Top Slab | = | 0.15m These dimensions will vary with the type of culverts |
| Opening | = | 0.60m |
| Bottom slab | = | 0.15m |
| h1 (h2) | = | 1.70m (1.424m) Culvert and drain invert levels must coincide at culvert outlet. |

The same procedure can be followed to set out other sizes of culverts.

For flat terrain, the outlet drain gradient could be reduced to 2%.

## 6.5 DRIFTS

A drift allows water to flow across the surface of the road rather than below it whilst a vented drift allows normal water flows to pass under the road and on top during floods. Design and construction of vented drifts are not included in this manual. Drifts are normally used for seasonal water crossings although they are also suitable for permanent water courses. Drifts are used in the following situations:

- Where rock exists at or just below the ground level and a culvert would be too costly or consume excessive resources;
- On a wide watercourse where the water flow (seasonal or permanent) can be spread across the structure so that vehicles and foot traffic can safely cross for most of the year;
- Where culverts have a tendency of silting up very fast, or where trees, branches or stones are brought down to the crossing site by flood water that would block culverts or bridges. For example in Botswana where the land is relatively flat, drifts were often preferred for this reason, as culverts would often silt up during floods or heavy rainfall.

Drifts are not suitable where water is fast flowing or the volume of water would endanger the passage of vehicles, people or animals. Careful consideration should be given to the type and cost of crossing over very wide seasonal rivers in semi-arid areas, particularly on roads with low volumes of traffic.

### 6.5.1 Features

Drifts are normally constructed with natural stone, gabions, masonry or concrete. However all require certain features described below and illustrated in Figure 6-10.

### 6.5.2 Running surface

The running surface across a stream or a river bed should be almost flat and may be constructed out of natural hand packed stone (slow flows only), masonry or concrete. The hand packed stone surface requires more maintenance than the cement bound surfaces. Gabions do not provide a suitable surface for foot or vehicle traffic.

The drift surface must be able to resist the “plucking” action and eroding power of the flood water. The extent of the running surface should be clearly shown by marker posts, which are visible even under flood conditions. Figure 6-10 provides various designs for drift running surfaces.

### 6.5.3 Approaches

The approaches should allow vehicles to descend to and leave the drift without grounding or loosing traction. On short drifts (less than 10 metres long) the approaches should not be steeper than 5% (1 in 20). On longer drifts the approaches can be steepened to 10% (1 in 10). There should be a smooth gradient transition between the approach ramp and the main area of the drift. Approaches should be surfaced in the same way as the main part of the drift. Surfacing should be extended to at least the level of the highest previous flood (Figure 6-11).

Care should be taken not to reduce the cross sectional area of the water course by building the approach ramps into the existing water course.

### 6.5.4 Cutoff walls

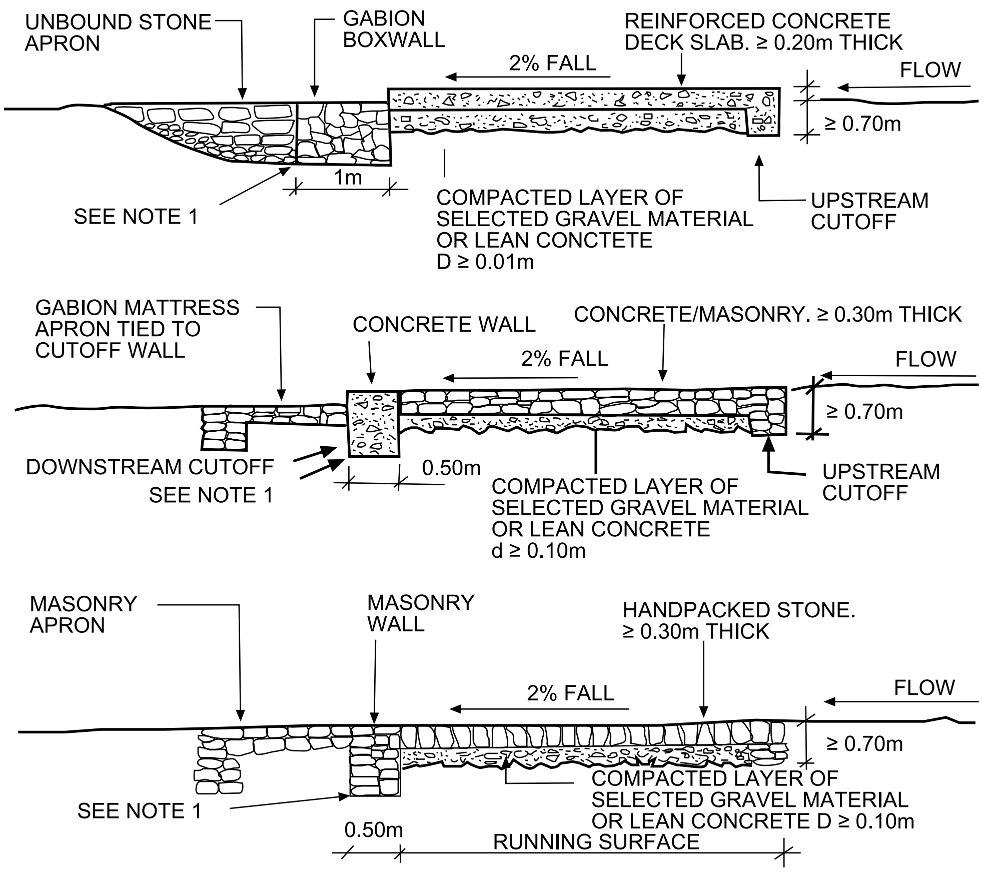
A drift normally incorporates a buried downstream cut-off wall in its structure. This anchors the drift into the bed of the water course and prevents scouring and undermining of the drift slab. An upstream cut-off wall reduces the seepage and lifting forces of water passing under the structure.

### 6.5.5 Apron

An apron is required immediately downstream of the buried wall to protect the drift from erosion resulting from turbulence created by the structure. An apron, including cut-off walls, may also be necessary on the upstream side of the drift.

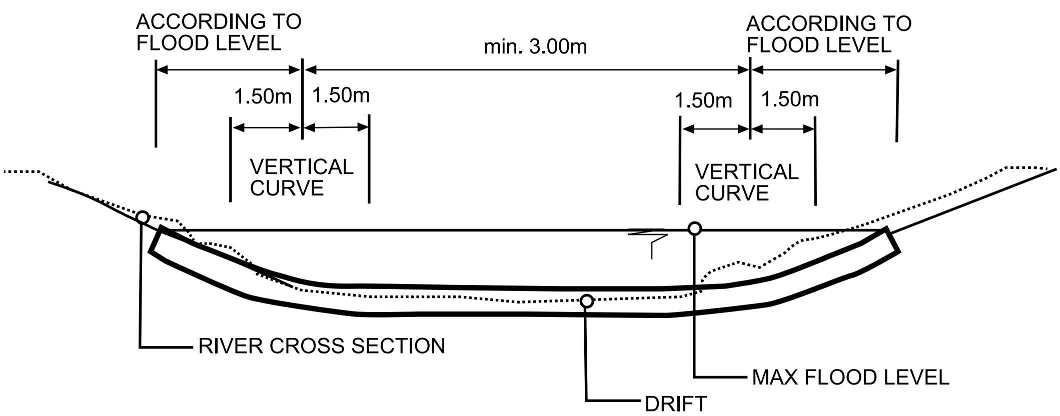
### 6.5.6 Other erosion protection

The drift may need further erosion protection on the approach ramps to protect against flood damage.




**NOTE 1.**
DOWNSTREAM CUTOFFS SHOULD EXTEND 1 - 1.5 METERS BELOW BED LEVEL. DEPENDING ON SCOUR RISK

**Figure 6-10: Drift features**




**NOTE:** STRUCTURE SHOULD NOT REDUCE THE CROSS SECTION AREA OF THE WATERCOURSE

**Figure 6-11: Drift approaches**

### 6.5.7 Siting

A drift or similar structure should not be sited where the stream or river is likely to change its course and thus bends should be avoided. The drift should ideally be located on a straight section of watercourse with a fairly even bed and sites with severe scour or silting should be avoided. The approach ramps should not require large earthworks.

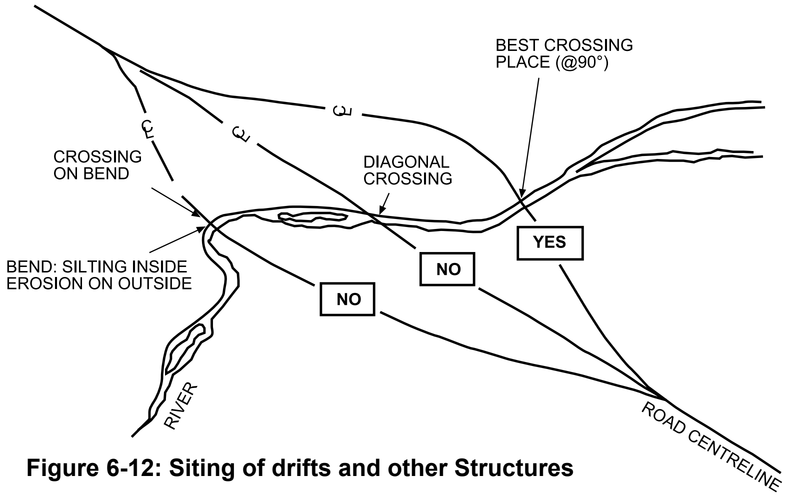



**Figure 6-12: Siting of drifts and other Structures**

The invert level of the drift should be set just slightly above the average existing stream bed level. If it is set too high, siltation will occur upstream of the drift and there will be an increased risk of erosion immediately downstream of the structure. If the level is set too low the drift will silt over.

If there is a small step between the running surface and the apron (up to 0.30m), the drift will be self-cleaning and silt will be discouraged from being deposited on the running surface.

### 6.5.8 Construction

The aim of constructing the drift should be to disturb the flow of water as little as possible. Any change in the cross section or longitudinal profile of the stream bed will cause turbulence in the flow and increase erosion potential, particularly under flood conditions.

If a change in level is required to keep the drift running surface clean or to accommodate a change in bed level, this should occur where the wall and apron join. However the two parts of the structure should be securely tied together to resist the inevitable erosion forces.

The wall should normally extend at least one metre below bed level to act as a key, and as a water seepage cutoff in the case of impervious masonry or concrete running surface slab construction. If erosion forces are expected to be severe, this wall should be even deeper.

Impervious running surfaces (masonry and concrete) should have an upstream cutoff wall extending at least 0.70m below the river bed.

The drift may have to be constructed while there is water flowing in the river or stream. In this case the water will have to be diverted around the structure, or the drift needs to be built in two halves. In either case, temporary earth bunds or sand bags will have to be installed to contain the water flow. The excavations may need to be drained by hand, using buckets or an engine driven pump.

### 6.5.9 Gabion works

Gabions are wire mesh boxes filled with stones and tied together to form basic structures. They are used principally for:

- Retaining walls
- Drifts
- Erosion protection.

Gabion boxes may be made from:

- Purpose made gabion cages
- Welded steel mesh sheets
- Galvanised chain link fencing.

**Gabions used as retaining wall for road side slope**

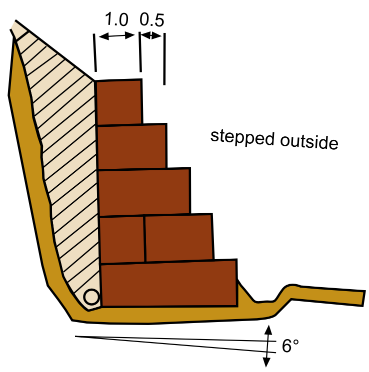



**Figure 6-13: Cross-section of gabion layout**

Gabions are used as a substitute for concrete or masonry. Gabion structures should be built with the same principles of good foundation, stability and quality control. The advantages of gabions are their simplicity of construction (requiring low levels of skill), use of local materials (stones), ability to let moisture pass through thus avoiding the build-up of water pressure, and flexibility (should minor settlement occur).

### 6.5.9.1 Gabion construction

Foundations should be excavated level and cleaned as for a conventional structure, with any unsuitable material removed and replaced with good soil, stone or gravel, and compacted. The baskets should be erected in their final position. The steps to be followed in constructing gabion boxes are illustrated in Figure 6-14.

Cages should be woven together using 3 mm binding wire, securing all edges every 0.15m with a double loop. The binding wire should be drawn tight with a pair of heavy duty pliers and secured with multiple twists. The connected baskets should be stretched and staked with wires and pegs to achieve the required shape.

Filling should be carried out by hand using hard durable stones not larger than 250 mm and not smaller than the size of the mesh. The best size range is 125 - 200 mm. The stones should be tightly packed with a minimum of voids.

Boxes of 1 metre height should be filled to 1/3 of the height. Horizontal bracing wires should then be fitted and tensioned with a windlass to keep the vertical faces even and free of bulges. Further bracing should be fixed after filling to 2/3 of the height. Boxes of 500 mm height should be braced at mid height only. Gabions of 250/330 mm size do not require internal bracing. Where water falls directly onto the top of the gabion, vertical bracing wire should also be fitted to secure the gabion lid when closed.

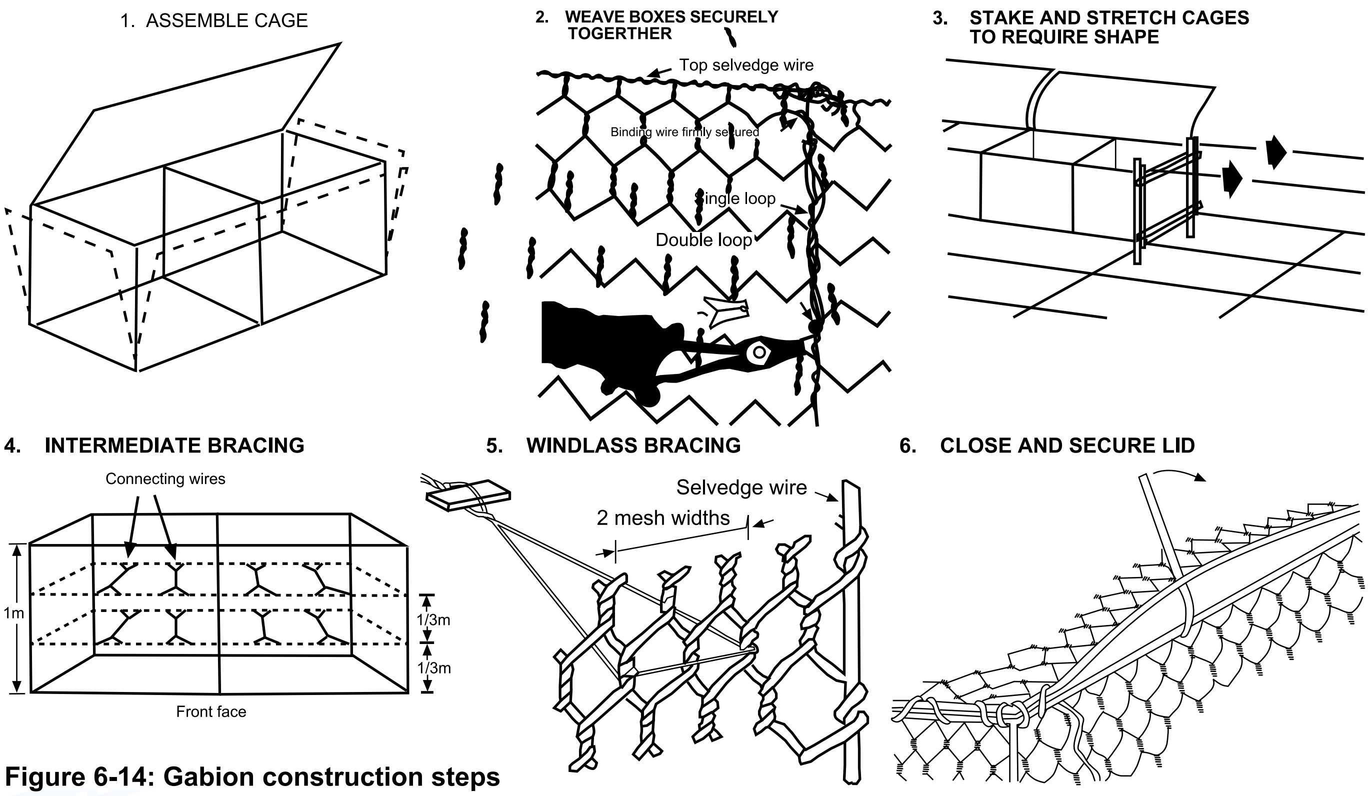



**Figure 6-14: Gabion construction steps**

The stones should be carefully packed to about 30 - 50mm above the top of the box walls to allow for settlement. Smaller material can be used to fill the voids on the top face, but excessive use of small stones should be avoided. The lids are then closed and stretched tightly over the stones, (carefully) using crowbars if necessary. The corners should be temporarily secured to ensure that the mesh covers the whole area of the box. The lid should then be securely woven to the tops of the walls, removing stones if necessary to prevent the lid from being overstretched.

## 6.6 SUB-SURFACE DRAINAGE

In some areas, ground water can pose a problem to the road pavement. This occurs where the road alignment traverses marshy or swampy land on which stagnant water, high ground water table and/or spring water is present for long periods. This also occurs where subgrade soil is poor and seepage from the banks of a cutting is likely to be severe or when a cutting at the top of the hill cuts into a pervious stratum above which the water table lies.

If the alignment cannot be changed to avoid such locations then specific subsoil drainage measures may be required. The objective of such subsoil drainage is to:

- Minimise opportunities for groundwater to enter the pavement
- Collect and convey infiltrated surface water to an outlet.
- Protect the subgrade, and
- Minimise cost of moisture control.

Typical subsurface drains may be constructed using Perforated pipes made of corrugated or rigid smooth walled plastic, or fibre reinforced pipes, or rubble (French) drains. Plastic pipes have a lower crushing strength, but are lighter and easier to lay than other types of pipe. Typical subsuface drain types and their positioning are as respectively shown in figures 6-15 and 6-16 below.

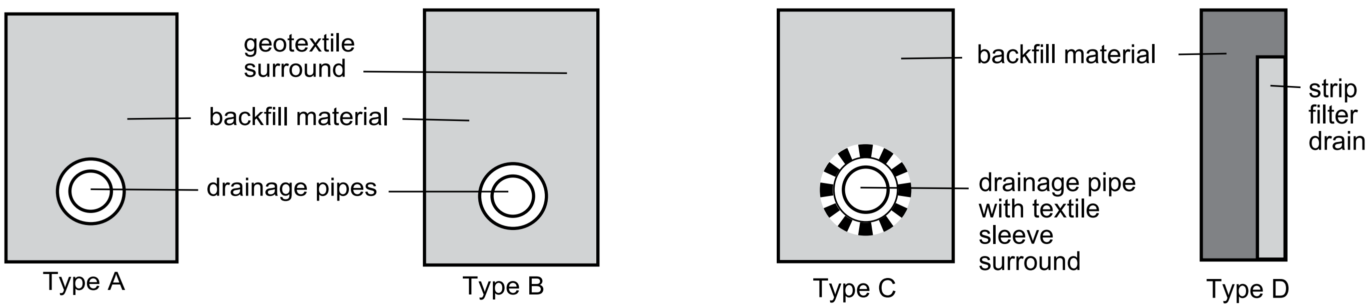
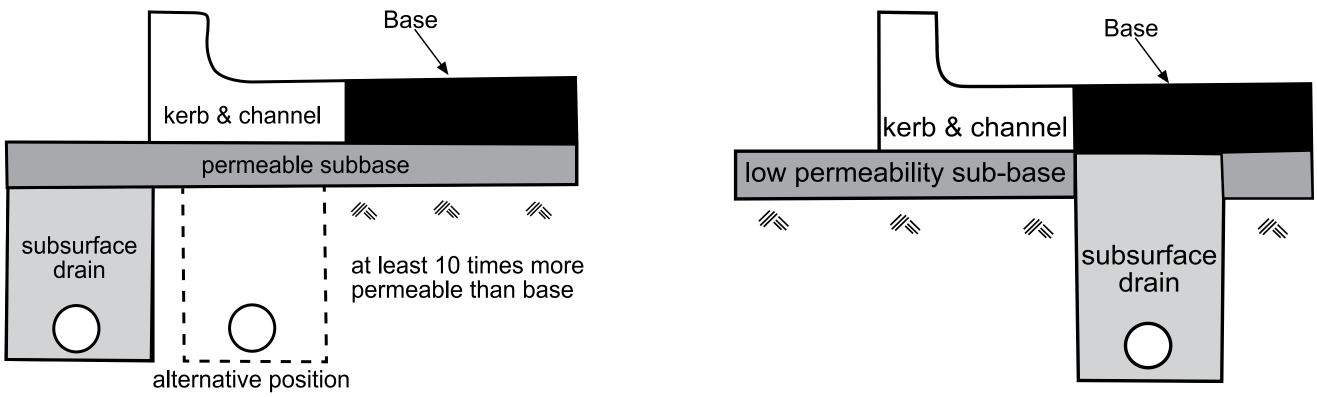



**Figure 6-15: Cross-section of typical subsoil drains**




Water from the base course is able to reach the subsurface drain through the subbase.

Alternative satisfactory subsurface drain arrangement. Water from the basecourse is given direct access to the subsurface drain.

**Figure 6-16: Satisfactory subsurface drain arrangement**

**Drainage task rates/productivities**

Table 6-2 provides recommended productivities for drainage works by hand.

**Table 6-2: Drainage Productivities (ILO)**

<table>
<tr><th colspan="4">TASK RATES / PRODUCTIVITY NORMS</th></tr>
<tr><th colspan="2">ACTIVITY</th><th>TASK RATE</th><th>REMARKS</th></tr>
<tr><td colspan="2">Stone Collection and Loading</td><td>2.5 m³/wd</td><td></td></tr>
<tr><td colspan="2">Sand Collection and Loading</td><td>3.0 m³/wd</td><td></td></tr>
<tr><td colspan="2">Hand Placing of Stones for Retaining Walls</td><td>2.5 m³/wd</td><td></td></tr>
<tr><td colspan="2">Scour Check Construction</td><td>5 Nos./wd</td><td>Where stone is available close by.</td></tr>
<tr><td rowspan="3">Culvert Construction</td><td>Standard slab culvert</td><td>48 wd/culvert</td><td></td></tr>
<tr><td>600 mm Ø culvert</td><td>17 wd/culvert</td><td></td></tr>
<tr><td>900 mm Ø. culvert</td><td>18 wd/culvert</td><td></td></tr>
<tr><td rowspan="6">Drift Construction</td><td>set out + supervision</td><td>4 wd/drift</td><td>Standard 10 x 6 drift.</td></tr>
<tr><td>excavate foundation</td><td>5 wd/drift</td><td></td></tr>
<tr><td>prepare base and place welded mesh</td><td>2 wd/drift</td><td></td></tr>
<tr><td>cut-off wall</td><td>12 wd/drift</td><td></td></tr>
<tr><td>casting slab</td><td>20 wd/drift</td><td></td></tr>
<tr><td>outlet protection, etc.</td><td>7 wd/drift</td><td></td></tr>
</table>

# SECTION 7: CONCRETE WORKS

## 7.1 CONCRETE PREAMBLE

Concrete is a construction material composed of cement (commonly Ordinary Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel, limestone, or granite, plus a fine aggregate such as sand), water, and in some cases chemical admixtures. The word concrete comes from the Latin word “concretus”, which means “hardened” or “hard”.

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. Concrete is used to make pavements, architectural structures, foundations, roads and highways, bridges and overpasses, parking structures, bricks and cement block walls and footings for gates, fences and poles.

In road works, most of the constructed structures involve concrete works, which if not properly constructed may adversely affect the life of the road. The in-situ preparation of concrete and its products allows for increased labour intensity on projects, but requires availability of materials and strict control for the achievement of quality assurance.

## 7.2 TYPES OF CONCRETE

There are many different types of concrete based on composition in relation to the intended use. The most commonly used in general civil engineering works are lean concrete, mass concrete, structural concrete, prestressed concrete and precast concrete.

Lean concrete has a low cement content meant for non-structural use. It is mainly used for filling such as over excavations. Mass concrete is also known as unreinforced concrete and used for foundations including blinding, mass structures such as dams and gravity retaining walls. Structural concrete is of relative high density consisting of stone aggregate and has high strength and usually reinforced and designed for load bearing purposes. Prestressed concrete is essentially structural concrete which is subjected to compression in those parts which in service are subjected to tensile forces so that generally, the concrete is nowhere in a state of tension under the working load. Precast concrete is that which is placed in separate moulds, under controlled factory conditions, to harden and then transferred to site for final erection. This procedure which allows high quality concrete castings to be made at low relative costs is used for the production of paving slabs, bricks, road channels, kerbs, lintels, fence posts, beams and the like. Precast units can include reinforcement and engineered steel inserts.

## 7.3 CONCRETE COMPOSITION

Concrete is normally composed of water, cement, sand and stone aggregate in specified proportion depending on the intended use and target quality.

### 7.3.1 Water

Water used for concrete should generally be free from oils, acids, alkalis and organic impurities. As a guide water fit for drinking can be used in concrete. However, when working in remote areas it may not be possible to get potable water and the project may have to use water that is not potable. The following should be noted:

- Soft water produces weaker concrete than hard water[28].
- Water from marshes is generally not suitable for concrete..

[28] Soft water has hardness as $CaCO_3$ of less than 50mg/l, reasonably soft 50 to 100 mg/l, Slightly hard 100 to 150 mg/l, Reasonably hard 150 to 250 mg/l, Hard 250 to 350 mg/l, very hard more than 350mg/l. Rain water is usually soft as it has very little opportunity to absorb chemicals.

- Water containing decaying vegetables is undesired as this contamination interferes with cement setting.
- Salt water seas is not preferred for any concrete works, in particular reinforced concrete works. However, sea water may be used for mass concrete if nothing else is available. Sea water retards setting and hardening with coupled risk of efflorescence[29] but will generally not affect the ultimate strength of concrete unless excessive quantities of salt are present in the water. Excessive salts tend to corrode reinforcement.

### 7.3.2 Cement

Most building and engineering works employ the use of Ordinary Portland Cement (OPC). In concrete works one should generally assume the use of OPC unless another type is specified. Not all other types[30] are available in many countries due to technological and demand constraints. As a guide the following should be adhered to:

- Cement should be stored in a dry place protected from atmospheric elements on a wooden platform raised at least 150mm above the floor
- Avoid stacking more than ten to twelve bags as the bottom bags may burst. Generally bags should not be stacked to a height exceeding 4.5 metres
- Store the cement in close stacks to avoid air circulation and absorbance of moisture from the air
- Avoid storing cement for more than two months from the date of leaving the Manufacturer’s premises before usage
- Cement stored for more than two months should not be used for critical structural members. Cement stored for more than two months but less than six months may be used in some minor works with the Engineer’s approval. Cement stored for more than six months should be discarded or at least re-tested before any reuse is considered. As a general rule stocks first in must be used first.

### 7.3.3 Stone Aggregate

Stone aggregate is the course aggregate which normally consists of crushed stone, which consists of materials which are mainly retained on a 5mm sieve. Characteristics of concrete are directly related to those of the aggregates. Aggregate should therefore be durable and chemically inert under conditions to which they will be exposed. Nominal maximum sizes of coarse aggregate are usually 50mm, 40mm, 20mm, 13mm and 10mm depending on the intended use of the concrete. As a guide the maximum size of the aggregate should not exceed 25% of the minimum member thickness and should not exceed the design cover to the reinforcement.

Stone aggregate used in concrete work must be clean and free from clay, loam, vegetable and other organic matter. Stockpiling of aggregate should ensure that segregation is avoided. All washed aggregate should be stacked and allowed to drain for at least twelve hours.

### 7.3.4 Sand

Sand is fine aggregate most of which passes a 5mm sieve. It is used as an ingredient in concrete that fills the voids in coarse aggregate to produce a dense concrete and reduce the quantity of cement used.

Sand used in concrete should be clean and free from impurities such as clay, silts, salts, mica and organic matter. Coal particles in sand are particularly undesirable as they corrode the reinforcement. Sea sand is generally too fine and its salts tend also to attack the reinforcement. Sands with high concentration of salt also tend to retard setting and hardening of cement in the concrete also causing efflorescence though this will not adversely affect the ultimate strength.

The following simple field tests are used for determining the extent of contamination of the sand used in concrete:

- **Test for silt or clay:** An approximate test may be carried out by rubbing a sample of sand between damp hands and noting the palm discolouration. Clean sand will leave the palms slightly stained whilst silty or clayey sands will leave them dirty.

[29] Efflorescence is the phenomenon when salts and other water dispersible materials come to the surface of concrete and mortar.

[30] Other types of cement are: high alumina, super sulphated, and special cements.

- **Decantation test:** This is a more precise test. Half fill a constant diameter glass with sand and then fill it up to three quarters with clean potable water. Mix the contents thoroughly by shaking the glass and then allow it to settle for an hour. Clean sand settles immediately. The presence of clay will leave the water at the top muddy. Clay/silt will slowly settle as a layer on top of the sand. If the thickness of the clayey layer is more than 6% of the sand layer then the sand needs to be washed.
- **Test for organic impurities:** Place a sample of sand in a glass bottle with an equal volume of a 3% solution of caustic soda (i.e. 25 grams in 1 litre of water) and then allow the mixture to stand for 24 hours. The water mixture above the sand should normally be pale yellow if the sand is clean. If the water mixture is markedly yellow or brown this indicates the presence of excessive amounts of organic material.

## 7.4 MIXING CONCRETE

Concrete is mixed using different proportions of its basic ingredients, depending on the purpose and function of the completed structure. The quality of the concrete is highly dependent on the portion of each of these ingredients. Equally, the methods used for mixing and curing determine the final quality of the concrete.

### 7.4.1 Type of mixes

Concrete is classified into Class or Grade according to strength which influences application. A mix design depends on the type of structure being constructed, environmental considerations, properties of the materials and workmanship amongst others. Concrete mixes are usually specified arbitrarily in the ratio of 1 unit of cement to sand and stone aggregate for example 1:2:4. Normally when volume batching, a 50kg bag of cement is taken to have a volume of 35 litres. Different manufacturers of cement specify a bag of cement volume to range from 33 to 36 litres. *Assuming a bag to be equivalent to 35 litres, this means that a 1:2:4 mix will be one 50kg cement bag mixed with 70 litres (2 x 35 litres) of sand and 140 litres (4 x 35 litres) of stone.* This fundamental concept of concrete mixing is important for concrete professionals, designers and end users.

The following provides a basic guide of concrete mixes used for different purposes.

**Table 7-1: Concrete mix guide for different applications**

| Concrete Mix Guide | | | Suitable Types of Construction |
|---|---|---|---|
| 1 : | 1 | : 2 | Heavily loaded reinforced columns; long span arches |
| 1 : | 1.5 | : 2 | Reinforced concrete reservoirs and water retaining structures; concrete roads; concrete piles; fence posts; precast Reinforced concrete members; other works where dense concrete for impermeability or high strength. |
| 1 : | 2 | : 4 | Normal Reinforced Concrete works in beams, columns, walls, arches, and road slabs. |
| 1 : | 2.5 | : 5 | Mass concrete in superstructures, massive reinforced concrete members, floors for machinery, walls below ground level, house foundations, footings, foundation footings for single storey light structures, cement concrete blocks |
| 1 : | 3 | : 6 | |
| 1 : | 4 | : 8 | Mass concrete foundations, lean mixes to replace incompetent foundation soils. |
| 1 : | 5 | : 10 | |
| 1 : | 6 | : 12 | |

*ILO - LIC Guidelines for water provision, sanitation, solid waste and building works*

The concrete mix design is always subject to approval by the Engineer.

## 7.5 PROPERTIES OF CONCRETE

Strength and durability are generally considered the most important qualities of concrete. Other important properties of concrete that are not discussed in this document include creep, shrinkage, elastic modulus, fire resistance, abrasion resistance and thermal conductivity.

### 7.5.1 Strength

Compressive strength is the most common measure of assessing concrete quality. The characteristic strength of concrete is its compressive strength based on a 28-day cube strength. The 150mm cubes are compressed to failure after 28 days of mixing and the crushing strength is noted and recorded giving the sample's characteristic strength. Testing is usually done using a suitable compression testing machine.

### 7.5.2 Durability

Durability of concrete is concerned with its ability to withstand environmental conditions. Durability is directly related to concrete's permeability. In concrete design and construction the main requirements for durability are intrinsically governed by the following:

- Setting an upper limit to the water cement ratio
- Setting a lower limit for the cement content
- Setting a lower limit to concrete cover to reinforcement
- Ensuring good compaction
- Ensuring adequate curing

Conforming to the above ensures durability of the concrete.

### 7.5.3 Water-cement ratio

The strength of concrete depends to a great extent on the amount of water used during mixing. The amount used should be the minimum necessary to give sufficient workability for efficient consolidation of the concrete. Using too much water compromises the ultimate strength of the concrete whilst using less water reduces its workability and also compromise quality. The amount of water is specified by weight and stated as a fraction of the cement used, alternatively weight of water divided by weight of cement:

$$Water\ Cement\ Ratio = \frac{Weight\ of\ \ water}{Weight\ of\ \ Cement}$$

If the sand is damp (moisture can amount to up to 25% of its weight) then the added water quantity has to be reduced. A simple hand test helps to determine whether the mix has the right consistency and water content:

- Pick a handful of mixed concrete and form a ball in your hand. If this is not possible, then the mix is too wet.
- Drop this ball onto a hard surface and observe whether the ball retains its general shape. If the ball totally collapses, then the mix is too wet.

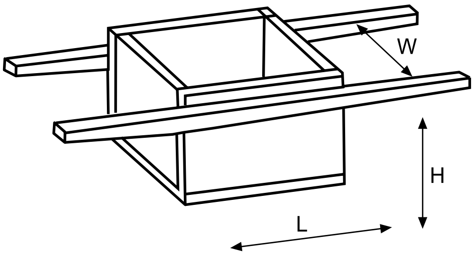
## 7.6 BATCHING FOR CONCRETE MIXING

For ease of construction, the various concrete ingredients are measured by volume or by weight where accuracy and equipment permit. This is referred to as batching. Small quantities of concrete is usually mixed by hand on site. Larger volumes are produced using a concrete mixer available on site or ordered from a nearby concrete mixing plant. In urban areas pre-mix concrete suppliers are readily available. Hand mixing is used for minor works involving low grade concrete (say 25MPa or less) such as for culverts, manhole bases and other small works. Hand mixing can also be promoted in order to maximize employment creation. When volume batching, in order to achieve the required mix proportions gauge boxes are used to batch the dry aggregates.

Batching (measuring material proportions) can be done in two ways, namely by volume or by weight. A gauge box, made out of wood or steel, can easily be manufactured to same volume as a 50kg bag of cement - 35 litres when filled level with the top. The box is fitted with handles for ease of lifting and unloading within mixing areas or at concrete mixers as shown in Figure 7-1.

When mixing concrete for water retaining structures it is strongly recommended to use weigh batching because of the increased quality requirements.

**Figure 7-1: Concrete gauge box**




Internal measurements:
Length = 40 cm
Width = 35 cm
Height = 25 cm
Volume = 0.035m$^3$

= 35 litres

Table 7-2 gives prescribed mixes for ordinary portland cement using volume batching. Table 7-2 assumes mechanical vibration of the concrete.

**Table 7-2: Concrete mix Guide for different grades of concrete**

| Grade | Mix Ratio | Water Cement Ratio | Nominal Stone Size |
|---|---|---|---|
| 10 MPa | 1 : 4 : 8 | 0.85 | 50 mm |
| 15 MPa | 1 : 3 : 6 | 0.70 | 19 mm |
| 20 MPa | 1 : 2.5 : 5 | 0.60 | 19 mm |
| 25 MPa | 1 : 2 : 4 | 0.56 | 19 mm |
| 30 MPa | 1 : 1.5 : 3 | 0.52 | 19 mm |
| 40 MPa | 1 : 1 : 2 | 0.50 | 19 mm |

*Source: DPW Specification 377, South Africa*

## 7.7 HAND MIXING

Hand mixing involves the use of labour and simple hand tools such as shovels, spades, and watering cans. Hand-mixed batches should not exceed 0.5m$^3$ and the mixing should never be done on the bare ground, as this will result in contamination of the mix. A platform of about 4m by 4m can be built with timber boards, metal sheets or lean concrete. The following are typical steps for hand mixing:

- Measure the amount of sand and stone with a gauge box according to the specified ratio and place them in alternating layers on the platform.
- Spread the required quantity of cement over the top.
- The dry materials should be mixed at least three times. Two persons, one on each side of the heap, shovel the heap to a convenient spot, turning the material in the process. This operation is repeated, the heap being thrown back to its original position and then back again until the colour of the dry mix is uniform.
- Water is then added by a third person while turning the mix the fourth time using a watering can or a bucket (use your hand to sprinkle from the bucket) so that the water is spread evenly while the material is mixed again. Only the correct amount of water should be added.
- The water from the middle getting lost, mixing must be continued (to be turned at least three times) until the concrete is uniformly wet and has reached the required consistency (see Figure 7-2 below).
- Another, often applied method is to spread the dry mix, make a hollow in the middle and then add the water into this hollow. Afterwards the mixing is done very carefully to avoid any of the water in the middle getting lost.

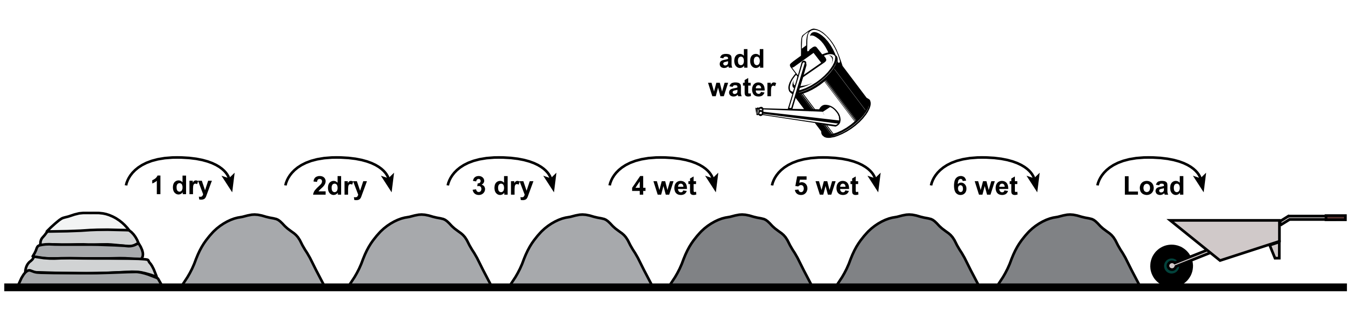



**Figure 7-2: Hand mixing of Concrete**

## 7.8 MACHINE MIXING

This section focuses on the use of mobile concrete mixers to manufacture concrete. This section focuses on the use of mobile concrete mixers. These are normally used on site in combination with labour and hand tools. Batch Concrete Mixers are available in tilting and non-tilting types. Tilting Mixers tilt to discharge their contents whilst non-tilting ones empty their contents by means of chutes. Concrete mixers sizes are designated by two numbers say 142/100; 199/142 in the metric system *(alternatively in imperial units is stated as 5/3.5; 7/5)*. The first figure indicates the drum capacity in litres *(alternatively in imperial units in cubic feet)* and this is the capacity of the mixer for dry materials. The second indicates the approximate volume of concrete produced in litres *(alternatively in cubic feet)*. A 142/100 mixer produces 100litres of concrete from 142 litres of dry material *(alternatively a 5/3.5 mixer produces 3.5 cubic feet concrete from 5 cubic feet of dry material)*.

**The following are typical steps for using concrete mixers:**

**Step 1:** Transport batched materials close to the mixer.

**Step 2:** Stone aggregate is placed first in mixer hoper followed by sand and then cement.

**Step 3:** A small quantity of water is then added into the revolving drum to lubricate it followed by the dry mixture to achieve uniformity.

**Step 4:** Add the remaining quantity of water gradually whilst mixing. The concrete should be mixed for at least two minutes until the concrete is uniform in colour and consistency.

**Step 5:** After each batch is discharged the drum should be washed clean before placing the next batch.

Table 7-3 gives an estimate of suggested concrete output rates for selected concrete mixers.

**Table 7-3: Concrete Mixer recommended Minimum Daily Outputs**

| Mixer Size Type | Output per eight hour Shift in $m^3$/shift (6 hours operations plus 2 hours rest and clean-up) |
|---|---|
| 142/100 (5/3.5) | 7.3 |
| 199/142 (7/5) | 9.3 |
| 284/199 (10/7) | 11.7 |

## 7.9 TRANSPORTING CONCRETE

Concrete should be mixed as near as possible to the site it is to be placed to avoid segregation during transport and to shorten the time between mixing and placing. On site, concrete is usually transported in wheelbarrows, head pans or buckets. Ready-made (pre-mix) concrete is transported to site by trucks and thus good access needs to be secured to where the concrete will be placed.  All formwork needs to be ready and approved by the engineer before commencing a conctrete pour.

## 7.10 PLACING AND COMPACTION OF CONCRETE

Concrete should be placed as soon as possible and before it starts setting. It should be placed within one hour of discharge from a concrete mixer and within fifteen minutes of mixing if hand-mixed. The formwork, or shuttering, must be clean, secure from movement or leakage and should be wetted before the concrete is poured. Steel and wooden formwork should be oiled (used engine oil mixed with diesel is acceptable for this purpose) to allow it to be removed easily later on.

Compaction of concrete may be undertaken in two ways, either manually by hand ramming or by using a mechanized vibrator (poker vibrator). For concrete layers of thickness not exceeding 30cm hand vibration may be considered. This may be increased to 50cm when a vibrator is used. Each layer should be rammed or vibrated before the next layer is spread. As a rule of thumb, sufficient compaction is achieved when water appears on the surface and/or drips through the joints of the formwork, provided the water/cement ratio is correct and the formwork has been constructed with tight joints. Care must be taken not to over-vibrate the layers as this leads to segregation and compromises its ultimate strength.

Manual vibration can be carried out using a round steel reinforcement bar. Poke the bar in small distances deep into the concrete layer, twist the bar and move it up and down at the same time. Repeat this procedure at every 10cm to 15cm in all directions on the layer.

Before placing the concrete, ensure that the reinforcement is free from loose scales, loose or scaly rust, oil and grease. A thin coat of light rust which firmly adheres to the steel bars is not considered harmful. When steel rods are stored for long periods they may be given a cement wash to mitigate against rust and placed off the ground with cover against rain. Loose rust can be removed by using wire brushes. Oil, grease and paint may be removed by mild heat from a blow torch. Overheating of steel rods should be avoided at all costs.

Quality screeding of flat surfaces can be achieved by using a rectangular wooden board or where appropriate power and bull floats may be used.

## 7.11 CURING CONCRETE

Curing concrete is the process of providing moisture and favourable temperature to enable cement to continue to hydrate thereby increasing the strength of concrete. A chemical reaction, commonly known as hydration, takes place when water is added to cement, which result in the setting and hardening of cement. The concrete should be maintained at a temperature of between 5°C and 25°C in the first half day after casting as higher temperatures may retard future development in strength whilst lower temperatures may reduce significantly the ultimate strength of the concrete. This is achieved by using isolation mats to keep the concrete warm. Keeping the concrete moist lowers the temperature when the water evaporates. It is generally accepted that concrete continues to harden for at least one year after casting. Table 7-4 below shows the relationship of strength and concrete age over a period of one year.

**Table 7-4 Comparative strength of OPC concrete**

| Age | Strength as a Percentage of Specified Criteria |
|---|---|
| 3 days | 40% |
| 7 days | 65% |
| 28 days | 100% |
| 3 months | 115% |
| 6 months | 120% |
| 12 months | 130% |

*Source: ILO- LIC Guidelines for water provision, sanitation, solid waste and building works*

It takes at least 28 days for concrete to gain design strength. This time span is called the curing period and special care must be provided during this time. The surface of the concrete should be kept constantly wet. This can be achieved by any or combination of the following:

- slabs can be covered with damp sand or wet canvas and watered regularly;
- covering the concrete with polyethylene sheets (additional water must be added from time to time);
- continuous watering;
- concrete should be protected from direct sunshine; .
- the crown of walls and beams should be covered with wet canvas, polyethylene sheet or leaves;
- water should be added to the crown at least during the first 7 days.

Formwork should not be removed before the stipulated time in the specification. Table 7-5 gives a guideline for formwork striking off (removal) times.

**Table 7-5: Formwork striking off times**

| DESCRIPTION | Minimum period for removal of formwork in days for | | | |
|---|---|---|---|---|
| | Normal Cement | | Rapid Hardening Cement | |
| Weather: | Normal | Cold | Normal | Cold |
| Beam sides, walls, unloaded columns | 2 | 4 | 1 | 2 |
| Slabs with props left under | 4 | 7 | 2 | 4 |
| Beam soffits with props left under including ribbed slabs | 7 | 12 | 3 | 5 |
| Removal of slab props | 10 | 17 | 5 | 9 |
| Removal of beam props | 14 | 28 | 7 | 12 |

*Source: NDPW Specification 371*

## 7.12 CONCRETE REINFORCEMENT

Concrete is weak in tension and strong in compression. Different types of reinforcement are usually employed to improve its tensile strength in the tension area to prevent failure as shown in Figure 7-3:

These include steel reinforcing bars, steel plates, welded steel fabric reinforcement, glass fibre and plastic fibre. Steel Bars and welded steel fabric are the most commonly used due to the abundance of steel. Care should be taken to maintain the concrete cover by placing spacers for the reinforcement and ensuring it is not displaced.

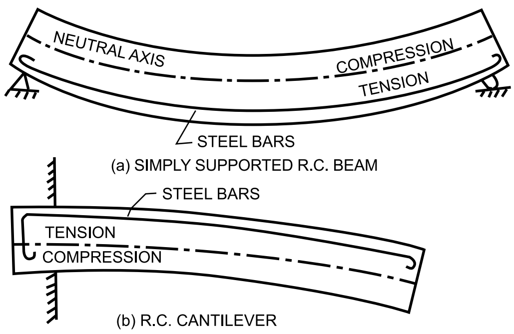



**Figure 7-3: Reinforced concrete beams in tension and compression**

### 7.12.1 Steel reinforcement

Mild Steel, High tensile steel bars and welded steel fabric reinforcement (mesh) [31] are normally used as reinforcement. Typically mild steel has a yield strength of 250 and 300 N/mm$^2$, for high tensile steel yield strengths of 410, 450 and 460 N/mm$^2$ are common. Bars are normally supplied in lengths of 6 to 18 metres in increments of 1 metre as ordered for sizes 6, 8, 10, 12, 16, 20, 25, 32 and 40 mm diameters.

## 7.13 HAZARDS IN HANDLING CONCRETE

Cement is essentially a chemical and exposure to it may have adverse health effects. Care therefore has to be taken in concrete manufacture, transportation and placing in order to mitigate potential hazards by using gloves

[31] In South Africa reinforcement bars have to comply to SANS 920 and fabric reinforcement to SANS 1024.

and taking care not to get splashing cement into your eyes. Protective clothing should be used to avoid cement in contact with skin. Eyes can be severely damaged by cement. In case wet cement splashes into the eyes of a worker, it is necessary to rinse the eyes copiously in clean water for at least 30 minutes.

Finally, it is worth reminding that the formwork and shuttering needs to be sufficiently strong to carry the load of the concrete before it has cured. The stability of formwork and shuttering needs to be carefully monitored when pouring concrete for beams and slabs. When pouring takes place for such structures it is important that people stay at safe locations and avoids areas onto which the formwork may collapse.

## 7.14 CONCRETE WORK PRODUCTIVITIES

Table 7-6 gives a guide to concrete work labour productivities

**Table 7-6: Task rates/productivities for concrete works**

| TASK RATES / PRODUCTIVITY NORMS | | |
|---|---|---|
| **ACTIVITY** | **TASK RATE** | **REMARKS** |
| Stone Collection and Loading | 2.5 $m^3$/wd | |
| Sand Collection and Loading | 3.0 $m^3$/wd | |
| Mixing of concrete by hand | 1.0 $m^3$/wd | |

## Notes

# SECTION 8: SEALING OPTIONS USING EMPLOYMENT INTENSIVE METHODS

## 8.1 GENERAL

Unsealed earth and gravel roads in developing countries usually deteriorate rapidly mainly due to non-traffic-related factors such as climate, terrain, soil conditions and ineffective maintenance thus resulting in huge annual maintenance costs. Furthermore dust pollution created by these roads cause adverse environmental degradation and health hazards. The fast depletion of the non-renewable construction material (gravel) in some countries makes the rehabilitation and maintenance of the expanding road network unsustainable.

Surfacing of gravel roads using appropriate designs conducive to labour-based work methods can reduce maintenance requirements while at the same time increase benefits to local economies. Regional research[32] has shown that it is economically justified in the long term to seal gravel roads, considering life cycle costs even at traffic levels less than 100 vehicles per day (vpd).

The purpose of this section is to share experience from research on low-volume road seal options carried out in Limpopo Province in South Africa which have been replicated in other countries including Tanzania, Kenya, Indonesia, and Cambodia, and to present technical solutions that are labour-friendly and amenable to employment intensive approaches.

## 8.2 FUNCTION OF A SEAL

Bituminous surfacings are an integral component of the road pavement and perform a number of functions that offer many advantages over unsealed roads. These include:

- Providing a durable, impervious surface which seals and protects the pavement from moisture ingress and consequent loss of strength;
- Provides a skid-resistant surface that resists the abrasive and disruptive forces of traffic and the environment;
- Prevents the formation of corrugations, dust and mud thereby allowing safe travel at higher speeds and lower vehicle operating and maintenance costs.

As for all bituminised roads, the pavement strength must be sufficient to carry the anticipated traffic loads.

## 8.3 TYPES OF SEALS

This section covers specifications, construction procedures, and challenges encountered and recommendations of the best options for types of seals which are labour-friendly and amenable to labour-based methods:

- o Hot Bitumen seals
    - Otta Seal
    - Grav Seal
- o Emulsion-based seals
    - Sand Seal
    - Modified Otta Seal
    - Cape seals
    - Slurry seals
    - Slurry-bound macadam seals
- o Cold Asphalt seals
    - Labour Based Seal (LBS – Proprietary)
    - In-situ Cold Mix Asphalt

Bituminous binders for seals are produced either in the form of straight penetration grade bitumen, cut-back bitumen or bitumen emulsions. All the above can be modified e.g. with crumbed rubber or latex to improve their properties.

[32] SADC Guideline on Low-Volume Sealed Roads, July 2003

## 8.4 CHOICE OF SURFACE TYPE

The choice of bituminous surfacing type depends on a number of factors such as:
- Type of pavement (strength, flexural properties, etc.);
- Economic and financial factors (funds available, life cycle costs, etc.);
- Required riding quality;
- Operational factors (traffic, surface stresses, geometry, etc.);
- Safety (surface texture, interference with traffic, etc.);
- Environmental considerations (climate, noise, etc.);
- Construction and maintenance strategies;
- Characteristics of available materials (aggregate, binder, etc.).

Apart from the surfacing type meeting various technical and environmental requirements, a life cycle cost comparison of alternative surfacing types needs to be carried out in order to determine the most cost-effective solution. Such comparisons would normally consider not only initial construction costs, but also include maintenance and vehicle operating costs.

## 8.5 GENERAL REQUIREMENTS FOR SEALING OPERATIONS

### 8.5.1 Lead times

Project managers must ensure that the site is prepared and necessary resources are mobilized to site before the sealing operation commences. All equipment needs to be in good working order, materials have been delivered and proficient personnel have been mobilized. The most critical items are:
- **The bitumen products to be used.** Management needs to place orders in good time before the planned starting date for the sealing operations. Bitumen should be stored in a safe and easy to use manner;
- **The aggregate to be used.** It can sometimes be difficult to get the correct grading of aggregate from the nearest crusher. A special production run may have to be made for the required aggregate grading and time must also be set aside for testing the aggregate and transport to site. It is therefore important to secure a guarantee from suppliers to deliver the products in good time. Allow for possible wastage when ordering aggregate;
- **The motorized hand sprayer.** It must be checked to be in good working order. If any part is defective, there may be a considerable lead time to get it delivered and fitted. A spare set of fast moving parts should always be kept in stock (spark plugs, belts, filters etc.).
- **Spray screens.** These could be manufactured by a workshop. They should be made of 1mm smooth steel plates measuring 1m by 2m mounted on a frame of square steel tubing and have two handles on one of the long sides to enable easy holding and moving.
- For spotting of aggregate, a half drum open in both ends fitted with two handles is required and this could also easily be manufactured in a workshop.

All other items and material needed are off-the-shelf and readily available at all times (diesel, paraffin, tar solve, twine, mutton cloth, pegs, buckets etc.). Make sure to acquire these items and get them to site on time.

### 8.5.2 Base preparation

#### 8.5.2.1 Repairing and cleaning base course surface

As a general rule, no part of the works should be covered up by another pavement layer before it has been tested and approved. Therefore, before the prime or seal is applied its base needs to meet all specifications in terms of:
- Compaction (or density)
- Level
- Surface texture
- Surface regularity

It is important that the above is confirmed in writing by the Engineer. Any irregularities or weak spots must be repaired as instructed and approved before priming and sealing works commence. On the day of the sealing, the base is broomed to remove all loose matter, debris, animal droppings etc. Special care must be taken to ensure that all fine dust is thoroughly broomed off. Otherwise the prime or seal will not bond properly to the surface of the base course.

#### 8.5.2.2 Dampening of the base

Bitumen will not penetrate into and bond properly to the base if the surface is completely dry. This is because of the surface tension of the base material that causes the material to repel the bitumen. In order to break this surface tension, the base is therefore lightly sprayed with water just prior to the application of the bitumen. A fine mist spray applied with a hose pipe and spray nozzle is best in order to avoid over application and soaking of the base. Watering cans with spray nozzles can also be used. If for some reason the bitumen application is delayed and the base has dried out, water should again be applied before the bitumen is sprayed. Failure to break the surface tension will result in “fish-eyes”, i.e. bubbles in the bitumen with no coverage and bonding to the underlying base. These are potential weak spots, which, if not rectified, will result in premature localized failure of the seal and the early development of potholes.

### 8.5.3 Quality control measures

Quality Control measures for sealing works as outlined below should be put in place through conducting specific tests on materials, components and workmanship standards to ensure the final product complies with the project specifications.:

- Good quality hand tools and appropriate equipment as specified should be used
- Testing the quality of the seal aggregates
- The engineer must check and give approval/acceptance of the following surfacing operations:
  - Bitumen and aggregate supplied, and pre-coating, if applicable
  - Prime coating, if applicable.
  - Binder spread rates.
  - Aggregate spread rates.
  - Brooming and rolling.
  - Construction setting out/levels, joints, transverse and longitudinal
  - General quality of workmanship
  - Traffic management

For approval of the bitumen and aggregates the following tests may have to be carried out at a reputable laboratory:
Seal aggregates:

- Hardness and durability
  - Los Angeles Abrasion Value (LAA)
  - Aggregate Crushing Value (ACV)
  - Aggregate Impact Value (AIV)
  - 10% Fines (aggregate crushing) Value (10% FACT)
  - Sodium Sulphate Soundness
- Shape
  - Flakiness Index (FI)
  - Average Least Dimension (ALD)
- Size and grading
  - Nominal size
  - Sieve analysis (Particle Size Distribution)
  - Plasticity Index (PI)

Binders and primes:

- Penetration grade and cut-back bitumen
  - Penetration at 25 °C.
  - Ring and ball softening point.

  - o Viscosity.
  - o Distillation to 190, 225, 260 and 316°C.
- Emulsions
  - o Saybolt Furol viscosity.
  - o Storage stability.
  - o Coating ability.
  - o Distillation and tests on the residue.

For bitumen products the contractor may have to rely on the manufacturer's certificate which should accompany all deliveries from factory to site.

### 8.5.4 Weather constraints

Sealing operations should only be done during the day and only in good weather conditions and when rain is not imminent. The road surface temperature should be above 10°C. Spraying in the late afternoon is not advisable as the reduction in air temperature by dusk will influence the setting and curing of the prime or binder. Care should be taken when spraying on a windy day as the spray may be carried some distance and damage property or passing vehicles down-wind of the operation.

### 8.5.5 Traffic control

It is quite costly and seldom are bypasses provided on labour based construction projects. Normally, traffic is allowed to use one-half of the unconstructed road whilst the other half is under construction. Due to the risk from traffic adjacent to the works, measures must be taken to warn and protect both road users and the road workers. Road signs must be placed on both sides of the road works in order to warn traffic coming from both directions of the obstruction ahead. The warning signs should alert traffic to the presence of men working, a closed lane, loose chippings and speed restrictions at the site. These signs must be placed ahead of the road works to give advance warning of the danger to traffic, along the length of the road works to protect the site from traffic, and at the end of the road works in order to indicate that there is no further restriction to traffic. Traffic cones should be used to mark the boundary of the work site. Either a temporary traffic light system should be used, or a traffic operator using a reversible 'stop/go' sign.

Traffic accommodation needs to be well managed as it places the entire workforce at risk. Temporary speed bumps may be needed to slow down passing traffic. Training in the correct operation of traffic accommodation at road works is vital for the safety of the workmen team as well as allowing safe, free flowing traffic.

### 8.5.6 Occupational Health and Safety

The welfare of the workforce is key to achieving good productivity and a quality end product. The health and safety of the workers is governed by the national labour laws and regulations and must be adhered to. Occupational Health and Safety measures in sealng works include safe storage, handling, spraying of hot bitumen products, first aid, personal protective equipment (PPE), and firefighting equipment.

## 8.6 HOT BITUMEN SEALS

### 8.6.1 Construction of Otta seal

An Otta Seal is a bituminous surfacing that was originally developed in the early 1960's by the Norwegian Road Research Laboratory. It derives its name from the location in Norway where it was first used – Otta which is a town in the valley of Gudbrandsdalen. Although originally intended to serve as a temporary surface for newly constructed gravel roads, its good performance led to its adoption as a permanent single or double seal surfacing for both new and existing roads in Scandinavia as well as in East and Southern Africa and to a limited extent in Asia.

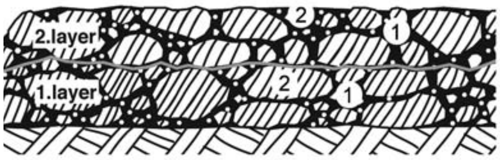
Otta Seals essentially consist of a 16 - 32 mm thick bituminous surfacing constituted of an admixture of graded aggregate from natural gravel or crushed rock in combination with relatively soft (low viscosity) binders, with or without a sand seal cover. The mechanism of performance is as follows - the graded aggregate is placed on a relatively thick film of comparatively soft binder which, on rolling and trafficking, works its way upwards through the aggregate interstices. In this manner, the graded aggregate relies both on mechanical interlocking and bitumen binding for its strength – similar to a bituminous premix. Traffic on the seal immediately after rolling is desirable producing its final appearance after 4 - 8 weeks giving a "premix" like appearance. Priming of the base is normally not required. This surface type contrasts with the single sized crushed aggregate that is 'glued' to a relatively hard (high viscosity) binders used in conventional surface dressings e.g. Chip Seals, as shown in Table 8-1. Depending on the prevailing conditions, Otta seals can be laid as a single or double seal, both types with or without a sand cover.

**Table 8-1: Comparison of Otta seal with conventional chip seal**

**Otta Seal**

SINGLE OTTA SEAL
No Prime
1 Binder
2 Graded aggregate


DOUBLE OTTA SEAL
No Prime
1 Binder
2 Graded aggregate




**Conventional Chip Seal**

SINGLE CHIP SEAL
1 Prime
2 Binder
3 Stone


DOUBLE CHIP SEAL
1 Prime
2 Binder
3 Large Stone
4 Binder
5 Small stone


| **Parameter** | **Otta Seal** | **Conventional Chip Seal** |
|---|---|---|
| **Aggregate quality** | Relaxed requirements for:<br>- strength<br>- grading<br>- particle shape<br>- binder adhesion<br>- dust content<br>- Maximises use of locally available natural gravel or of the crushed product. | Stringent requirements for:<br>- strength<br>- grading<br>- particle shape<br>- binder adhesion<br>- dust content<br>- Maximised use of the crushed product is difficult, use of natural gravel is in practice inappropriate |
| **Binder type** | Relatively soft binders (low viscosity) are required: 150/200 penetration grade or MC3000 or MC800 cutback bitumen. | Relatively hard binders are required for necessary stone retention: (80/100 pen. grade under Botswana conditions). |
| **Design** | Empirical approach to design. Relied earlier to a large extent on experience and site trials. | Empirically based rational design methods. |
| **Construction technique** | Relatively little sensitivity to standards of workmanship. Labour intensive methods easy to apply if desired. | Sensitive to standards of workmanship. Labour intensive methods difficult to apply. |
| **Construction costs** | In most instances costs are lower than Chip Seals, up to 40% depending on the availability of aggregate. | Cost competitive only where good quarries are located nearby; the bitumen price is high and the traffic volumes are high (> 500 vpd). |
| **Contractual matters** | Additional contractual issues need to be resolved. | Contractual issues well-known |
| **Aesthetics** | An appealing, uniform appearance can be difficult to achieve. However, such an achievement is not necessarily an indicator of a good result for Otta Seals. | Ranges between a very appealing and a poor appearance depending on quality of construction workmanship. |
| **Skid resistance in wet weather** | Poorer than a Chip Seal that is well designed and constructed using large chipping. However better than Slurry Seals and Asphalt Concrete. | Ranges between the extremes of excellent and very poor depending on quality of construction workmanship. |

| Parameter | Otta Seal | Conventional Chip Seal |
|---|---|---|
| **Use on fresh bituminous base layers** | Not suitable due to the need for high bitumen contents required for quick rise of the binder through the aggregate interstices. | Suitable, but requires careful design and construction if excessive bleeding is to be avoided. |
| **Periodic maintenance between reseals** | Generally little need for periodic maintenance between reseals. | Rejuvenation with emulsion fog spray between reseals is normally required for maintaining stone retention. |
| **Durability of the seal** | The use of relatively soft binders and a dense matrix enhances durability of seal. | The use of relatively hard binders reduces the durability of the seal. |
| **Typical service life** | Typical service life:<br>- Double Otta Seal: 12 – 15 years<br>- Single Otta Seal with a sand cover seal: 9 – 11 years | Typical service life :<br>- Double Chip Seal: 8 - 10 years<br>- Single Chip Seal: 5 - 6 years<br>Adequately workmanship is essential |

*Source: Ministry of Works, Transport, and communications, Roads Department, Botswana (June 1999). The Design, Construction and Maintenance of Otta Seals Guideline No. 1. ISBN 99912-0-285-4. Allkopi AS, Oslo: Norwegian Public Roads Administration (NPRA).*

### 8.6.2 Advantages of Otta seals

Some of the factors favouring the use of Otta Seals include situations where:
- Road construction is taking place in remote areas where only natural gravels occur and where it may be prohibitively expensive to set up crushing facilities;
- Eliminating transport of stone chippings over long distances and thus reducing in overall road cost
- Workmanship may be of indifferent quality;
- Flexibility and durability of the surface require high tolerance to comparatively low quality, low bearing capacity pavements with high deflections;
- There is a low maintenance capability;
- High solar radiation levels prevail.

### 8.6.3 Challenges

One of the main challenges of Otta Seals is their initial, inconsistent and somewhat patchy appearance during the first 4 - 6 months of their service life. During this stage, the surface may appear rich in bitumen or may even “bleed”, necessitating the spreading of sand or crusher dust over the affected area to absorb the excess of bitumen. This tends to give the erroneous impression to the lay person that something is wrong with the surface or that it is of inferior quality to the more traditional Chip Seal. However, this is certainly NOT the case. After some 8 - 12 weeks with traffic the Otta seal will start to “bed down” and provide a more uniform and consistent appearance which looks somewhat like the more expensive Asphaltic Concrete seal that is generally used on heavily trafficked roads.

Another disadvantage with the use of Otta Seals relates to the need to consider some additional contractual issues in order to address some of the specifications particular to Otta seals.

### 8.6.4 Specifications

#### 8.6.4.1 Aggregates

Aggregate used in Otta seals is well graded, such as natural or crushed gravels. Since the seal can be constructed with natural gravels, it is a good option in areas where it is difficult to obtain commercial stone chippings. The preferred aggregate grading, to some extent, depends on the traffic volume at the time of construction, as well as during the two months immediately following the sealing operation, as this contributes significantly in forming the Otta Seal.

The preferred maximum particle size is 16 mm, but >19 mm can be accepted in the first seal when a double seal is constructed. The amount of fines (<0.075 mm) should preferably not exceed 10%. Higher fines content may result in construction problems, as the binder tends to coat the finer particles before the larger ones, and may lead to a less durable surfacing. This challenge can to some extent be compensated by increasing the bitumen content. Experience show that the aggregate specifications for Otta Seals are indicative and that practical experience show good results also when aggregate does not fully conform to the soil grading curves.

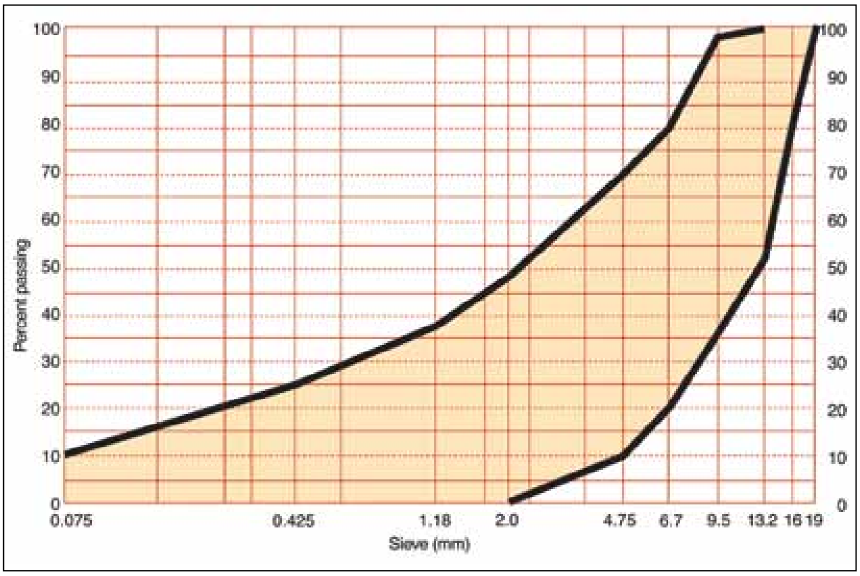
### 8.6.4.2 General grading envelopes and aggregate strength

Tables 8-2 and 8-3 show the aggregate grading requirements for an Otta Seal and Chart 8-1 the general grading envelope. The aggregate strength requirements are as given in Table 8-3 whilst Tables 8-4 and 8-5 provide respectively the bitumen requirements and spray rates. Table 8-6 also gives the Aggregate spray rate.

**Table 8-2: Otta seal aggregate overall grading requirements**

| Material properties | Requirements | TMH test method |
|---|---|---|
| Plasticity Index | max 10 | A 3 |
| Flakiness Index | max 30 (applies only for crushed material) | B 3T |
| **Sieve sizes [mm]** | **Overall grading requirements [% passing]** | |
| 19<br>16 | 100<br>80 - 100 | A 1 |
| 19<br>16 | 100<br>80 - 100 | |
| 13.2<br>9.5 | 52 - 100<br>36 - 98 | |
| 6.7<br>4.75 | 20 - 80<br>10 - 70 | |
| 2.00<br>1.18 | 0 - 48<br>0 - 38 | |
| 0.425<br>0.075 | 0 - 25<br>0 - 10 | |

**Chart 8-1: General grading envelope for Otta seal**




*Source: The Design, Construction and Maintenance of Otta Seals; Guideline No. 1, June 1999*

As guidance for the designer of Otta Seals, three grading envelopes, depending on traffic, have been produced to allow for a more rational design. However, the designer should always bear in mind that generally all types of aggregate which fall within the general specified envelope can be used, provided the binder viscosity and spray rates are tailored accordingly.

**Table 8-3: Alternative grading envelopes**

| 1. ALTERNATIVE GRADING ENVELOPES | | | | |
|---|---|---|---|---|
| **Sieve sizes (mm)** | **Open grading** | **Medium grading** | **Dense grading** | **TMH test method** |
| | (% passing) | (% passing) | (% passing) | |
| 19<br>16 | 100<br>80 – 100 | 100<br>84 – 100 | 100<br>93 – 100 | A 1 |
| 13.2<br>9.5 | 52 – 82<br>36 – 58 | 68 – 94<br>44 – 73 | 84 – 100<br>70 – 98 | |
| 6.7<br>4.75 | 20 – 40<br>10 – 30 | 29 – 54<br>19 – 42 | 54 – 80<br>44 – 70 | |
| 2.00<br>1.18 | 0 – 8<br>0 – 5 | 3 – 18<br>1 – 14 | 20 – 48<br>15 – 38 | |
| 0.425<br>0.075 | 0 – 2<br>0 – 1 | 0 – 6<br>0 – 2 | 7 – 25<br>3 – 10 | |

**Table 8-4: Bitumen requirements**

| 2. CHOICE OF BITUMEN IN RELATION TO TRAFFIC AND GRADING | | | | |
|---|---|---|---|---|
| **AADT at the time of construction** | **Type of bitumen** | | | |
| | **Open grading** | **Medium grading** | **Dense grading** | |
| More than 1000 | Not applicable | 150/200 pen. grade | MC 3000<br>MC 800 in cold weather | |
| 100 - 1000 | 150/200 pen. grade | 150/200 pen. grade in cold weather | MC 3000<br>MC 800 in cold weather | |
| Less than 100 | 150/200 pen. grade | MC 3000 | MC 800 | |

80/100 pen. grade bitumen shall NEVER be used in Otta Seals unless softened or cut back to meet the above viscosity requirements.

**The cut back bitumen grades can be made by blending 80/100 pen. grade on site using the following proportions:**

To make 150/200 pen. grade: 3 - 5% softener mixed with 95 - 97 % 80/100 pen. grade.
Softener can be a purpose-made petroleum distillate, alternatively engine oil, old or new. In addition 3% points of power paraffin shall be used.

**The cut back bitumen grades can be made by blending 150 /200 pen. grade on site using the following proportions:**

To make MC 3000: 5 - 8% power paraffin mixed with 92 - 95% 150/200 pen. grade.
To make MC 800: 15 - 18 power paraffin mixed with 82 - 85% 150/200 pen. grade.

Circulation in the tank shall be carried out for at least 1 hour after mixing.

*Source: Ministry of Works, Transport, and Communications, Roads Department, Botswana (June 1999 ). The Design, Construction and Maintenance of Otta Seals Guideline No. 1. ISBN 99912-0-285-4. Allkopi AS, Oslo: Norwegian Public Roads Administration (NPRA).*

**Table 8-5: Bitumen spray rates**

| 3. BITUMEN SPRAY RATES | | | | | | |
|---|---|---|---|---|---|---|
| **Type of Otta Seal** / **Grading** | | **Open** | **Medium** | **Dense** | |
| | | | | **AADT <100** | **AADT >100** |
| Double | 1 st layer | 1.6 | 1.7 | 1.8 | 1.7 |
| | 2 nd layer (*) | 1.5 | 1.6 | 2.0 | 1.9 |
| Single, with a sand cover seal | Fine sand | 0.7 | 0.7 | | 0.6 |
| | Crusher dust or coarse river sand | 0.9 | 0.8 | | 0.7 |
| | 1 st layer (*) | 1.6 | 1.7 | 2.0 | 1.9 |
| Single (*) | | 1.7 | 1.8 | 2.0 | 1.9 |
| Maintenance reseal (single) | | 1.5 | 1.6 | 1.8 | 1.7 |

(*) On a primed base course the spray rate shall be reduced by 2.0 l/m$^2$ in the first layer.

Notes: - Where the aggregate has a water absorbency of more than 2%, the bitumen spray rate shall be increased by 0.3 l/m$^2$.
- Binder for sand cover seal shall be MC 3000 for crusher dust or coarse river sand, MC 800 for fine sand.

**Table 8-6: Aggregate application rate**

| 4. AGGREGATE APPLICATION RATES | | | |
|---|---|---|---|
| **Type of seal** | **Aggregate spread rates (m$^3$ /m$^2$)** | | |
| | **Open grading** | **Medium grading** | **Dense grading** |
| Otta Seals | 0.013 – 0.016 | 0.013 – 0.016 | 0.016 – 0.020 |
| Sand cover seals | 0.010 – 0.012 | | |

In practice, the aggregate application rates will very often be increased in order to reduce the risk of bleeding.

*Source: Ministry of Works, Transport, and Communications, Roads Department, Botswana (June 1999 ). The Design, Construction and Maintenance of Otta Seals Guideline No. 1. ISBN 99912-0-285-4. Allkopi AS, Oslo: Norwegian Public Roads Administration (NPRA).*

### 8.6.5 Otta seal construction procedures

The following steps are followed in Otta sealing using LIC methods:

i. Due to the high temperatures, the soft bitumen binders used for Otta seal are supplied to sites using bitumen distribution tankers. For cost-effectiveness, the minimum supply should be about 5,000 litres.

ii. This means that at least 1km of base formation should have been prepared and ready for the sealing operation. It should be noted that a good bond between the base course and the surfacing is as important for Otta Seals as for any bituminous seal. On an un-primed base course, the surface should be broomed free of all dust or any other foreign matter before commencing the surfacing operations. In order to suppress any dust, and to promote some penetration into the base course, it is necessary to carry out light watering prior to spraying the binder. After watering, the base course should be allowed to dry to a dampened state before the binder is sprayed.

iii. For ease of spreading by labour, the aggregate is spotted and spaced in accordance with the aggregate spray rate along both sides of the road section to be sealed.

iv. Based on appropriate task rates, estimate the required labour force needed to spread the chippings and provide the workers with the necessary handtools. Since the bitumen is sprayed at a fast speed using the distributor pump, adequate number of workers should

**Bitumen distributor**

**Watering the base Surface**

**Spotted aggregates**

be assigned to the chip spreading team to match the spraying rate.

v. Before starting the spraying, the bitumen distributor needs to be checked to ensure that:

a. The temperature of the bitumen is correct

b. None of the spray nozzles are clogged

vi. The bitumen should be discharged by the distributor at the correct spray rate. If there is no provision for traffic diversion, one half width of the road should be sprayed at a time. A section of about 300m should be sprayed at a time to allow the chip spreading team to cover with the aggregates before spraying the next section. However, during the time of waiting for the next spraying, it should be ensured through heating that the spray nozzles do not clog as that will affect the spray rate of the next section.

vii. The chip spreading team should cover each section sprayed as fast as possible and within about 20 minutes. With careful organization and brooming, an acceptably uniform spreading and smooth surface can be obtained by hand although better results and speed is gained with the use of manually operated ‘Chippy’ spreaders if available, or by use of an improvised drag broom. The recommended task rate for manual spreading is on average $2m^3$/day. Due to the urgency to immediately cover sprayed bitumen sections, spreading is mostly done as group work instead of individually assigned sections. Tools used for spreading are shovels, wheelbarrows, and hard brooms. An example of the calculation of spacing of aggregate spots is provided in section 8.13.5.

viii. Compaction of the uniformly laid chippings should preferably be done with pneumatic-tyred rollers of a minimum weight of 12 tonnes or more. This type of roller has the superior ability to knead the binder upwards into the aggregate, and to apply pressure over the entire area. A minimum of 15 passes with a pneumatic-tyred roller is required, shoulders included, on the day of construction. Loaded trucks can also be guided to make several passes in assisting in compaction. Sufficient rolling of the Otta Seal cannot be over-emphasised.

ix. After the initial rolling (on the day of construction) it may be an advantage to apply one pass with a static tandem steel roller to improve the embedment of the larger aggregate. During this process any weak aggregate will be broken down and is contribute to the production of a dense matrix texture.

**Spraying Bitumen by Bitumen Tanker**

**Aggregate spreading by Hand**

**Use of Chippy Spreader**

**Multiple use of ‘Chippy ‘ Spreaders**

Commercial traffic should be allowed on the surfaced area immediately following completion of the initial rolling with the pneumatic roller(s). This provides further kneading of the binder into the aggregate admixture.

A maximum speed limit of 40 - 50 km/hour should be enforced immediately after construction and sustained for 2 - 3 weeks when any excess aggregate is swept off.

x. It is essential that follow-up inspections of the Otta Seal are carried out to ensure that any defects that may have occurred during the sealing operation are corrected. An inspection must be made during the first 6 - 7 days following sealing, particularly if there is a major change in the weather conditions e.g. rainfall or an extreme change of temperature. A sudden change in traffic loads may also affect the newly constructed surface..

xi. Immediate post-construction care is important for successful sealing and should not be neglected. This includes additional rolling and brooming back of the aggregate that has been dislodged by traffic. During the first two days after sealing, extensive rolling by pneumatic rollers should take place in order to ensure that all particles embedded in the binder are properly coated. A minimum of 15 passes with the pneumatic tyred roller should be applied daily, covering the entire surfaced area. 2 - 3 weeks after construction, aggregate that has been dislodged by traffic during the immediate post-construction period should be broomed back into the wheel tracks as required during the first 2 - 3 weeks. This ensures that maximum amounts of aggregate particles are embedded into the soft binder. A newly constructed Otta Seal may be dusty and could produce “flying stones” for the first few weeks after construction. 2 - 3 weeks after construction, any excess aggregate can be swept off and the traffic speed limitations can be lifted. If natural gravel with a fairly high content of fines is used the period should be prolonged.

**Compaction by a Pneumatic Roller**

**Loaded Tipper Trucks assisting in compaction**

**A completed Otta Seal section**

xii. Where a double seal is applied, a minimum period of 8 - 12 weeks should elapse between the construction of the first and the second layers. This is to allow as much traffic as possible to traverse the surface as well as to allow evaporation of the solvent. During this period, the surfacing becomes more settled and in the wheel paths, where the aggregate has become embedded by traffic, a “premix” like appearance should start to appear.

xiii. The initial occurrence of bleeding and isolated fatty spots should not be any cause of concern, and can be blinded off with aggregate and preferably rolled into the surfacing. Signs of slight bleeding confirm that the aggregate/binder ratio has been optimal.

xiv. When using a natural gravel with a fairly high fines content, the period before sweeping off the excess gravel should be prolonged as long as possible, and not less than 6 - 8 weeks.

### 8.6.5.1 Use of natural gravel in Otta seal

In places where there are no commercial aggregate sources, natural gravel can be excavated and sieved to obtain the required grading within the envelopes as shown above and used for the sealing.

The photos below illustrate Otta sealing operations using natural gravel:

**Sieving of natural aggregates at the borrow pit**

**Spreading Natural Gravel by Hand in Otta Seal**

**Using a drag broom to level spread natural gravel by hand**

**Compacting Otta Seal natural gravel**

**Compacted natural gravel Otta Seal**

## 8.7 GRAV SEAL

Grav Seal is a proprietary product of Colas SA derived from the Otta Seal principles and constructed in a similar process. The main difference is that the binder used for Grav seal is a modified bitumen containing a polymer (latex) which makes it retain its elasticity over time. In all other respects the Grav seal is similar to the Otta Seal although the aggregate is preferably sourced from commercial crushers.

## 8.8 CHALLENGES IN HOT BITUMEN SEALING

Although the above discussed hot bitumen sealing option provides good quality seals, challenges encountered and experience gained in the application of LBM has revealed that hot bitumen seal applications are not labour-friendly due to the following reasons:

- Penetration grade bitumen or cut-back bitumen (using solvents like kerosene and/or diesel) must be heated to between 130 and 190oC before use. At these temperatures the bitumen is extremely flammable and can easily cause severe damage and injuries to personnel if not handled carefully and in accordance with safety regulations.
- Hot bitumen sealing, for cost-effectiveness, require huge capacity distributors (about 5,000litres) for delivery, and hence long stretches (about 1km) of road base has to be formed for once-off spraying with the motorised bitumen distributor. If not adequately protected from traffic, the road base built using labour based methods is exposed for long periods and gets damaged by traffic prior to sealing thus requiring costly and difficult repairs before sealing. Avoiding of this situation requires a complete close down of the road section by providing detours sometimes at an added cost to the project.
- Toxic fumes from hot bitumen pose health risks to labourers as illustrated by photos.
- The pace of application of aggregate by labour is not commensurate with the fast spraying pace of a motorised bitumen distributor. Hence spraying of bitumen by the distributor is done in small sections at a time. Whilst waiting for the aggregate spreading before spraying the next section, the nozzles of the sprayer get clogged leading to uneven spraying and low quality of the finished seal due to stripping or ravelling of the subsequent sections.
- Due to remoteness of sites and breakdowns of bitumen tankers and spreaders inevitably increase costs and cause logistical bottlenecks for the contractor in relation to the redundancy of the mobilised workforce and other resources for the sealing operation. This situation arises especially when the breakdown occurs once the tanker is already on site for spraying.
- High technical competence and supervision is required in ensuring the correct:
    - o Bitumen spray rate
    - o Bitumen spraying temperature
    - o Chip application rate;

**Hot bitumen temperature and toxic fumes**

**Slow spreading rate of aggregates by hand**

- It is difficult to obtain a uniform chippings application by hand. Other improvised equipment (the "Chippy"[33]) has to be employed for uniform application at additional cost;
- Hot bitumen seals such as Otta Seals require extensive after-care for up to three months for sweeping back dislodged aggregates and blinding off patches of extensive bleeding. This has proven difficult to handle contractually and has caused contractors to "overprice" the Otta Seal;
- Loose stones can cause damage to vehicle windscreens during the first months before all loose aggregate is eventually securely lodged in the seal or are swept off;
- Contractors are reluctant to re-mobilise after three months for the application of fog spray and sand cover seals;
- Extensive compaction is required, preferably with a heavy smooth roller, for chip seals to glue the chippings onto the sprayed bitumen. Otta seals require a pneumatic roller for at least three days after sealing. This is required in order to knead the bitumen up through the aggregate ensuring that all particles are coated and held together. However, pneumatic rollers are often scarce in developing countries and cannot always be mobilized to site as and when required. As a replacement the rolling can be done using loaded trucks, but this requires careful monitoring to ensure that the entire surface receives the required compaction effort.

**Un-even spreading of aggregate**

- Where natural gravels are used, the seal still appears in colour initially like a gravel layer. This has caused resistance among the uninformed public and communities who tend to think they are not getting a proper "black-top" road;

Currently, the general trend in the industry is to use more and more emulsion based solutions due to the improved environmental conditions when using emulsion. The use of cold bitumen eliminates the need for careful monitoring of the bitumen temperature – which is always a major challenge.

## 8.9 EMULSION-BASED SEALS

Due to the challenges with hot bitumen seals as indicated above, focus has been shifted to use of bitumen emulsion[34] based sealing techniques. The reasons for using emulsion-based seals are that they provide:

- Cold processes that save energy
- Easier handling and storage (low viscosity)
- Safe and environmentally friendly
- Low-cost on-site and in-place techniques

New techniques using emulsion based seals have also been developed for low volume roads. Several options are now available for use on labour based road works projects, all of which are based on bitumen emulsion, viz:

- Sand Seal
- Modified Otta Seal or Penetration Seal
- Cold Mix Asphalt

Other types of labour-friendly emulsion based seals not covered in this guideline are slurry seals, cape seals, and slurry-bound macadam seals.

[33] The "Chippy" is an un-motorised plant custom-designed in South Africa for uniform labour application of aggregates

[34] Bitumen Emulsions are mixtures of two immiscible liquids, such as oil and water, stabilized by an Emulsifier.

### 8.9.1 Types of emulsion binders

The following types of emulsion binders with characteristics as described in Table 8-7 can be used for low-volume sealing:

**Table 8-7: Characteristics of anionic and cationic bitumen emulsion binders**

| Anionic Emulsion (60% bitumen and 40% water) | Cationic Emulsion (65% bitumen and 35% water) |
|---|---|
| a) Have negative charge, adheres to positively charged particles like limestone, alkaline in nature.<br>b) Works better in low humidity climates<br>c) The viscosity is lower than that of cationic emulsion and the rate of application for a tack coat should be reduced to approximately 0.7 to 0.8litres/m2, otherwise the binder tends to flow even at minimum gradients.<br>d) More appropriate for dusty aggregates (Possibly very absorptive e.g. crusher dust from basic rock origin.) Wetting down stockpile may also help.<br>e)<br>f) Hard non-absorptive stones | i. Have positive charge; adheres to negatively charged particles like silica, is acidic in nature, used with wet aggregates and in cold weather<br>ii. Cationic stable breaks[35] slower depending on the evaporation rate. Ideal in high humidity climates<br>iii. Slow curing depending on evaporation rate.<br>iv. May be used at ambient temperatures with aggregates, which need not be completely dry.<br>v. Lower costs are incurred due to a considerable saving on fuel for heating purposes.<br>vi. Operating at lower temperatures for cold mixing gives a greater margin of safety.<br>vii. Enables cold mix to be stockpiled for long periods, or packaged in small containers and stored. This facilitates the treatment of very small areas quickly, cleanly and economically.<br>viii. Ideal for most naturally occurring aggregate e.g. river sand are negatively-charged in aqueous media, and have a capacity to absorb cationic emulsifiers.<br>ix. In the absence of Cationic Emulsion (65% bitumen and 35% water) Cationic (60% bitumen and 40% water) can be used but increasing the emulsion content by 1% (i.e. 65 divided by 60) |

Bitumen emulsions are classified by the different setting times (time taken for the bitumen droplets to coalesce after application and the water to evaporate) and the stability of the emulsion (ability of the droplets to stay in suspension). Both Anionic and Cationic emulsions can be:

- Rapid Setting (RS)
- Medium Setting (MS)
- Slow Setting (SS)

The grades of bitumen emulsions are determined by the amount of emulsifier being used in the manufacturing process. The emulsion grades are:

- Spray grade
- Pre-mix grade
- Stable grade

Normally a prime coat is required on the prepared base layer the application of the emulsion binder in the sealing process

[35] Emulsion breaks when the water in the emulsion evaporates leaving bitumen droplets to coalesce until asphalt cement is formed.

***Prime Coats and Tack Coats***

***A prime coat** entails spray applications of low viscosity asphalt on a granular base in preparation for placing an asphalt mixture. A prime coat performs several important functions:*

- *Coats and bonds loose mineral particles on the surface of the base*
- *Hardens or toughens the surface of the base*
- *Waterproofs the surface of the base by plugging capillary or interconnected voids*
- *Provides adhesion or bond between the base and the asphalt mixture*

*Emulsions that can be used for priming are Slow Setting SS-1, SS-1h[36], CSS-1 and CSS-1h and almost always require dilution with water. The dilution rates normally ranges from 1:1 to 10:1 (water to emulsion) dependent upon the base material characteristics and method of treatment. The application rates can vary for a 1:1 diluted emulsion from as low as 2.3 l/m2 for high fines and tight bases and up to 6.8 l/m2 for loose sands and very porous surfaces. In very dense material, it may be necessary to use a higher dilution and make multiple applications at lower rates. This is done to improve penetration and prevent runoff and pudding of the emulsion.*

*On the other hand, **a tack coat** is a very light spray application of diluted asphalt emulsion. It is used to create a bond between an existing surface and an asphalt latex (cold mix) being placed.*

*Asphalt emulsions commonly used for tack coats are diluted Slow Setting SS-1, SS-1h, CSS-1 and CSS-1h. The emulsion is diluted by adding an equal amount of water. To prevent premature breaking, the water must be added to the emulsion and not the emulsion to the water. Warm water is preferable for dilution and the diluted material is typically applied at a rate of 0.25 - 0.70 l/m2. A tack coat should be applied only to an area that can be covered by the same day's paving. The best results are obtained when the tack coat is applied while the pavement surface is dry and the surface temperature is above 25°C. The surface to be tack coated must be clean and free of loose material so it will adhere. A good tack coat results in a very thin but uniform coating of residual asphalt on the surface when the emulsion has broken.*

*After spraying the tack coat, time must be allowed before the overlay is placed for the complete breaking of the diluted emulsion (brown to black colour). Traffic should be kept off the tacked area.*

The procedures and equipment for the application of a prime are exactly the same as described in the following sections for tack coats and will not be covered separately.

These emulsion based techniques eliminates most of the problems faced by the contractors in the application of labour based methods with hot bitumen applications in that:

- The sealing can follow the pace of the base construction and thereby eliminates the need for long stretches of base to be constructed and being exposed to traffic and weather before sealing can take place. It affords daily 'seal as you go' process as in labour-based graveling operations;
- The prime and seal serve as a curing membrane for stabilized base layers thus solving the problem of achieving optimum curing of the base.
- Increases labour-intensity and daily production outputs without compromising on the quality of the finished product;
- Does not require high technical supervision as compared to the hot bitumen options; hence the technology is suitable for emerging (in-experienced) contractors.
- Affords easy transportation of emulsion to site in 210 litre drums and eliminates all bottlenecks associated with the use of heavy motorised bituminous distributors.
- Minimises handling and health hazards to the workforce.
- Requires less equipment since the tankers and the heating equipment are no longer needed.

[36] The "SS" means slow setting, and the trailing number "1" denotes low viscosity. Usually the higher the number the higher the viscosity (higher bitumen content). The letter "h" denotes the hardness whilst an "s", denotes a soft (penetration grade) of the base bitumen used for the emulsion.,

Slurry Seals and Cape seals also use emulsions and are labour-friendly but not covered in this guideline.

Other proprietary emulsion based mixes which have been tried with good results but not discussed in this document are:

- Labour based sealing (LBS)
- Tar Fix
- Coulgar Cold mix

## 8.10 PROCEDURE FOR APPLYING BINDER

The procedures for the priming and application of emulsion binder in sand seals and Modified Otta seals are the same. Normally a motorized hand sprayer as shown below is used for attaining quality standards. The general specification and mode of operation of a typical hand sprayer are described in Table 8-8.

**Example of a motorized hand sprayer**

**Table 8-8: Motorized bitumen hand sprayer specification guide**

| Parts | Specification |
|---|---|
| **Engine** | 5 kW diesel engine (also available with 3,7 kW petrol engine) |
| **Pump** | Gear type pump, direct drive from the output shaft of the engine reduction gear through a flexible coupling. The output when spraying is approximately 17 – 18 litres/minute. |
| **Lance** | 5 metre oil resistant delivery hose fitted to a 1 metre lance including handle grip, shut off valve and two 65-degree flat spray adjustable nozzles. |
| **Heating equipment** | Ideally sized burner ring, gas regulator, air control valve, heat deflector shield and gas bottle carrying bracket. |

For the efficient and extended use of the equipment it is advisable and strongly recommended that the working, operation and maintenance of the equipment is thoroughly understood and that good sound practice is applied. Many hours can be wasted if the equipment is not systematically cleaned and serviced.

### 8.10.1 Operation

The following are some steps involved in operating the sprayer:

- Before starting the engine check the oil levels by unscrewing the two oil plugs at the bottom of the engine. The oil level should always be flush with the bottom rim of the oil plugs.
- Check whether there is enough fuel in the tank before starting the machine.
- Never let the tank run dry as this will lead to the engine having to be “bled”.
- Before starting the engine, the intake pipe/sump of the spray machine must be placed in the 210 litre drum of emulsion and the control valve on the spray lance must be open.
- Start the engine by switching it to the on position, opening the choke and pulling the starter rope. The sprayer pump takes approximately one minute to prime.
- The sprayer pump is self-priming, however if the machine has not been used for several weeks the sprayer pump must be primed. This is done by removing the filter and adding just sufficient oil in the filter cap so that it will not spill when fixing it back in place on the engine.

- Once primed the control valve on the spray lance can be set to the off position. The engine can be left running as the sprayer normally has an automatic bypass system built into it.

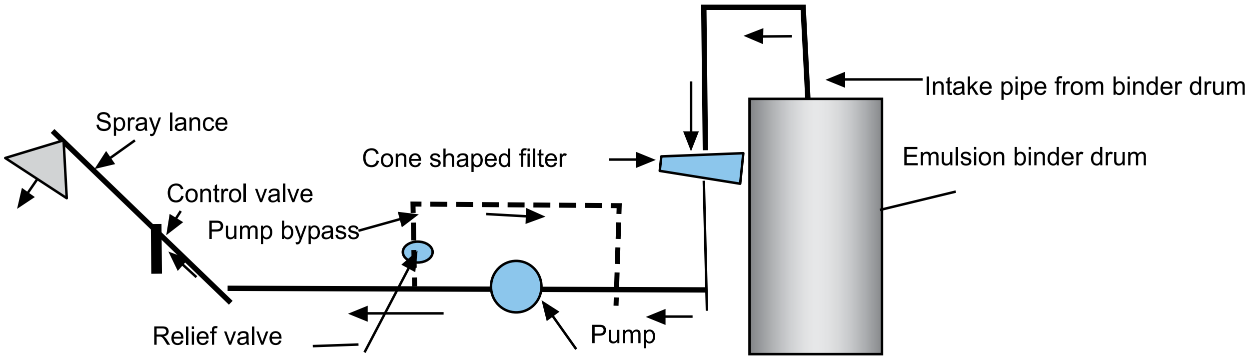



**Figure 8-1: Schematic layout of a motorized handsprayer**

- In cold weather, when it is difficult to start the engine, remove the rubber cap on the top of the engine, put 5ml of oil in the tube and replace the rubber cap.
- Some motorized hand sprayers have a gas heating system attached for the purposes of heating the emulsion drum as and when required.
- Caution must be exercised every time the sprayer is used to ensure the safety of workers and property. The following must be observed:
- Use the flint to light the burner. Do not use matches. If flint is not available, use a rolled up length of paper. Never light the burner with the drum on the machine.
- First light the burner then place the drum in position.
- Never leave the drum being heated unattended – always have someone checking the temperature and gently stirring the emulsion to prevent the emulsion from boiling over.
- Always keep the machine in a clean condition – not only externally but internally. By using "Tar Solve" with diluted paraffin (4 parts paraffin to 1 part Tar Solve) applied with a brush or spray, the equipment can be washed off with a hose. The process should be done at the end of each shift to keep the equipment clean.
- Always use protective clothing when operating spray equipment, i.e. gloves, boots and overalls.
- When it is necessary to heat the emulsion use a flint gun and not matches to light the burner
- Make sure all valves are closed on the gas cylinder when finished heating the drum to the specified temperature.
- Store the gas cylinder in a safe place on completion of spraying.
- Do not use diesel for cleaning spray equipment or hands.

### 8.10.2 Spray procedure

- Before commencing any spraying of emulsion, it is essential to have three clean half drums (105 litres) available on site. Half fill one drum with water and fill the second half full with paraffin.
- Before using any drums of emulsion for spray work, it is essential to check their contents to establish if there has been any settlement of the bitumen in the bottom of the drum. Open the drum and dip a broom handle (stick) into the drum and test the bottom of the drum for settlement. When extracting the stick "dipper" the consistency of the emulsion coating can be visually gauged. Settlement in the drums is a problem and a drum must not be used until the problem has been rectified. This is achieved by cutting open the drum and stirring the contents until a uniform consistency is obtained and pumping the contents into a clean drum. The suction of the thick sludge into the sprayer can cause severe delays and problems.
- Once the machine has been primed with the sump/intake pipe in the drum spraying can commence.
- When the contents of one drum have been depleted, switch the engine off and replace the empty drum with a full drum of tested emulsion. Start the engine and continue spraying.
- At the end of a shift or at a lunch break, remove the pump intake pipe from the drum and empty the emulsion in the system and immediately place the sump in the ½ drum of water and continue to re-circulate the clean water through the system until there is "clear water" flowing through the system.

- Once the flow of water is clear, place the pump intake pipe in the half drum of paraffin and circulate the paraffin through the system back into the drum.
- Note that you have only a maximum of two minutes to move the pump intake pipe from the water into the drum of paraffin.
- If the containers of water and paraffin are not ready switch off the engine until the containers are ready. Under no circumstances should the engine run for more than two minutes without "feeding" the pump with emulsion, water or paraffin.
- The same paraffin should be used as long as it is sufficiently clean. – this paraffin cannot be used for fuel.
- The water should be replaced for each daily shift.
- When spraying ceases and after cleaning, the spray lance should not be placed on the ground with the nozzles in the dirt. Two "saddles" fitted to a half drum are usually provided to overcome the problem - as shown in Figure 8-2:
- The third half drum is used for checking the rate of delivery of the pump. The rate of delivery of the pump must be determined before surfacing work commences.

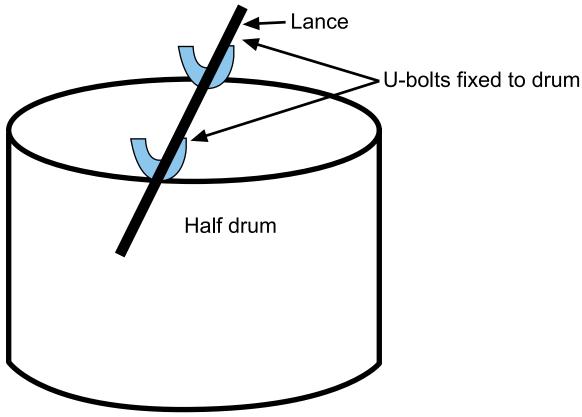



**Figure 8-2: Rack for spray lance**

### 8.10.3 Determining the delivery rate of the sprayer

#### 8.10.3.1 Delivery rate

Before either the tack coat or penetration sprays are applied, it is essential to check the delivery rate of the sprayer against the manufacturer's specification. For the sample sprayer shown in the previous section the spray rate is 17 litres per minute. The rate of delivery varies depending on the binder viscosity, which will also vary according to the temperature at which the binder is sprayed. The methods for testing the delivery of the pump are as follows

**Method 1:**

- Spray the binder to be used into a clean standard emulsion half drum (105 litres) for one or two minutes, with the emulsion binder drum in position on the motorized hand sprayer chassis and the empty half drum on the road surface;
- With a calibrated dipstick measure the quantity of binder sprayed in the one or two minutes
- This will then indicate the delivery of the pump in litres per minute. This can be compared with the manufacturer's specification which is normally 17 litres/min to18 litres/min.

**Method 2:**

- Measure the drums of emulsion to be sprayed with a dipstick – $L_1$
- Spray a measured area of say $2.75m \times 2m = 5.5m^2$
- Record the time ($T$) in seconds which elapsed to spray the measured area
- Measure the drum after spraying – $L_2$
- The quantity of emulsion sprayed in litres is $L_1 – L_2$
- The amount of binder sprayed in litres per second is then $(L_1 – L_2)$ /T ($l/s$)
- The rate of delivery can then be compared with the manufacturer's rate of delivery.

***Note:** Before any spraying can proceed, the delivery rate must be determined as it is basis for calculating the time required for spraying the binder at the specified rate of application over a certain area.*

#### 8.10.3.2 Time control of spray rates

Knowing the rate of delivery of the pump in litres per minute and the rate of application of the binder that is required for any layer of aggregate, it is possible to calculate the time in minutes and/or seconds that the spray operation is allowed for covering a certain section using a motorized hand sprayer machine or any other sprayer for that matter. This is calculated as follows:

$$Time\ of\ spraying\ required\ per\ unit\ area\left(\min utes/m^2\right) = \frac{Rate\ of\ application\left(litres/m^2\right)}{Rate\ of\ delivery\ of\ Pump\left(litres/\min ute\right)}$$

#### 8.10.3.3 Training of spray equipment operators and team

#### 8.10.3.3.1 Uniformity

Before attempting any bituminous surfacing it is recommended that the spray operators and the supporting team is introduced to the spray operation by initially practicing with spraying water at a uniform application per square metre. Actual spraying of emulsion must not be attempted until the operator and team are fully conversant with all aspects of the operation and confident in applying a uniform application of water.

Practicing the spraying operation normally involves:
- Initiating the burners (if required);
- Starting the spray machine;
- Checking the delivery of the pump;
- Practicing the movement of the protective screens while spraying;
- Practicing the initiating of the spraying by a stop watch operator;
- Checking the rate of application for 2m; 3m and 4m control sections
- Practicing keeping the spray lance at a uniform height above the surface to be covered while spraying;
- Recording the results of the times and dipstick readings.

Once the unit is comfortable in all the phases and aspects of the spray operation, the next step is to apply the diluted 1:10 emulsion as a prime on the section of road to be surfaced. At the same time the use of protective screens to protect any kerbs, etc. must be introduced and the workers trained on the systematic movement of the screens along the edge of the area to be surfaced. The use of screens is essential for a clean and safe operation. The screens must move slightly ahead of the binder application. The use of reinforced brown paper also ensures clean trimmed sprayed joints.

**Spraying using protective screens and reinforced paper**

**Spraying emulsion on an already primed surface**

The ideal height (H) of the spray lance is such that to obtain an overlap of approximately half the width of one jet as illustrated in the Figure 8-3 below. It is better to use a slightly higher than lower height. Try to keep the height constant during the spray thereby achieving an even overlap, in turn resulting in a uniform application.

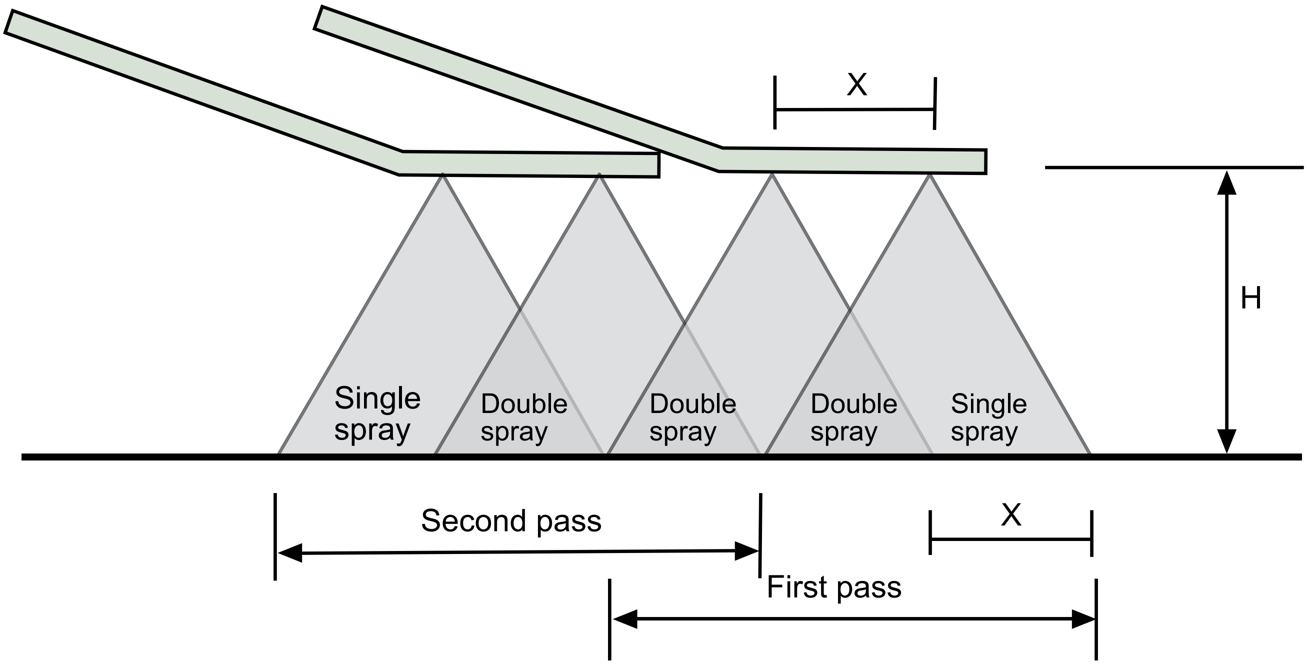



**Figure 8-3: Spraying height and sequence of spraying**

Once the correct spraying height (H) has been determined, it can be maintained by tying a piece of wire with the correct length to the lance as illustrated in Figure 8-4.

In order for the two spray fans not to "collide" or interfere with each other and thus produce an uneven application, the valves should be set at a slight angle from the centre line of the lance as shown in figure 8-5.

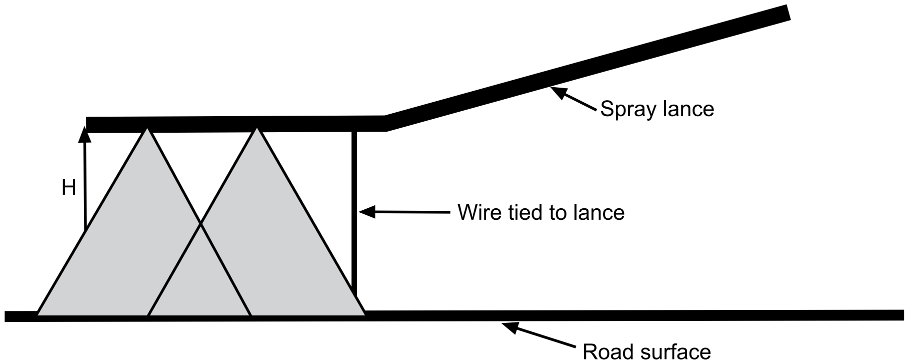



**Figure 8-4: Maintaining correct height for spraying**

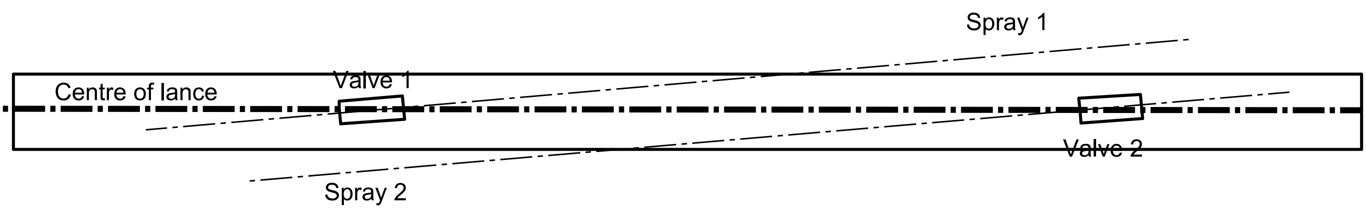



**Figure 8-5: Valves set at slight angle from centre line of lance**

A common mistake in spray operation is that the operator moving the lance in an arc (or semi-circle) while being almost stationary in the centre of the road. The operator must instead move the lance directly across the road by walking sideways holding the lance parallel to the centre of the road as shown in Figure 8-6.

Movement of spray lance should be directly across the road with the lance parallel to the centre line.

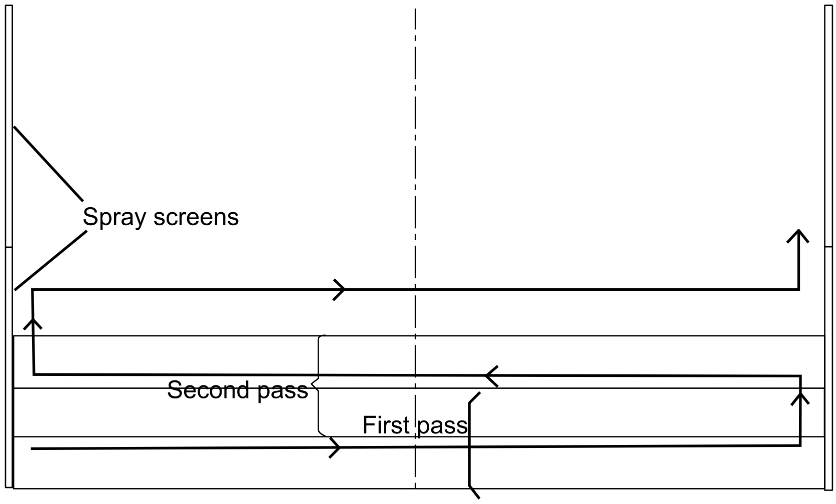



**Figure 8-6: Direction of Movement of Lance**

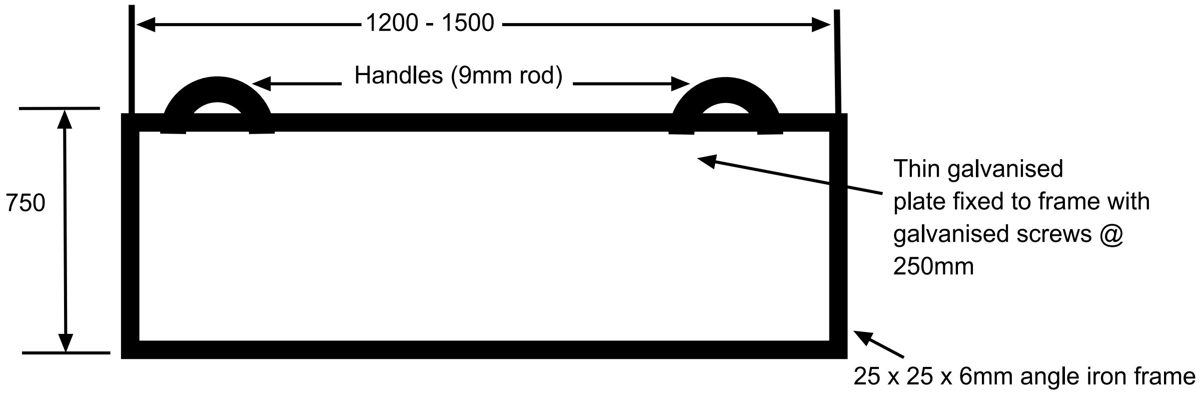



**Figure 8-7: Protective Spray Screen**

## 8.11 APPLICATION OF BINDER

### 8.11.1 Checks

Before spraying commences the following checks must be done:

- o Ensure that there is sufficient emulsion, aggregate, fuel and paraffin on site to complete the work. To do this the area to be surfaced and the rate of application of the binder and aggregate must be established;
- o The delivery rate of the pump should be determined as described;
- o Check that the aggregate has been correctly supplied and spotted;
- o Make sure that the surface to be sealed is clean and any repairs properly attended to;
- o Verify that the area to be surfaced has been correctly set out;
- o Ensure that arrangements to protect the kerbs etc. are in place;

**Spraying operation in practice**

- o Reinforced paper has been placed at the start and finish joints;
- o Finally check that all members of the team are at their posts and ready for action, i.e. that the workforce for spreading the chips and moving the spray screens, and recording operators are in position.

### 8.11.2 Control of application using a trial/control section

For the accurate application of the binder, the work must be controlled by counting off the time to apply the calculated amount of binder over a predetermined area. It is recommended that two metre control sections are set out and the time to spray each section recorded. The time required to spray each section at the required rate is calculated in advance. Before a trial section can be done the following information needs to be established:

- o The rate of delivery of the pump (l/min);
- o The rate of application of the binder (l/m$^2$);
- o The area of the trial section (2m long x width) (m$^2$);
- o The volume to be sprayed must be calculated in litres (l);
- o The time for spraying the volume must be determined (min or seconds)

For the accurate application the work must be controlled by a separate operator using a stop watch and calling out the seconds as the work progresses so that the spray operator can control the pace of the work. The time keeper needs to record (see Table 8-9) the time taken to spray each of 4 or 5 control sections and guide the operator time-wise, either to speed up or slow down the coverage of the area.

**Table 8-9: Calculated time for spraying the control section**

| Control section (metres) | Calculated Time for Spraying (Seconds) |
|---|---|
| 0 - 2 | 0 - 21 |
| 2 - 4 | 0 - 42* |
| 4 - 6 | 42 - 84 |
| 6 - 8 | 84 - 126 |
| 8 - 10 | 126 - 168 |
| *Stop watch set to zero | |

**Table 8 -10 Sample application of penetration coat**

| Description | Value |
|---|---|
| Delivery rate of sprayer | 0.283 litre per second (17 l/min divided by 60) |
| Spray application rate of penetration coat | 1.7 litre/m$^2$ (tack coat of 0.7 litres/m$^2$ subtracted from total requirement of 2.4 litre/m$^2$ ). The total application rate of binder is obtained from ALD graph in Chart 7-3. |
| Width of road | 3.5 m |
| Control length | 2m |
| Area of control section | 7m$^2$ (2m x 3.5m) |
| Amount to be applied to control section | 7 x 1.7 = 11.9 litres |
| Time to apply 11.9 litres over control section | 11.9/0.283 = 42 seconds |

Each time the spraying stops at the end of the control section or sections, dipstick readings needs to be taken and recorded before the commencement of the next spray, and also taken at the end of the spraying operation. The rate of application of binder calculated using the stop watch and delivery rate of the sprayer described above should be checked against dipstick readings as illustrated in Table 8-11.

**Table 8 -11: Check using dipstick readings**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Area to be sprayed (length x breadth) A ($m^2$) | Application rate using pump delivery (D-litres/sec) and time (T) | | | | Check using "dips" as described in this section | | |
| | Calculated time of spray $(A \times R)/D$ $T_c$ *(sec)* | Actual time of spray $T_a$ *(sec)* | Volume of spray applied $(T_a \times D)$ *(litres)* | Rate of Application $(T_a \times D)/A$ $R_d$ (litres/$m^2$) | Initial dip $D_1$ (litres) | End of spray dip $D_2$ (litres) | Rate of Application $(D_1\text{-}D_2)/A$ $Ra$ (litres/$m^2$) |
| $A_0$ | | | | | | | |
| $A_1$ | | | | | | | |
| $A_2$ *etc.* | | | | | | | |

**Table 8-12: Description (Key) of symbols**

| Column | Symbol | Description | Unit |
|---|---|---|---|
| 1 | $A_0$ | Control area to be sprayed (width x 2m length | $m^2$ |
| | $A_1$, $A_2$ etc. | Subsequent control areas to be sprayed (width x length) | $m^2$ |
| 2 | $T_c$ | Time calculated to spray control area and subsequent control areas $(A \times R)/D$ where $R$ is the required application rate | Seconds |
| 3 | $T_a$ | Actual time for spraying control area and subsequent areas | Seconds |
| 4 | $T_a \times D$ | Volume of binder applied to the control area and subsequent control areas based on pump delivery and spray rate | Litres |
| 5 | $R_d$ | Rate of application of binder to control area and subsequent areas based on pump delivery and spray time | Litres/$m^2$ |
| 6 & 7 | $D_1 - D_2$ | Volume of binder sprayed based on dip readings | Litres |
| 8 | $R_a$ | Rate of application of binder based on dip readings | Litres |

Once the time for spraying control section 1 for the 2m length of road has been calculated and sprayed, the clock must be set at zero and the time taken for spraying sections 2, 3, 4, (and 5) must be calculated and the spray operator guided for each section by the time controller. The time the spray operator actually takes for each section is recorded in column 3 in Table 8-11. The variation of spray application can be checked by comparing the actual application rate calculated in column 5 with the design spray rate. {The recording of the times in column 3 must be done by a separate operator (recording operator) as it cannot be done by the time controller}.

The dipstick readings are undertaken using a steel rod calibrated/graduated in 10 litre intervals up to 210 litres. The amount of emulsion sprayed for each cycle of spraying is recorded in litres. The time controller, recording operator and spray operator must work very closely together. Spraying can only commence after the time controller has zeroed the second hand of the stopwatch and gives the signal to start spraying.

The recording operator will mark the separate sections for checking at 2m intervals and record the time at the end of each 2m section that is sprayed. From these readings a double check of the accuracy of the work can be established by multiplying the pump delivery D by the time taken to spray each section. The spray operator controls the rate of moving the spray lance by listening to the time controller calling out the seconds required for each 2m section using his wristwatch (or preferably a stopwatch), bearing in mind the number of seconds he/she has to cover for each 2 m section of road.

*The above may appear complicated but if the operators are given ample time to practice a few times initially with water, and then with diluted emulsion, it becomes a simple exercise.*

## 8.12 CONSTRUCTION OF A SINGLE SAND SEAL

A sand seal comprises a single or double seal of aggregate (river sand, crusher dust or grit) held together with a bituminous binder. For a permanent wearing course at least a double sand seal would normally be required. A single sand seal can be used as a temporary seal until the permanent seal can be applied.
Sand seals are well suited for construction by labour and light plant as:

- The binder, in the form of a bituminous emulsion can be applied using a motorised hand spray;
- The sand aggregate for the single seal can be distributed with shovels and brooms;
- Suitable sand aggregate can often be found near the construction site and easily supplied by manual labour
- The seal can be compacted using a pedestrian roller

### 8.12.1 Specifications

Sand is fine aggregate most of which passes a 5mm sieve. It is used as an ingredient in concrete, and bituminous sealing that fills the voids to produce a dense matrix. Sand used in construction works should be clean and free from impurities such as clay, silts, salts, mica and organic matter. Sea sand is generally too fine and its salt content tends also to be detrimental to construction works.

Specifications[36] for sand seals are provided in various countries as part of standard surfacing specifications.

### 8.12.2 Materials

Materials required for the construction of a Sand seal are:

- Surfacing aggregate of the specified size (obtained from a commercial source/quarry or natural source)
- Bituminous binder in the form of a bitumen emulsion Cationic[37] spray grade emulsion (65/35).

### 8.12.3 Grading

The grading of sand may vary to a fair degree, but the specifications below should normally be met. However, if sand from commercial sources satisfying these specifications is not available or is too expensive (due to transport costs), good results may be achieved using locally available sources (e.g. river sand or leached sand on the road side) in which case care should be taken to remove excessive dust.

**Table 8-13: Sand grading envelope**

| Sieve Size (mm) | Percentage by Mass Passing through Sieve |
|---|---|
| 6.70 | 100 |
| 0.300 | 0 - 15 |
| 0.150 | 0 -2 |

### 8.12.4 Construction plant and equipment

The following are the main tools and equipment used in the construction of Sand Seal:

- Motorized hand sprayer
- Lifting frame
- Half drum containers for spotting of aggregate heaps (105 litres)
- Wheelbarrows

[36] In South Africa, for instance sand seal specifications are given in COLTO (1998), Section 4900.

[37] Most river sands tend to be acidic and are attracted to cationic emulsifiers, hence the use of cationic emulsion. Anionic emulsion would be more appropriate where crusher dust from commercial quarry is used.

- Shovels
- Protective screens
- 6 mm rope
- Nails
- Hammer
- Reinforced brown paper – to obtain clean trimmed edges of joints
- Calibrated Dipstick

### 8.12.5 Bitumen

Cationic spray grade emulsion (65% bitumen and 35% water) is ideal for natural sand seals. In cool weather it is advisable to heat the emulsion to 50°C. The flow properties of this emulsion are better than that of anionic emulsions. For instance, this grade Cationic emulsion does not flow as easily as anionic emulsion; therefore, the application rate can be higher.

### 8.12.6 Application of binder

The tack coat is applied at 1.6 litres/$m^2$.
During spraying the team must:

- Protect kerbs and other road furniture using suitable protective material
- Reinforced brown paper should be used to obtain neat joints.
- The binder should be applied evenly with the hand sprayer following the procedure described earlier in this chapter..

### 8.12.7 Application of sand

- The spread rate of the sand is 0.007$m^3/m^2$.
- The washing of the sand (if it is required) should be done well ahead of the construction date.
- Stockpile the sand of known quantity along the road at calculated intervals. See procedure below for calculating the spotting distance.
- Apply the aggregate only after the emulsion has partially broken (as an indication, the colour of the emulsion changes from brown to black when it breaks. The duration for this to occur depends on the temperature on that particular day).
- To reduce dust in the sand, flip the shovel during the spreading in order for the sand to be lifted into the air before dropping onto the binder. The wind will thus blow most of the dust away.
- Uneven sand patches can be rectified by the use of hand brooms.

For spotting of the sand, use the following steps to determine the spacing distance along the road:

| | | | |
|---|---|---|---|
| 1. | Rate of application of the aggregate | = | 0.007$m^3/m^2$ |
| 2. | Width of the road | = | 5.5m |
| 3. | Volume of the ½ drum | = | 105 litres (0.105$m^3$) |
| 4. | Volume of aggregates spread from half drum | = | 5.5m x y x 0.007 $m^3/m^2$ |
| 5. | Therefore the spacing distance $y = \frac{0.105}{5.5 \times 0.007}$ | = | 2.73m |
| 6. | Hence the area covered by each half drum = 5.5 x 2.73 | = | 15.02$m^2$ |

The sand from the half drums are spaced at 2.73m intervals and spread evenly over the entire area which has been demarcated with stones beforehand.


**Use of 'leached' natural sand**

### 8.12.8 Rolling and aftercare

The rolling of the aggregate is carried out with a pedestrian roller, but the use of a tractor or loaded truck would add further compaction, especially if there are undulations in the surfacing.


**Compaction of Natural Sand Sealed Section**

The sand should be swept back onto the road with brooms periodically after the application of the sand seal. Patches where bleeding occurs are blinded off with more sand.

Crusher dust meeting the grading requirement can be used with anionic emulsion. Example of sand seal using commercial crusher dust is shown below;


**Sand Seal with Commercial Crusher Dust**

# 8.13 CONSTRUCTION OF A PENETRATION SEAL

## 8.13.1 General description

The penetration seal is a variation of the "Otta" seal and it is to enable a graded seal to be constructed using labour-based work methods with a bituminous emulsion as binder. It comprises placing a graded[38] aggregate on a bituminous emulsion tack coat at the predetermined application rate and then penetrating the aggregate layer with a bituminous emulsion. The thickness of this seal layer is based on the Average Least Dimension (ALD) of the large fraction of the aggregate. Apart from being more labour-based than the Otta seal the penetration seal has the following advantages:

- It requires the application of lower quantities of aggregate and binder than the Otta seal as it forms a thinner layer;
- It does not require a tanker to apply hot bitumen;
- It does not pose a threat of damage to vehicles and possible claims due to loose aggregate;
- It does not require the aggregate to be broomed back on the road over an extended period of time, which is a decidedly expensive operation.

## 8.13.2 Materials

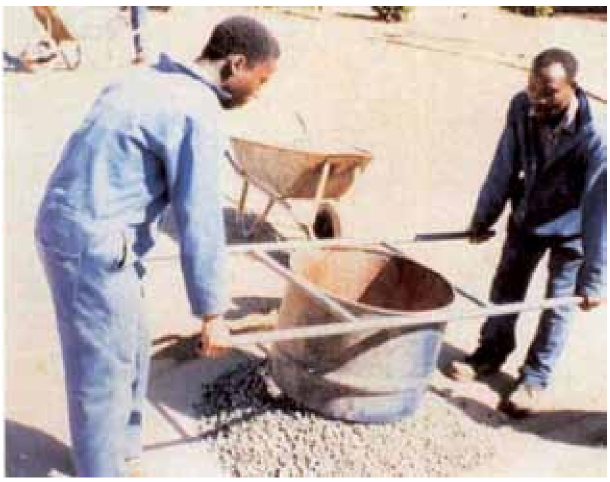
Materials required for the construction of a single seal are:

- Surfacing aggregate of the specified grading (obtained from a commercial source/quarry), and
- 60% stable grade anionic bituminous emulsion binder (due to the use of commercial quarry aggregates as explained in section 7.3.5).

## 8.13.3 Tools and Equipment

The following tools and equipment is recommended for the construction of the single seal surface by labour intensive methods:

- Shovels
- Brooms
- Wheelbarrows
- Hammer
- 7mm Sisal rope, 2 x 50m rolls
- Reinforced paper, 4 rolls x 1 metre wide
- Steel pegs, 300mm x 9mm
- Chalk line equipment
- Steel tape, 50m
- 105 litre drums open ended with lifting handles for spotting aggregate
- Heavy duty plastic sheet for spotting aggregate (1,5 x 1,5 m – 5 No)
- 105 litre drums (checking spray rates and cleaning spray equipment)
- Drum lifter for lifting full drums of binder
- Calibrated Dipstick for dipping emulsion in drums
- Motorized hand sprayer
- Suitably sized vibratory pedestrian roller ( 750kg – 1.5 tonnes)
- Spray screens (Figure 7-8)



**Half drums for spotting**

[38] Only aggregates from commercial sources have been tried for the modified Otta seal. No natural gravels have been used.

### 8.13.4 Construction

**i. Preparation of surface**

The surface of the base should be properly cleaned and prepared applying the seal. This involves:

- Sweeping the road clean. All loose material, mud and dung patties on the surface should be removed.
- Staking out the width of road to be surfaced, marking out the edge of the road with a 7mm sisal rope.
- If necessary lightly spraying the surface with a diluted 1:8 emulsion (1 litre emulsion to 8 litres water). Normally with an Emulsion Treated Base this should only be necessary if the ETB has been exposed to traffic for an extended period. This application of emulsion and water could be regarded as lightly priming the ETB (applying 0.5 – 0.6 litres/$m^2$ of diluted anionic stable grade emulsion).
- Protecting any kerbs and drains, etc. from the emulsion spray using the spray screens.

**ii. Application of bituminous binder**

Cleanliness when working with any binder on site is essential. If spillage of the binder does occur it should be cleaned up immediately.

The emulsion binder is applied using a motorized hand sprayer as described in Section 7.26.7 above.

The heating of the emulsion binder, if required, should be carefully done by stirring the binder while being heated to avoid "surging" and boiling over. The binder temperature is continuously checked with a thermometer. It normally takes approximately 45 – 60 minutes to raise the temperature to 50oC if ambient or overnight temperatures are low i.e. less than 10oC. The heating of emulsion specifically applies when using cationic emulsion. Anionic emulsion can be applied in the warm summer months without heating, but it is advisable to heat it in cool winter weather.

**Spraying of binder in more than one application**

The low viscosity of the emulsion (compared to a penetration bitumen) makes it impossible to spray emulsion at more than 0.6 – 0.7 litres/$m^2$ without the binder starting to flow (even on the "flattest" surfaces). To overcome this problem, the tack coat is sprayed at 0.6 – 0.7 litres/$m^2$ and the balance of the calculated binder is applied as a penetration spray on top of the laid aggregate, where the aggregate will inhibit any untoward flow of the binder.

**iii. Application of aggregate**

The application of aggregate should only commence after spraying approximately 10m of the road to avoid aggregate falling on unsprayed road sections. The method of applying the aggregate is the same as described earlier in the sand seal section for spotting of aggregate and spreading by hand. As an alternative the application of aggregate could also be carried out using a manual chip spreader. In this instance the spreader would have to be adjusted and trial sections spread to ensure the correct application of aggregate.

**Spotting of aggregate and spreading by hand**

Steps involved:

- Spot the heaps of aggregate accurately along the length of the road, at the spacing (x) determined by the engineer, based on the determined application rate in $m^3/m^2$ of the aggregate, as this will assist in obtaining a uniform rate of application. The aggregate should be placed on plastic sheets of 1.5m x 1.5m to reduce wastage.

A shovel of aggregate is taken and pitched into the air and in the process the shovel twisted rapidly and in so doing the chips are sprayed uniformly over the area to be covered. In this way the stone will fall onto the wet tack coat while the dust, if any, falls onto the top of the stone or if there is a breeze, is blown away from the surface.

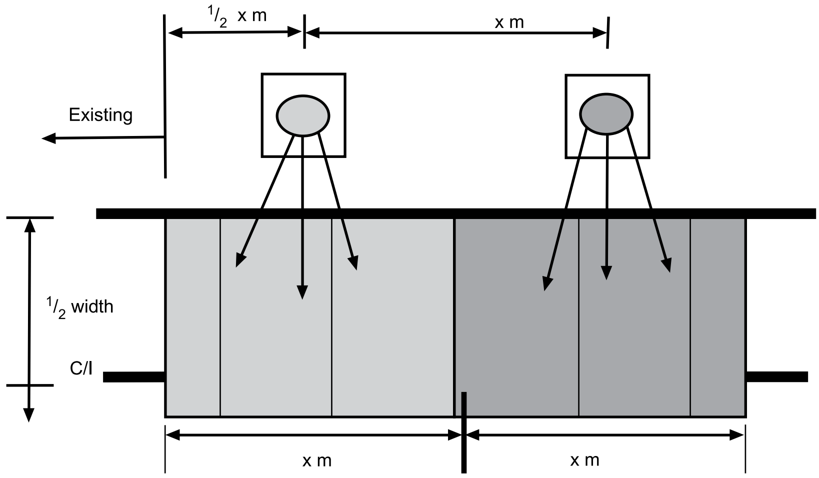



**Figure 8-8: Spotting of aggregate**

**Note: Fill the drum properly**

**Spotting of aggregate (note the plastic sheet)**

**Spreading of aggregate by hand**

**Brooming the surface**

**Rolling**

Once sufficient stones have been applied so that one can walk on the surface without coming into contact with the wet binder, the bare spaces are filled with additional stones. Gently broom the surface to distribute the aggregate uniformly. An efficient seal can be achieved by simply following the outlined process.

As soon as the surface has been covered with the aggregate without bare patches of binder showing, rolling, with a pedestrian roller, can commence. After the surface has been rolled once (i.e. a complete coverage of the roller) attention must be given again to covering bare patches. The first roll must be done without vibration but subsequent rolling, when the aggregate is properly placed with full coverage obtained, can be done with the intermediate vibration of the roller. The rolling carried out in straight lines parallel to the centre line or edges of the road. It is essential that rolling is uniformly done across the width of the road surface. Typically three passes should be sufficient to seat the aggregate.

### 8.13.5 Application of penetration spray

The remainder of the bitumen emulsion that was not applied in the tack coat is now sprayed as a penetration spray. The same precautions regarding joints and protection of kerbs, drains etc. apply as was the case for the tack coat. If the surface is left open for any period before applying the penetration spray (it is recommended to apply within 24 hours) the following must be attended to:

- Any dust, dirt or sand blown onto the surface voids must be removed/blown out with a compressor, and
- The surface must be broomed and rolled once to reseat any aggregate that may have been unseated or disturbed by unauthorized traffic. No traffic should be allowed on this surface before the second layer of binder has been applied.
- The road can be opened to traffic once the emulsion has “broken’.

**Design Considerations**

The attention to detail when planning surfacing work is essential. The amount of emulsion depends on the amount of aggregate applied. The amount of aggregate in turn is determined by the ALD. The graph provided in Chart 8-2 calculates the application rate of emulsion directly based on the ALD. Once the rates of application have been established, it is equally essential to apply them as accurately as physically possible.

The penetration seal normally consists of a graded aggregate of 9.5 mm and smaller. The grading should fall within the grading envelope in Table 8-14 and Chart 8-2, below but tends towards the lower limit of the envelope.

**Table 8-14: Aggregate grading**

| Sieve aperture (mm) | Percentage passing % | | |
|---|---|---|---|
| | Upper limit | Ideal | Lower limit |
| 13.2 | 100 | | |
| 9.5 | 96 | 90 | 85 |
| 6.7 | 82 | 74 | 65 |
| 4.75 | 70 | 58 | 45 |
| 2.00 | 50 | 35 | 20 |
| 0.850 | 30 | 20 | 10 |
| 0.425 | 16 | 10 | 2 |
| 0.250 | 10 | 6 | 1.8 |
| 0.150 | 8 | 5 | 1.5 |
| 0.075 | 5 | 3 | 1 |
| <0.075 | | | |

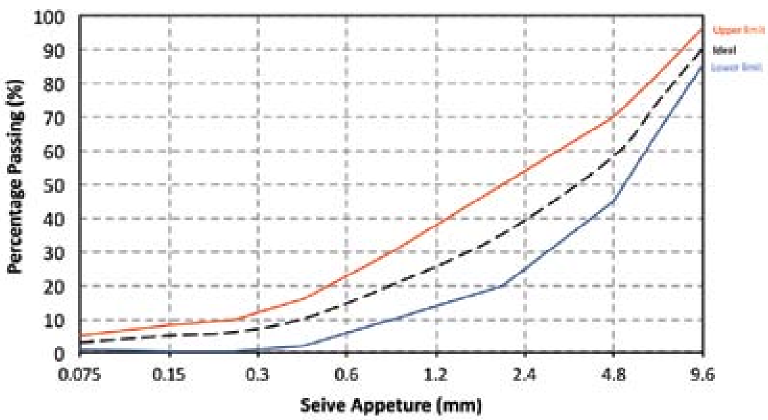



**Chart 8-2: Grading limits envelope**

It is critical to limit the lower fraction material to not exceed the upper limit of the grading envelope as a percentage of fine material tends to:

- o Trap the binder in the upper surface of a seal preventing proper penetration of the layer.
- o Absorb the binder resulting in a “dry” product

**Application of aggregate**

**Rate of application and spotting of aggregate**

The rate of application of the aggregate (R) determines the quantity of stone required for any job.

Find the size of the work or AREA to be sealed by measuring the length and width of the road in metres
$L$ (m) x $W$ (m) = $A$ (m²) (AREA).

If the rate of application/m² is known then the quantity or volume is found by multiplying the Area (m²) $x$ rate of application ($R$) m³/m²

Volume $V$ (m³)= $A$(m²) x $R$(m³)/m²

**The pan and cylinder method**

The pan and cylinder (Figure 8-9) is an aid developed to visually determine the ALD of the aggregate. Based on this figure it is possible to determine the application rate of the aggregate in m³/m² and the application rate of the bituminous binder in litres/m².

The apparatus consists of:

- A pan of a precise given diameter in which the aggregate to be used in the
- construction of the surfacing is spread as described later
- A cylinder of a precise given diameter and height into which the aggregate from the pan is poured
- A graduated measuring rod from which the Average Least Dimension (ALD) of the aggregate can be read.

The rate of application of the aggregate is determined by using the “Pan and cylinder” apparatus, by placing material from a representative sample of the graded aggregate fractions in the pan to obtain the visually desired texture. The thickness of the layer is determined by the largest fraction while the voids filled with the smaller fractions. This amount of aggregate is then poured into the cylinder and the application rate determined by reading the theoretical ALD of the aggregate off on the gauge and dividing this figure by 1000 to determine the application rate of the aggregate in m³/m².

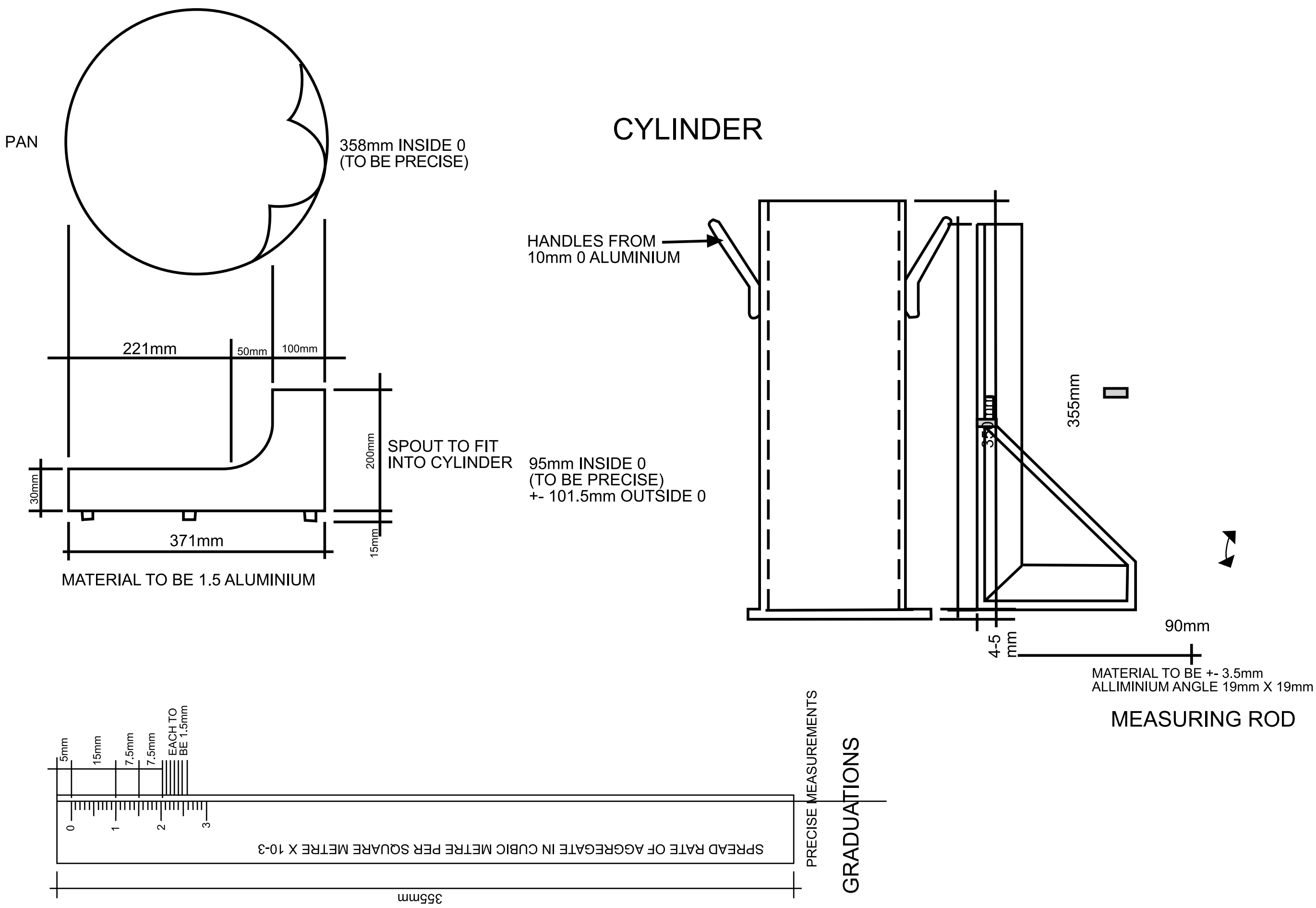



**Figure 8-9: Pan and cylinder**

**8.13.5.1.1 Spotting of aggregate**

To obtain a uniform application of aggregate by hand labour, it is necessary to place the heaps of aggregate in predetermined quantities and at uniform intervals along the side of the road to be surfaced. A half 210 litre drum with the bottom of the drum removed and two handles attached to the drum for ease of handling, can be used for this operation. The spacing of the aggregate heaps 'y' can be calculated as follows:-

1. Rate of application of the aggregate = $0.0098 m^3/m^2$
2. Half Width of the road = 2.75m
3. Volume of the ½ drum = 105 litres ($0.105 m^3$)
4. Volume of aggregates spread from ½ drum = $2.75m \times y \times 0.0098\ m^3/m^2$
5. Therefore Spacing distance $y = \frac{0.105}{2.75 \times 0.0098}$ = 3.90 m
6. Hence the area covered by each ½ drum = 2.75 x 3.90 = $10.73\ m^2$

The aggregates from the ½ drum must be spaced at 3.90 m intervals and spread evenly over the entire area which has been demarcated with stones beforehand.

## 8.13.6 Application of binder for the seal

**Types of binder**

Emulsions are ideal for manual application as they do not have to be heated thus eliminating the need for a tanker and the dangers associated with working with hot binder.

As they contain 35 – 40% of water the problem of over application resulting in bleeding of the surface is to a large extent overcome.

A 60% Anionic spray grade emulsion (60% bitumen and 40% water) has proved suitable for the construction of a penetration seal in that it allows sufficient time for the emulsion to penetrate the seal before breaking.

> ***Note:***
> *When heating this emulsion, care must be taken to heat it with burners on a low flame. The temperature to which it is heated must not exceed 50°C. Supervision and stirring while heating is essential*

**Rate of application of binder**

The amount of binder that is required per $m^2$ is dependent on the ALD of aggregate to be used. Therefore, the ALD needs to be established before the quantity of binder can be determined. The amount of 60% or 65% emulsion for a single seal can be determined from Chart 8-3 when the ALD is known.

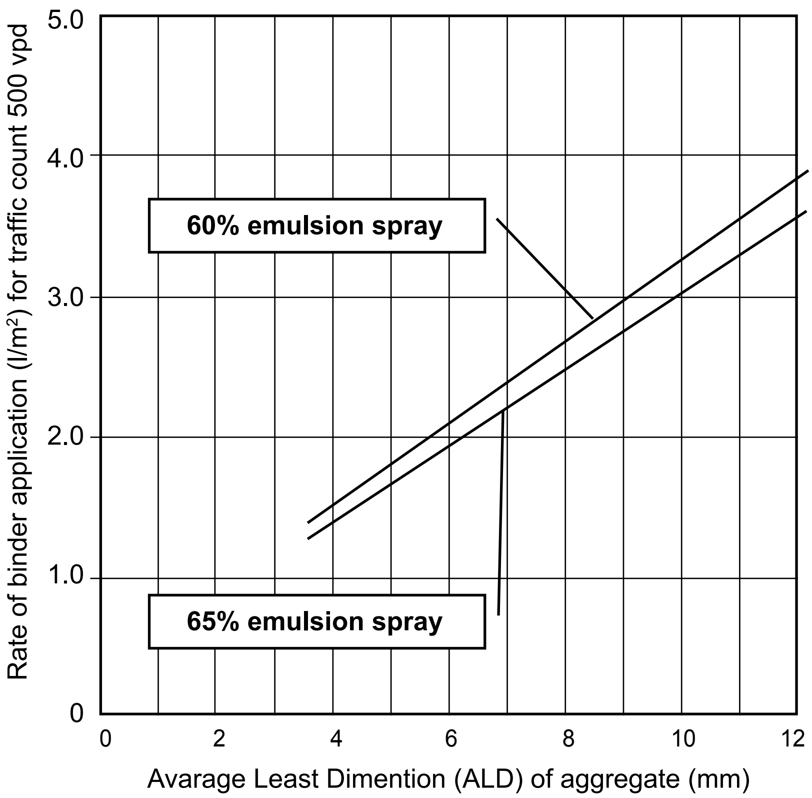



**Chart 8-3: Rate of binder application**

If the traffic is less than 250 vehicles per day, then a further 10% of binder can be added. If the traffic is between 250 and 500 vehicles per day, then add 7.5% of binder (ref. Table 8-15).

***Note:***
*The purpose of increasing the bitumen content is because lightly trafficked roads with emulsion bitumen seals fail as a result of a breakdown of the surface treatment for reasons not related to excess loading. This failure is primarily caused by oxidation[40] of the bitumen binder which becomes brittle leading to cracking and raveling whereas heavily trafficked roads have a beneficial effect by closing micro-cracks in bitumen films and surface voids in asphalt, hence constraining oxygen flow. This oxidation effect is countered by increasing the bitumen application rate on lightly trafficked roads and thereby ensuring lower air voids in the asphalt mixes.*

**Table 8-15: Adjustment to binder for traffic count**

| Traffic Count of Vehicles per day (Estimate for the road) | Adjustment to calculate Total Spray |
|---|---|
| 500 + vehicles per day | No Adjustment |
| 250 - 500 vehicles per day | Add 7.5% to the calculated binder |
| Less than 250 vehicles per day | Add 10% to the calculated binder |

**Example:**
If the rate of application of binder for an aggregate with an ALD of 8mm is 2.5 litres per m², and the traffic count is between 250 – 500 vpd then this rate should be increased by 7.5%:
*2.5 x (100 + 7.5) % = 2.5 x 107.5% = 2.69 litre per m²*

**Say 2.7 litres per m²**

It must be noted that a tack coat should not exceed + 0.6 – 0.7 litres/m² and the balance of the binder must be sprayed as a penetration spray. Before any spraying of the binder it is advisable to train the operator in spraying water and checking the rate of application (using a stop watch), as described earlier.

**Heating of binder on larger projects**

In cold weather, the emulsion needs to be heated to 50°C to attain the right viscosity for effective spraying. Heating can be done using gas burners mounted on the hand sprayers, or by using firewood. On larger projects it is recommended that separate mobile drum heaters are used to heat the binder. A drum (burner) heater can raise the temperature of a drum of emulsion by 15°C to 20° C in the time taken to spray 210 litres. Depending on the ambient nocturnal temperature more than one mobile drum heater may be required. Table 8-16 gives an indication of the time required to heat a 210 litre drum of emulsion to 50°C

40 Oxidised binder is defined as a binder which has become hard and brittle as a result of chemical attack by oxygen in the presence of heat and sunlight.

**Table 8-16: Time for heating a 210 litre drum**

| Minimum Temperature°C | Spraying Temperature°C | Approximate Time to heat 210 litre Drum (minutes) |
|---|---|---|
| 0 | 50 | 30 - 40 |
| 15 | 50 | 20 - 30 |
| 20 | 50 | 20 - 25 |
| 25 | 50 | 15 - 20 |

### 8.13.7 Challenges with Bituminous Seals

Even though emulsion seals are quite labour-friendly eliminating some of the challenges of the use of hot bitumen, it still has some bottlenecks in that:

- High precision is required in ensuring that:
  - The rate of application of binder is right
  - The rate of application of aggregates is correct

### 8.13.8 Cold Mix Asphalt Surfacing

The latest research innovation is the successful production on site of cold hand-mixed asphalt. This seal is very easy to prepare and is highly recommended using labour-based methods. It simply entails mixing on site of an emulsion binder with a uniformly graded aggregate having grading and properties as shown below, placing it on a prepared road base and compacting it to refusal. It has the following advantages:

- Increases labour-intensity and daily production outputs without compromising on quality of the finished product.
- Does not require sophisticated technical supervision as compared to other options; hence it is suitable for works carried out by emerging contractors with limited experience in bitumen works.
- Affords easy transport of binder to site in 210 litre drums and eliminates all challenges associated with the use of heavy bitumen tankers.
- Minimizes handling and health hazards.
- Affords same-day opening of completed section to traffic.

**Technical Specifications**

Materials required for the in-situ cold mix asphalt are:

- Bituminous binder as tack coat in the form of a 60% Anionic stable grade emulsion.
- Emulsion binder for the asphalt in the form of 65% Cationic premix grade (Tosas KMS 65)

**Grading of aggregate**

The grading of the aggregate should fall within the grading envelope in the Table and Graph below.

| Sieve aperture (mm) | Percentage passing % | | |
|---|---|---|---|
| | Upper limit | Ideal | Lower limit |
| 13.2 | 100 | | |
| 9.5 | 96 | 90 | 85 |
| 6.7 | 82 | 74 | 65 |
| 4.75 | 70 | 58 | 45 |
| 2.00 | 50 | 35 | 20 |
| 0.850 | 30 | 20 | 10 |
| 0.425 | 16 | 10 | 2 |
| 0.250 | 10 | 6 | 1.8 |
| 0.150 | 8 | 5 | 1.5 |
| 0.075 | 5 | 3 | 1 |
| <0.075 | | | |

**Table 8-17: Grading limits envelope**

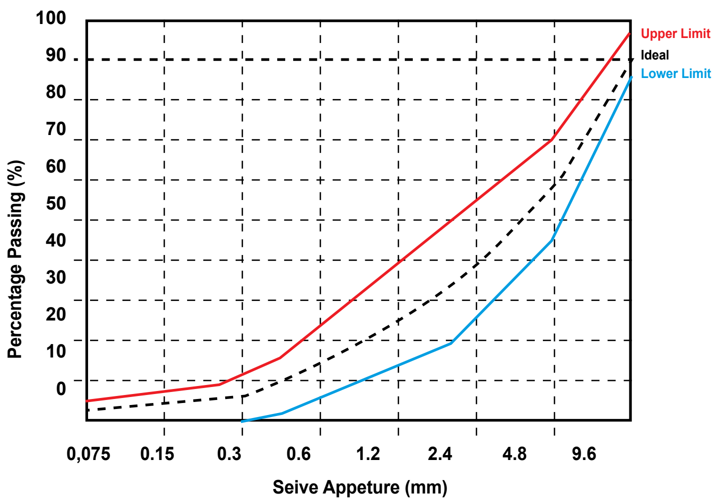



**Chart 8-4: Grading limits envelope**

The aggregate should be free from decomposed materials, vegetable matter and other deleterious substances. If the grading of the aggregate tends towards the lower limits it may be necessary to increase the percentages of the middle fractions but still remaining within the envelope to provide a more continuous grading.

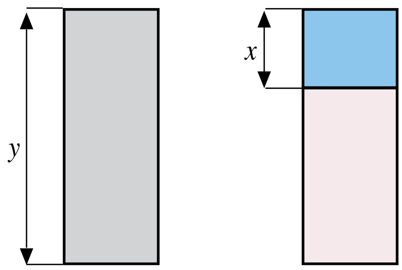
It is critical to limit the lower fraction material not to exceed the upper limit of the grading envelope. A too high percentage of fine material tends to absorb the binder resulting in a “dry” product.

**Bulking of the aggregate**

Bulking of the aggregate poses a problem which must be addressed especially if the aggregate is damp. If the aggregate is dry, there is no problem. But normally aggregate supplied from crusher quarries is damp and the problem arises when part of the heap is damp and part is dry.

To overcome this problem, wet the heap thoroughly with a hose some 6 to 8 hours or more before use and cover the heap with a plastic cover. Find the degree of bulking using a 25 litre container applying the following procedure:

- Determine the inside height of the 25 litre can (say y);
- Fill the can with damp material and strike off the excess material level with the top of the can;
- Add water to the can of aggregate until completely saturated, making sure all the air is released by rodding the can with a thin rod (e.g. rake handle or reinforcing bar);
- Pour off excess water and measure the drop in height of the aggregate (say x);
- Then x/y will give the degree of bulking (bulking factor) for adjustments of the quantity of emulsion to be used in the mix.




Therefore, if the quantity of emulsion to be used in the mix is 290 litres/m³, this amount of emulsion must be reduced by a factor of x/y.
º≠
The amount of emulsion to be used per m³ is therefore:

$$290 - \left(\frac{x}{y}\right) \times 290 = 290\left(1 - \frac{x}{y}\right) \text{ litres}.$$

> ***Note:*** *Using uniformly damp aggregate reduces the amount of water to be added to the mixture to produce the asphalt. It also overcomes the problem of balling of the fines when emulsion is added.*
>
> *If the aggregate to be used is completely dry add a small amount of water prior to adding the emulsion to ensure no balling of the mix takes place when the emulsion is added.*

**Hardness of the aggregate**

The aggregate crushing value (ACV) of the coarse material should not exceed 30.

**Porosity of the aggregate**

The porosity of the aggregate also affects the amount of emulsion to be added to the mix. Where the porosity of the aggregate is likely to be on the high side it is advisable to increase the amount of emulsion. The porosity of the aggregate can be determined by subjecting it to the Kerosene absorption test. [40]

[40] Note: It is always advisable to get a reputable laboratory to test and control the asphalt surfacing aggregate.

**Water content of asphalt**

The approximate amount of water to be added to produce 40 to 60 litres of asphalt is 1 - 3 litres. This amount could either be increased if the aggregate is completely dry and hot conditions prevail or reduced if the aggregate is damp. In any case, it should be controlled to ensure that the aggregate is thoroughly dampened before adding the emulsion.

**Plant and hand tools requirements**

The following tools and equipment is recommended for the construction of a cold asphalt seal using labour-based methods:

- Pedestrian vibratory roller (750kg – 1.5 tonnes);
- A mixing pan constructed of 3mm steel and of the dimensions, 3 No.
- Wheelbarrows,
- 7mm Sisal rope, 2 x 50m rolls,
- Flat spades,
- Hard brooms,
- Hammer,
- 150mm nails for holding down shutters,
- chalk line equipment,
- Steel tape, 50m,
- Steel squeegees,
- 20mm steel box sections as guide rails for placing asphalt (four lengths each of 2 and 3m long) with three 4mm diameter holes per section,
- 6mm thick x 50mm wide steel section (guide rail) to accommodate wet to dry asphalt (four lengths 2 and 3m long),
- 2m straight edge (Screed),
- 6 No. 20 litre measuring containers,
- 5 No. 10 litre measuring containers,
- 1 No. 5 litre measuring jug,
- Steel framed stand for decanting emulsion drums,
- 50 mm diameter ball valve for decanting emulsion from drums.

### 8.13.9 Mode of Mixing

**(a) Batching and mixing of asphalt in concrete mixers**

The cold mix makes use of concrete mixers to ensure that the required quality is achieved without contamination. All ingredients used in the mix needs to be accurately batched. The 20 litre drums used for measuring the aggregate must be calibrated to determine the 20 litre level and thereafter struck off level with this mark.

The following are some points to note when mixing with a concrete mixer:

- The concrete mixer should not be over-filled. It is recommended that the size of the mixer is such that when filled to half its capacity it delivers 100 litres of asphalt.
- The drum of the mixer should be in the horizontal position at all times when adding the wet ingredients and mixing.
- The area on which the concrete mixer and stand for the emulsion drum are placed should be clean, well-drained and have a sound surface to avoid dirt and mud being carried onto the base by the wheelbarrows. It should also be kept clean during operations to avoid bitumen being carried on to the new work by the wheelbarrows.

**Adding aggregate to mixer**

- The aggregate for the asphalt should be placed as close to the working site as possible preferably at the mid-point of the length of road that one load of aggregate will cover.
- Using the measuring cans, add the correct amount of aggregate to the mixer while the drum is turning.
- Water is then added slowly to the mixer and mixing continued until the aggregate is thoroughly dampened. The amount of water to be added is established before the work starts, but will be approximately 1% of the mass of the aggregate.
- Lastly the 65% Cationic mix grade emulsion (Tosas KMS 65 C or similar) is slowly poured into the mixer and not dumped into the mixer. By slowly pouring the fluid into the mixer, better, quicker and more efficient coating of the aggregate occurs without spillage or splashing of both the emulsion and the asphalt. The drum of the mixer should not be in the vertical position when pouring the emulsion.
- This vertical position must be used by the operator to protect from splash, due to dumping the emulsion into the drum. The drum should be just off the horizontal position and when slowly poured deep into the throat of the drum, very little of any splash will occur. Pour a little at a time and allow mixing to take place before the next pour.
- The inside of the drum should be regularly inspected for caking at the bottom of the drum. Caking is evident when a watery mixture of emulsion and aggregate (poorly graded) appears to form when some of the aggregate have caked at the bottom of the drum.
- This occurs if the operator has kept the drum for extended periods in the semi-vertical position while mixing. To rectify this situation, place the drum in the near horizontal position and tap the base of the drum with a 2kg hammer. The cake will then be released..


**Adding water to the mixer**


**Adding emulsion**


**Discharging mixed emulsion**

The use of concrete mixers restricts the daily seal production outputs by virtue of the limited mixer capacity and number of mixers, as well as increasing the sealing cost due to their rental, operating and maintenance costs. In addition, all works may come to a standstill if the mixer breaks down. These challenges are exacerbated in locations where concrete mixers are in scarce supply.

### (b) Use of Steel mixing Trays

In an attempt to surmount such challenges, customised steel tray pan have been developed for mixing asphalt that allow hand mixing within using the same time as when with concrete mixers, without compromising on the quality of the mix.

After several laboratory and field trials to determine the suitability of the pan design, it has been determined that a pan of the dimensions as shown below is optimal for effective and efficient mixing by a team of three workers mixing a volume of 40 to 60 litres within 1 to 2 minutes mixing time.


**Mixing Steel tray**

### (c) Mix proportions

Table 8-18 below indicates the amount of 65% Cationic Premix Grade emulsion to be added for various volumes of aggregate to provide the desired asphalt mix:

**Table 8-18: Amount of 65% Cationic grade emulsion for various mixes**

| Mix Volume (litres) | 100 | 80 | 60 | 40 |
|---|---|---|---|---|
| Volume of Aggregate (Dry) (litres) | 100 | 80 | 60 | 40 |
| Volume of 65% Emulsion (litres) | 15 | 12 | 9 | 6 |
| Volume of Water (litres) (approx.) | 3 | 2.5 | 1.5 | 1 |

**Note:** *In very cold weather it may be necessary to warm the emulsion to make it more fluid*

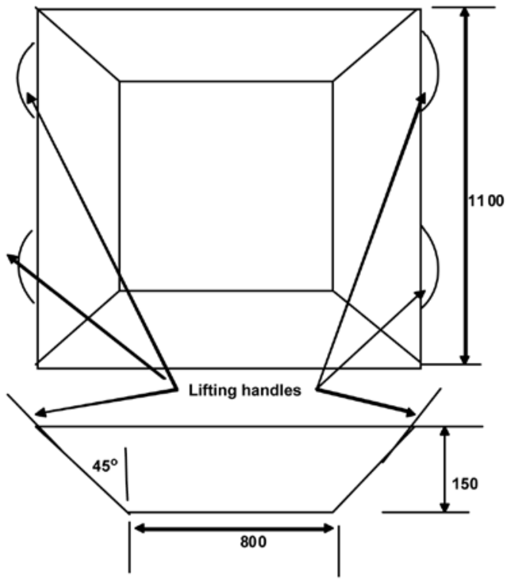



**Figure 8-10: Drawing of steel tray**

### (d) Steps in mixing, placing and compaction of asphalt

**Preparation of the road base surface**

- Sweep clean the road which has been constructed in accordance with the specifications. All loose material and mud that has been brought onto the surface must be removed, including any cattle dung.
- Stake out the width of road to be surfaced, marking the centre and edge of the road at intermediate points on which the box shutters for the asphalt surface are to be placed.
- The "spreading team" must check and rectify the levels of the base before laying the 20mm thick (wet and un-compacted) asphalt.
- Place 3 lengths of the 20mm steel box sections along the outer edge of the road. The asphalt surface is placed in sections with a width of 1 to 1.5 metres. Place another three lengths at the desired width advancing towards the centre of the road. Check the accuracy of the base levels and remove any high spots where a cover of less than 18mm is obtained. Isolated low spots can be accommodated with extra asphalt up to a maximum of 20mm. Large aggregate in the base can be treated/crushed with a 2 kg hammer to ensure a minimum cover of 18mm.

**Marking position of guard rails**

**Placing the guard rails**

**Application of tack coat**

- Apply a tack coat of diluted emulsion 60% Anionic stable grade emulsion (1:8 emulsion/water) using a watering can and broom evenly over the surface.

**Application of tack coat**

**Batching and mixing of asphalt**

When using a mixing tray there will normally be 3 persons mixing. One of the mixers should be appointed to be in charge of the mixing team.

This person is responsible for:

- Checking that the mixing tray is free of any foreign matter before any work starts.
- Ensuring that the correct amount of aggregate, water and emulsion is batched ready for use.
- Controlling the mixing operation to ensure that the aggregate, water and emulsion are thoroughly mixed.
- Ensuring that the mixing tray is clean at the end of the day's operations. The area on which the mixing tray and stand for the emulsion drum are to be situated should be clean, well-drained and have a sound surface to avoid dirt and mud being carried onto the base by the wheelbarrows. It should also be kept clean during operations to avoid bitumen being carried on to the new work by the wheelbarrows. The use of the drum stand and 50mm ball valve promotes the accurate measuring of the emulsion and minimises wastage due to spillage.

**Batching of aggregates**

**Emulsion drum on stand**

**Bulb and valve device**

In batching and mixing of asphalt:

- The aggregate to be used in the asphalt must be deposited as close to the working site as possible preferably at the mid-point of the length of road that one load of aggregate will cover.
- Using the 20 litre measuring cans add 40 - 60 litres of aggregate to the mixing tray.
- Water is then added slowly to the aggregate and mixing continued until the aggregate is thoroughly dampened. The amount of water added is established before the work starts and depends on the moisture content in the aggregate (normally 1.5 - 3 litres).
- Lastly the required amount of 65% Cationic premix grade emulsion (Tosas KMS 65 or similar), is decanted from the drum using the 50mm ball valve and evenly poured over the surface of the aggregate in the mixing tray and not dumped into the tray. By pouring the emulsion evenly over the aggregate, better, quicker and more efficient coating of the aggregate will occur without spillage or splashing of the emulsion and the asphalt.
- The person in charge of the mixing team should ensure that once all ingredients are thoroughly mixed, the asphalt is loaded into wheelbarrows without any wastage or mess taking place. Only one third to half a wheelbarrow load (20 - 30 litres) should be discharged at the time.

***Note:***
*When drums of emulsion have been stored for any length of time, the bitumen in the emulsion tend to settle at the bottom of the drum. Therefore it is essential to roll the drum and mix the contents well before use. It is recommended that the drums are turned upside down the day before being used, before being rolled for the next day's use. In very cold weather it may be necessary to warm the emulsion to make it more fluid.*

In-situ hand-mixing of asphalt

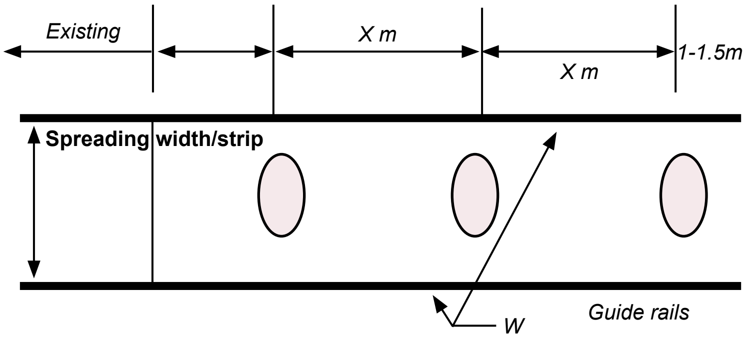



**Figure 8-11: Spreading strip**

**Placing the asphalt**

After the surface of the base has been prepared and the 20mm box sections placed in position to gauge the thickness of the wet asphalt as described in Step1 above, proceed as follows:

- Unload the wheelbarrow loads of asphalt with the assistance of shovels ahead of the screed at the spacing determined by the Engineer (see Figure 8-11 for how to spread the material using a screed to level the surface quickly and efficiently). The reason for tipping such small quantities is that placing too much asphalt too close to the screed makes the work both for the screed operators and squeegee operators more difficult and time consuming.

During the process of shovelling the asphalt from the barrow to the road, the shovels should be dipped into a drum of water and wiped with a wet mutton cloth.

**Note:**
*There is a limited period available from the time the emulsion binder is added to the mix to the time the material is unloaded and spread. It must be carried out before the binder starts breaking – this will facilitate the spreading operation. Therefore it is recommended that the width of a laid asphalt section does not exceed 1 – 1.5 meters. Try to arrange the guide rails so that they do not fall in any old wheelbarrow paths.*

**Spreading and compaction**

**Spotting the asphalt**

- Move the material to the front of the screed with the steel squeegees, assisted with the odd shovel as illustrated in Figure 8-11, so that the screed gang has the minimum effort to level the material into place and, with minimum spillage over the guide rails.
- Compaction can commence once the guide rails have been removed and the initial breaking of the asphalt has commenced for the full depth of the layer. This period is affected by the prevailing weather conditions.
- Rolling is continued until the 20 mm loose layer has been compacted to a thickness of approximately 14mm.
- Rolling the asphalt should take place along the longitudinal direction of the road. Wherever possible at least half the roller drum should be supported on compacted asphalt. Wrong rolling can result in the building in of undulations in the surface of the asphalt.
- Once rolling has been completed and before proceeding with the construction of adjacent asphalt surfacing

the edges of the compacted paving, against which these surfaces will be laid, must be neatly trimmed and squared and any material resulting from this operation removed from the road surface.

**Notes:**

- *Rakes should not be used to move the loose asphalt into place as this process results in the segregation of the aggregate, resulting in a non-uniform texture.*
- *If all hand tools are continuously cleaned in a half drum of water next to the work face, the operation will proceed more efficiently. Instead of using a half drum of water, a wheelbarrow of water can be more efficient as it is easily moved as the work progresses.*
- *It is essential that the process of batching, mixing, discharging, transporting, placing and screeding is properly controlled and efficiently executed to ensure that the process is completed before the emulsion breaks. Once the emulsion has broken it is difficult to place and screed it.*
- *If wet weather is predicted and imminent, no asphalt work must be attempted.*
- *No traffic should be allowed on the surface before the emulsion has broken and set.*
- *No asphalt should be placed on a dry surface. It is therefore essential to ensure that adequate watering facilities are in place before the work starts.*
- *Cleanliness of equipment is advisable at all times. Due care of the guide rails when storing and handling is essential to prevent the rails being damaged or bent.*
- *Cleanliness in and around the work site is essential to ensure that no free bitumen is carried onto the work by pedestrians or the work team.*
- *Once a mix is commenced, there must be no stoppage of the work until the cycle of mixing and laying has been completed, e.g. lunch breaks, etc. The screed operators should be replaced every hour to allow them to do less arduous work for at least an hour until the cycle of mixing and laying of the mix has been completed, e.g. lunch breaks etc. The screed operators must be replaced every hour to allow them to do less arduous work for at least an hour.*

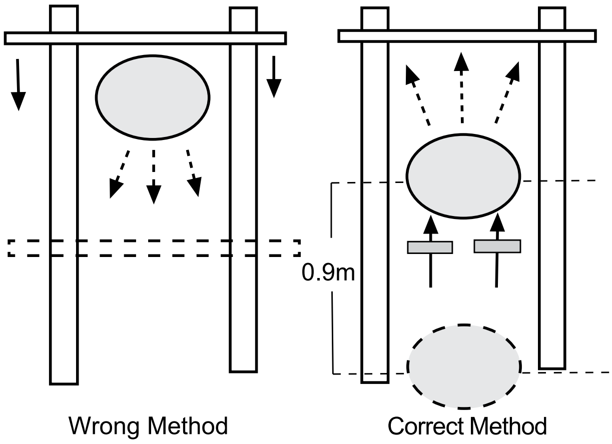


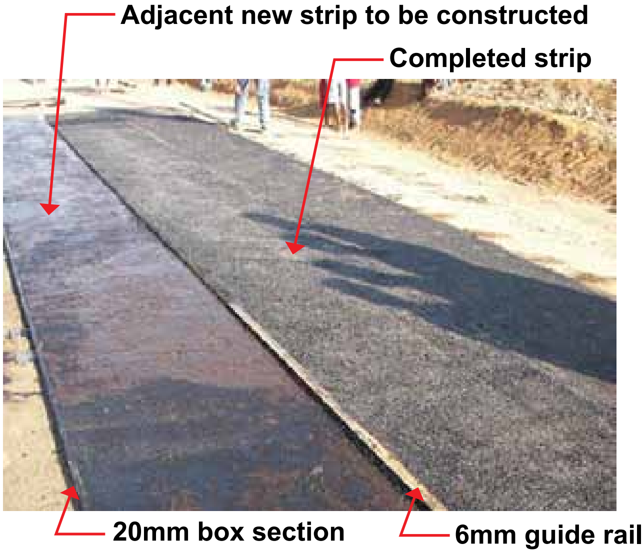

**Figure 8-12: Spreading asphalt**

**Screeding the asphalt**


**Compaction of asphalt**

### Construction of the next adjacent strip of asphalt surfacing

In placing the asphalt on the adjacent road section allowance must be made for the thickness (+ 14mm) of the dried and compacted asphalt already placed on the first section of the road. This is achieved by placing 6mm rails on top of the edge of the dried asphalt and parallel to the centre line of the road, and 20mm rails on the edge of the road as depicted in Figure 8-12.




**A day's production**

### Construction of adjacent section

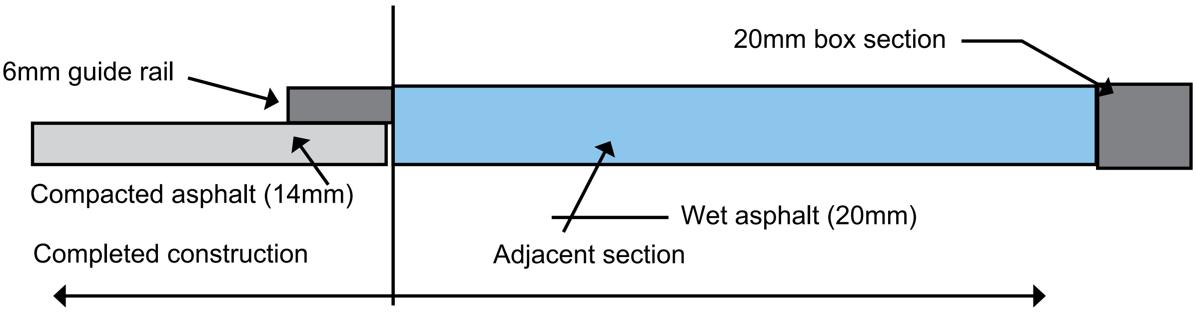



**Figure 8-13: Details showing how to accommodate wet and dry asphalt thicknesses**

**Completed asphalt sealed sections**

**Method of repairing a damaged surface**

i. Mark a neat rectangular shape for removal of damaged asphalt within this area.
ii. Neatly cut edges of marked area using a spade

**Mark the area of the pothole**

**Trim the pothole area**

iii. Carefully remove asphalt from the marked area and neatly trim the edges
iv. Broom the exposed area, apply a tack coat of 1:8 diluted emulsion and align 6mm guide rails neatly along two edges of the area

**Removal of old material**

**Area prepared for placing of asphalt**

v. Mix and spread the asphalt neatly between the guide rails and compact flush with existing surface after removing excess material

**Screed the top**

**Finished “patch” hardly visible**

## 8.14 CONCRETE SEGMENTED PAVING BLOCK

The choice of using concrete segmented blocks in road paving is another way of significantly increasing labour content on a low-volume road project with durable and high quality finished product..

Segmental concrete paving blocks designed for roads are made of high strength concrete (25+ MPa), with each unit typically 0.02 to 0.025 $m^2$ in plan area, 60 to 80 mm thick, with plain or indented sides having the top and bottom faces parallel and having either chamfered or no chamfered edges (see Figure 8-14). The thinner blocks are used for residential, pedestrian and low-volume road loadings with the thicker pavers used for heavy duty applications, including industrial pavements.

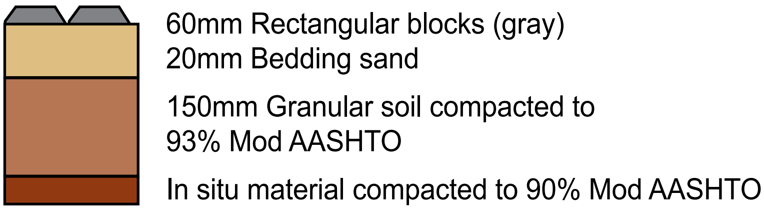



**Figure 8-14: Block Paving Layers**

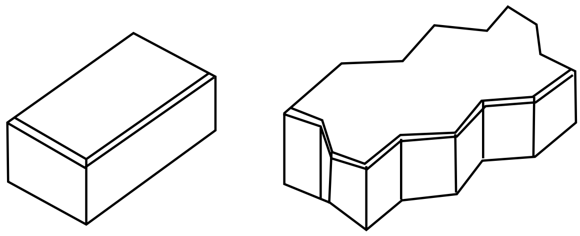


**Figure 8-15: Typical Shapes of Concrete Paver Units**

### 8.14.1 Purpose

As with concrete surfaces, the inherent durability of segmental concrete pavers make it an ideal surfacing where excessive wear is imparted to a pavement. The advantage of the concrete pavers as compared to a concrete surface is that the initial construction costs may be lower due to the use of a wide range of materials for the supporting layers. A concrete segmental paving surface (incorporating a thin bedding layer of sand) can be placed upon any qualiy substrate, either a fully bound material such as a stabilised granular material or a non-bound granular material.

Although made of very high strength concrete, individual block units would only fracture under extraordinary loading because of their limited size. The discontinuous nature of this high strength surfacing allows the surface to act in a much more flexible manner than that of concrete pavements. Design of these surfaces (pavements) is based upon flexible pavement design with resultant savings on the initial cost compared to concrete pavements.

The use of segmented block paving has several advantages with some few disadvantages as listed below:

### 8.14.2 Advantages of segmented block paving

These include:

- Excellent durability for abrasion and shearing forces, and chemical attack;
- Unitary nature of the concrete pavers means that they can be designed using flexible design mechanisms, being able to be supported by a wide range of sub straters, resulting in economic pavement compositions;
- High labour content thus increasing the overall labour intensity of the project
- Visual differentiation via the paver pattern and introduction of colour provides for permanent delineation of pavement use or function;
- Light colours provide excellent dry weather conspicuity of objects upon the surface;
- Ability to lift and reuse the paver units, especially for service line restoration; and
- Longitivity of surfacing macrotexture.

### 8.14.3 Disadvantages of segmented block paving

These include:

- Noisy for high speed traffic; and
- Require attention to ensure positive drainage of the bedding sand layer.

### 8.14.4 Design considerations

A number of design methods exist for concrete block pavements. They generally utilise linear elastic theory to determine the thickness and composition of the total pavement structure. One method includes considering each pavement layer separately, as a semi-infinite elastic layer and assigning elastic characteristics for the purpose of computer modelling using linear elastic layer theory. Design charts have been produced by Cement and Concrete Associations. These charts cater for traffic loads of commercial vehicles for the life of the pavement and allow for the use of either a bound base course material, typically cement stabilised crushed rock or an unbound material. These charts take into account the concept of lock-up of the paving units.

The concept of lock-up is as follows. When pavers are initially laid the stiffness of the resulting paver mat is low, due to the discrete nature of the paving units. Over time and with sufficient traffick it is claimed that the individual units begin to act in a more monolithic fashion as the jointing sand crushes and compacts between the joints, thus being able to confer some shear load transfer between adjacent units.

As with all concrete pavements, attention to detailed design is important to achieve a pavement with good long term performance. Particular importance is required to:

- The selection of paver shape and thickness and in certain cases, the paver orientation to the direction of the traffic; and
- Provision of edge restraint to confine the bedding layer and paver units.

### 8.14.5 Ride quality

Most segmental concrete pavements are used in low speed environments such as low-volume roads, industrial pavements, transport termini and in shared use areas where a low speed of traffic is intended. As such the ride comfort is of minor importance, as compared to pavements designed for high speeds.

It is possible to achieve satisfactory ride quality using block pavers, however the nature of the surfacing (small units) and the resultant placement of small areas of surfacing will, in general, produce additional unevenness compared to surfaces that are continuously laid, e.g. asphalt. The unevenness would, as indicated above, be more pronounced when travelling at higher speeds (> 60 km/h).

### 8.14.6 Construction

Bedding and jointing sand have significant influence in the performance of concrete segmental pavements. For paver bedding a nominal size, 5 mm graded material comprising angular particles placed in a very thin (usually 20 mm) layer is required to provide uniform support to each paver.

Jointing sand should be a well graded sand of a nominal 1 mm size and may contain a small amount of dry fines which assists in providing some waterproofing to the joints during the early life of the pavement.

If the condition of lock-up is to be achieved, it is important that a thin gap exists around each paving unit so as to accept the jointing sand. As well as providing more uniform support between the vertical faces of each block and providing the medium through which lock-up is achieved, the sand and additional debris from the pavement surface will form a material that is more able to resist the ingress of moisture.

The photos below show the construction of interlocking concrete segmental pavement.

After filling the joints with sand, the surfaces should be compacted at least twice with a heavy plate compactor (at least 200kg mass). After two passes with the compactor, extra sand should be swept into the joints again.

### 8.14.7 Construction on steep slopes

The construction of roads on steep slopes poses particular challenges. The surface (inclined) forces exerted on the road surface are severely increased due to traffic accelerating (uphill), braking (downhill) or turning. These surface forces cause distress in most conventional pavements, resulting in rutting and poor riding quality. Experience has shown that concrete block paving (cbp) performs well under such severe conditions. Although cbp performs well on steep slopes, there are certain considerations that must be taken into account during the design and construction of the pavement:

#### 8.14.7.1 Anchor beam

It is common practice to construct edge restraints (kerbing and anchor beams) along the perimeter of all paving, to contain the paving and prevent horizontal creep and subsequent opening of joints. Due to the steepness of the slope, the normally vertical traffic loading will have a surface component exerted on the blocks in a downward direction. This force is aggravated by traction of accelerating vehicles up the hill and breaking of vehicles down the hill. If uncontained, these forces will cause horizontal creep of the blocks down the slope, resulting in opening of joints at the top of the paving. An anchor beam at the lower end of the paving is necessary to prevent this creep. Figures 8-15 and 8-16 show typical section through an anchor beam. Anchor beams should be used on roads where the slope is greater than 12%. Between 8% and 12% anchor beams should be used at the discretion of the engineer.

**Packing of paving blocks**

#### 8.14.7.2 Spacing and position of anchor beams

There are no fixed rules on the spacing anchor beams (if any) above the essential bottom anchor beams. This should be determined by the engineer. However the following can be used as a guideline:

**Table 8-19: Recommended Spacing of Anchor beams**

| Slope | 12% | 15% | 20% |
|---|---|---|---|
| Spacing of Anchor Beam in metres | 30 | 20 | 15 |

*Source: Concrete Manufacturers Association, South Africa*

It is standard practice when laying cbp to start at the lower end and to work upwards against the slope. This practice ensures that if there is any movement of blocks during the laying operation, it will help to consolidate the blocks against each other, rather than to open the joints. If one is constructing a road over undulating topography, it is suggested that one begins at the low point of the dip and work away in both directions simultaneously. No anchor beam is then required at the low point.

**Completed block-paved sections**

#### 8.14.7.3 Construction of anchor beam

For ease of construction, it is recommended that the blocks are laid continuously up the gradient. Thereafter, two rows of blocks are uplifted in the position of the beam, the subbase excavated to the required depth and width and the beam cast, such that the top of the beam is 7 - 10mm lower than the surrounding blockwork. This allows for settlement of the pavers. This method of construction will ensure that the anchor beam interlocks, with the pavers and eliminates the need to cut small pieces of block.

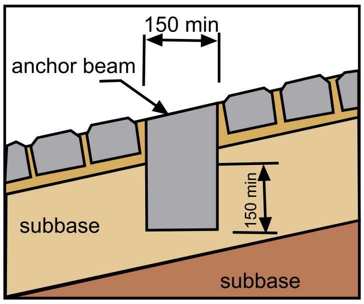



**Figure 8-16: Typical section through anchor beam showing dimensions**

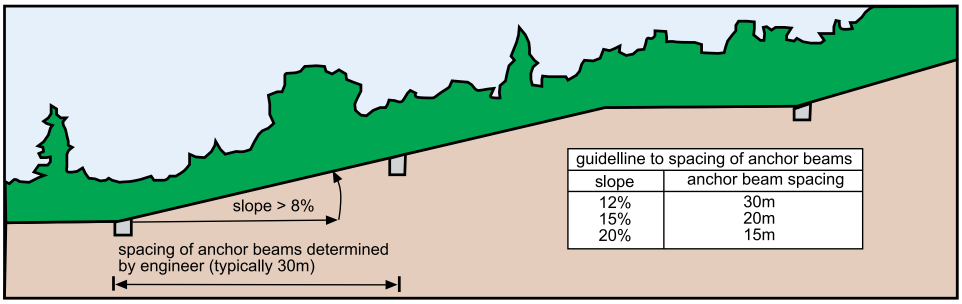



**Figure 8-17: Spacing of anchor beams**

#### 8.14.7.4 Subbase drainage

As with other pavement surfaces, rain water can penetrate through the joints in the concrete paving block. With steep slopes, the tendency is for this water to travel down the slope in the bedding sand layer and accumulate at the anchor beam. If unattended, this water can lead to softening of the subbase, settlement, and possible pumping. To eliminate this problem, it is important to provide subsoil drainage, immediately upstream of the anchor beam. Figure 8-17 shows two methods of achieving this.

#### 8.14.7.5 Surface drainage

Due to the steep slopes, the stormwater which flows down the road during a storm can attain relatively high velocities. If uncontrolled, this flow can cause erosion of the jointing sand and result in the paving losing its integrity. The following are a number of precautionary measures which can be used to prevent this erosion:

- Blocks should be laid in herringbone pattern at 45o to the kerbing. (See figure 8-18). Not only does this practice encourage the flow of water to the side channels, but it maximizes the arching action of the paving against the kerb;
- If the blocks are to be laid in stretcher bond, then it is important that the lines are normal to the direction of flow of water;
- The road should have a reasonable camber or crossfall (slope > 2%) to ensure that the stormwater is diverted to the gutters and does not run down the centte of the road. Blocks should be laid such that the:
    - o finished level is approximately 5mm above the gutter to prevent ponding along the edges;
    - o Interlocking blocks should be used as the shape prevents flow build up along the joints which reduces creep or surface movement;
- Care should be taken to ensure that joint widths are within specification;
- The gradings of bedding sand and jointing sand should meet the requisite specifications.

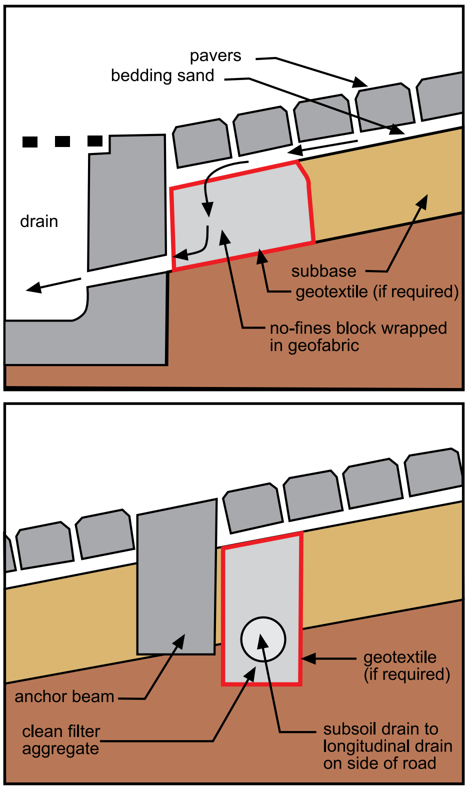
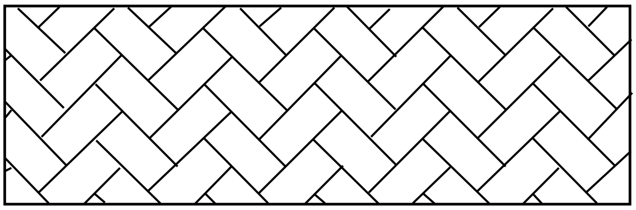
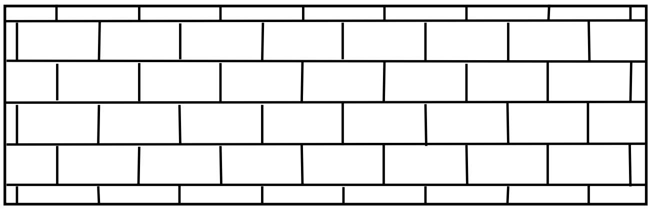



**Figure 8-18: Sub-base drainage methods**



Herringbone pattern



Stretcher bond pattern

**Figure 8-19: Laying patterns for surface drainage**

#### 8.14.7.6 Top edge maintenance

As a result of the forces described previously, there could be a small amount of horizontal creep and sliding of the blocks due to the horizontal consolidation of the jointing sand. This could result in an opening up of the top edge joint. Although this gap does not affect the structural integrity of the pavement, it does need addressing as it can lead to ingress of water. Typically, the pavement should be monitored after 3 - 6 months, and if a joint has opened up, it should be filled with jointing sand or a bitumen sealant.

### 8.14.8 Maintenance/rehabilitation

Individual concrete segmental paving units will rarely fail. However, the total pavement structure could become distressed resulting in severe deformations in the pavement surface. In extreme cases of deformation or where attention to proper jointing is not observed the units can spall, or in rarer cases, crack. In this case the pavement needs to be investigated from the subgrade upwards to determine the cause of the problem. Moisture regimes of the bedding sand and underlying base material should be noted as this type of pavement, which contains a porous sand interlayer (and a continuously cracked surfacing), requires positive drainage of the pavement itself, in addition to provision of surface drainage.

Reinstatement of service trenches can be achieved relatively easily due to the modular nature of the surfacing. Care needs to be taken though in preserving the block positioning at the trench edge so that there is enough room for all the pavers to be replaced across the opening.

## 8.15 STONE PAVEMENT

Where sources of abundant hard rock or natural smooth stones exist, it is feasible to process them for providing durable low-volume road paving. Stone paving[42] is unique as it is very labour-intensive, employing large numbers of quarry workers, chisellers and pavers, as well as creating hundreds of spin-off jobs in local tools manufacturing etc. There are two types of stone pavements namely Cobblestone and Dressed Stone:

Cobblestone pavement

Dressed stone pavement

[42] The information in this section is sourced from: Cobblestone Sector Guide for Ethiopian Cities, July 2009

### 8.15.1 Cobblestone pavement

Cobblestone pavement is made of small boulders usually river stone of about 50 – 250mm in diameter placed side by side on a bed of sand. It was commonly used in the past in street paving in European cities. Its rough surface leading to high traffic noise and vibrations is a disadvantage although it provides a durable road surface. Still, it can be used for village streets, markets, and rural road sections with steep slopes. The stones can be arranged in a pattern or at random and compacted with plate compactors. The spaces in-between are filled with sand although in town streets it is common practice to set the stones in a bedding of concrete.

The following section will focus mainly on Dressed Stone Pavement.

### 8.15.2 Dressed stone pavement

Dressed stone pavement is made from extracted stone of 30MPa minimum strength shaped and transported from rock quarries and placed on a prepared pavement with a sand bed layer. It provides a smoother surface than cobblestone pavement. It is mainly used in urban areas where high traffic volumes are expected. This pavement is among the most durable surface treatments available for roads and streets. It is commonly used on highly trafficked urban roads and streets often for its decorative and estetic values. Due to its exceptional durability, it is often prefered on roads where closing of traffic for maintenance works causes major traffic problems. The lifetime of this surface on high traffic roads in Norway is estimated at 30 years (where metal studs are used in tires during the winter).

Equally, as with concrete block pavement, stone pavement has high noise levels and vibration. For this reason, it is only used on roads and streets with low speeds. It is also an excellent surface for steep road sections.

It is however, also the most expensive surface which can apply to a road especially where the rock is quarried at locations requiring long transport distances to the road construction sites. Thereore it is recommeded that projects are selected where the dressing of the stone is carried out in close vicinity to the quarry, allthough some stone may need some final adjustments which is commonly carried out at the road site. When labour wages are low, this surface type becomes more attractive.

### 8.15.3 Establishment of quarry sites

The stone is sourced from a quarry site where it is mined and shaped. One of the first tasks is to identify and establish a quarry site. This is the most time-consuming stage in the stone paving process.

In selecting a good quarry, one should attempt to bring together a certain number of favourable conditions:

Advantage should be taken of the natural terrain which provide easy access, for example the side of a hill or where there is an outcrop of rock benches which can be used to establish a workface. If the area is flat, site clearing and overburden removal will have to be done to create a workface.

**Environmental considerations:**
The development of the quarry should be undertaken within the context of a progressive rehabilitation/restoration/re-use programme for the quarry environs. Furthermore, the area should be kept well-drained.

As far as possible, a quarry should be chosen near the site where the shaped stones will be used, in order to minimise transport costs.

**Rock quality**

The rock must be hard, of consistent texture, unaffected by erosion and neither crumbly nor cracked. When struck with a club hammer the rock should make a clear sound; if the rock sounds hollow, this means that either cracks are present in it or it is damaged. The rock's quality can be checked by taking samples and subjecting them to dressing tests; that is, producing a few sample paving blocks to ensure the suitability of the material. Table 8-20 provides the minimum test requirements for a prefered quality rock for road pavement:

**Table 8-20: Stone properties for road paving**

| Test Types | Recommended Results |
|---|---|
| Specific gravity test | >2.2 ton/$m^3$ |
| Water absorption test | < 5% |
| Los Angeles Abration test | <25% |

*Source: ILO*

Examples of good quality rock are: granite, baslt, hard sandstone, and gneiss.

**Quarrying methods**

Once the quarry has been sited, the environmental restoration plan agreed, and the preliminary clearing work completed, the method of quarrying the rock is chosen.

Depending on the type of deposit encountered, whether granite in the form of boulders or in benches from several centimetres to several metres high, the quarrying method chosen will involve the use of a crowbar, quarrying wedges, plugs and feathers, explosives or calmmite[43] to detach blocks of rock from the solid rock mass.

**Quarry stone raw materials**

The raw material is chiselled into the specified size blocks and transported to the paving site. Chiselling can either take place at the quarry site or elsewhere. During chiselling, around 80% of the raw material is lost, so sites must have enough space to cope with this. This waste can be crushed and used during base course preparation and for finishing the paved road., Experience show that after a while loss of raw material decreases due to more efficient chiselling.

### 8.15.4 Chiselling

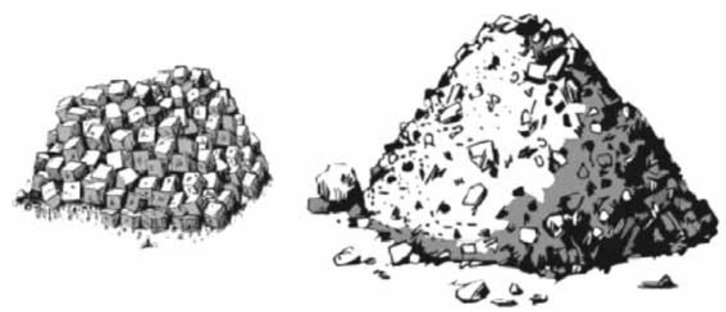
A chiselling site has to be established and the workforce trained and guided to produce enough paving stones and kerbstones to meet pavers' needs.

Chiselling is the most time-consuming and expensive stage in the process, accounting for over half of the entire paving budget. It is estimated that a single chiseller can produce 2-3 paving blocks per hour or 20 stones per day

[43] Calmmite, can sometimes serve as an alternative to explosives. Calmmite sticks are soaked in water before being placed in holes drilled in the rock. With hydration, Calmmite expands with great strength, breaking the rock after 12 - 36 hours without explosion. Although still relatively expensive, Calmmite is often an appropriate quarrying tool, especially in fragile mountain environments prone to landslides and erosion. Like explosives, Calmmite must be handled with care.

and that 100 chisellers can produce up to 2,000 shaped stonesper day. The workforce should be supervised in the beginning by one qualified quality controller. When planning the chiselling, the following four main activities need to be considered:

- Calculating and setting the price for the blocks
- Labour planning (calculating, recruiting, training)
- Labour organisation (payment, setting-up a chiselling site)
- Quality control of chiselled stones



**Chiselled dressed stones**

## 8.15.5 Tools requirement

Paving cannot happen without tools. And quality paving cannot happen without quality tools. The tools for quarry work, chiselling, and paving can either be produced locally or imported. It is also important to ensure that the pavers have access to supplies of water, sand and cement.

The following equipment and tools are required per a team of 6 pavers supported by 4 unskilled workers:

- 8 hammers, 1.5kg, one side stumpy, the other side flat (2 kept in reserve)
- 1 sledge hammers (4kg)
- 8 specially produced cobblestone hammers (2 kept in reserve)
- flat chisels (10 kept in reserve)
- spiky chisels (10 kept in reserve)
- 8 spirit levels (1.50m) (2 kept in reserve)
- straight edges (2.50 or 3m)
- 8 pocket rules (2 kept in reserve)
- 50 earth nails (80cm long and 12mm diameter)
- wheelbarrows
- 10 rolls of masonry stretch strings (100m each)
- packs of chalk (wax chalk if possible)
- shovels
- 6 brooms
- 6 rakes with teeth
- pickaxes
- 1 dynamic compactor per paving site for the compacting of the surface (> 250kg own weight)
- first aid boxes

Other paving equipment are as shown in the table below:

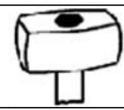
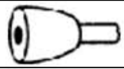
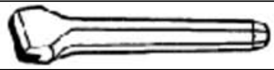
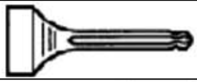
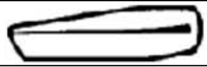
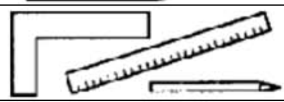
| Description | Quantity | |
|---|---|---|
| Club-hammer 1.250 kg | 1 |  |
| Metal mallet 1.250 kg | 1 |  |
| Steel grooving-chisel 0.8 kg | 10 |  |
| Tungsten carbide chisel 1 kg | 1 |  |
| Steel double chisel 0.9 kg | 1 |  |
| Steel wedges | 10 |  |
| Marking tools: -pencil, red wood ,charcoal,<br>Scribers, stone chip, rule, metal square | |  |
| Stonemason’s safety goggles | |  |
| Safety shoes | |  |
| Ear protectors | |  |
| Work gloves | |  |
| Crowbar 34 mm, length 1,800 mm | |  |
| Compressor 30 hp diesel engine, output 2.1 $m^3$/minute, 600kg | | |
| Compressor 30 hp diesel engine, output 2.7 $m^3$/minute, 800kg | | |
| Rock drill (see photo page 20), 18kg | | |
| Drill bit 037 mm, length 800 mm, 3kg | |  |
| Drill bit 042 mm, length 800 mm, 3kg | |  |
| Hammer drill (see photo page 20), 10kg | | |
| Semi-finished rough-forged tool (for above hammer drill), 1 kg | |  |
| Carbide chisel end, 0.5kg | |  |
| Plug and feathers 030 mm, length 400 mm, 1.5kg | | |
| Ear protectors | 0.24 kg |  |

**Table 8-21: Tools and equipment for stone chisselling works**

### 8.15.6 Dressed stones dimensions

Product dimensions
The typical dimensions of dressed stones most often used for road-surfacing work are the following:

| Description | Dimensions in cm | | |
|---|---|---|---|
| Allowance: | width (w) ± 1 cm | length (l) | height (h) l> 1 cm |
| Mosaic paving-block | 7 to 10 | 7 to 10 | 8 to 10 |
| Large paving-block | 14 | 20 | 14 |
| Bondstone | 14 | 30 | 14 |
| Edging curbstone | 16 | 80 | 20 |

**Table 8-22: Dressed stone dimension**

### 8.15.7 Paving

Once the sub-road preparation (including drainage and incorporating existing utilities) has been completed it is time for the pavers to complete the job. While not as time-consuming as some of the previous tasks, it is essential that this stage is successfully implemented. Paving requires skilled labour and a well-organised paving site with facilities for workers and material.

**Dressed stone paving**

The pavers must have a constant and adequate supply of cobblestones for this, so the the Site Agent must plan the supply of cobblestones accurately.

The paving site should be managed by an experienced fore-person. The most important aspects of paving construction management is presented below:

i. Dressed stone - Pavers cannot pave without delivered stones. Transport from the chiselling to the paving site must be planned so that work is not delayed. The stone should be delivered to a storage spot next to the paving workspace, not onto it.
ii. Sand, water, cement and crushed stone are essential for paving, yet sometimes they are hard to get. Ideally, the waste material produced by chiselling should be crushed and transported to the site prior topaving and used for bedding. The other materials should also be organised in advance.
iii. Division of the paving fields: Paving fields should be from 1.20m to 1.50m wide depending on the project site. Example: A 6.3 metre road could be divided into 5 fields of 1.25m (5 x 1.25m = 6.3m)
iv. String board: Strings are fixed to earth nails and placed 17cm above the final level of the sub-base (above the 5-7cm crushed stone bedding and 10cm dressed stone pavement). The surface will be approximately 15cm high after compaction. Note: If the road is straight, strings should follow a straight line.
v. Bedding - Dressed stone is placed on a 5-7cm bedding made from crushed stone. Unskilled labourers can prepare the bedding.
vi. Paving - The paving needs to start at the lowest point of the road. Dressed stone should be placed against the curb and pavers should work outwards, laying the stones at 10mm intervals (max). Once laid, the stones should be levelled and hit relatively hard 3 times. The engineer provides the slope for the pavement to ensure drainage for the area. The paver ensures that all stones are placed at the same height and slope with a spirit level. Pavers have to always check the arcs, joints and the level of their pavement.
vii. The Fore-person checks the segmental arcs and the level and the seams of the pavement. If the arcs are wrong or there is a difference of more than 1cm on a 1.5m long straight edge or 2cm on a 4m straight edge, the pavers have to correct the problem immediately. If the joints are bigger than 1cm, the pavers have to correct them.
viii. As soon as a large portion on the paving is finished, the crushed stones should be spread over the surface and swept into the joints.
ix. After filling the joints the surfaces should be compacted at least twice with a heavy plate compactor (at least 200kg mass). After two passes with the compactor, extra crushed stone should be swept into the joints again.
x. The pavement should not be used before it is compacted and checked by the Fore-person,


**Completed paved streets**

### 8.15.8 Productivity norms for dressed stone paving

Tables 8-23 and 8-24 provide a guide of task rates for various dressed stone paving works:

**Table 8-23: Productivity norms for dressed stone paving**

| TASK/DESCRIPTION | METHOD | AVERAGE TASK RATE [44] |
|---|---|---|
| **Quarry work** | | |
| Quarrying of 0.15 to 0.25 $m^3$ blocks from granite rock mass in benches up to 0.50 cm high, with many wide cracks. | Use of crowbar. Team of 3 workers who, using the crowbar as a lever, detach blocks from the rock mass and help load them onto a hand cart. | 4 $m^3$/day, that is 1.3 $m^3$/wd |
| Quarrying of 0.25 to 0.40 $m^3$ blocks from compact granite rock mass with benches from 0.50 to 1 m high. No cracks in benches. | Use of plug and feathers, rock drill and drill bit. Work carried out by 2 workers with one rock drill. Blocks detached from rock mass, then split if necessary before loading. | 1.8 $m^3$/day, that is 0.9 $m^3$/wd |
| Quarrying of 0.25 to 0.40 $m^3$ blocks from compact granite rock mass with benches 0.30 to 1 m high. | 2 workers make wedge-holes manually using grooving-chisel and club-hammer. Split blocks once more if necessary. | 1 $m^3$/day, or 0.50 $m^3$/wd |
| Boring using pneumatic drill: diameter of drill-hole ¢ 34 mm. Compact rock. | 2 workers work in shifts at drilling. | 2 50-cm deep wedge-holes per hour |
| Boring holes for quarry wedges. | 1 worker with grooving-chisel and club-hammer. | 3 holes/hour |
| Boring holes for quarry wedges using pneumatic hammer drill. | 2 workers work in shifts using hammer drill. | 7 holes/hour |
| Quarrying of 0.50 to 1 $m^3$ blocks from compact granite rock mass with benches over 1 m high. | Use of calmmite or black powder explosive. Drilling of blast-holes using pneumatic drill. 2 workers. One blasting officer for placing and firing explosives or placing and covering calmmite. | 6 $m^3$/day, or 2 $m^3$/wd |
| Cutting of 0.50 to 1 $m^3$ blocks to make 0.25 to 0.40 $m^3$ blocks. | Use of quarry wedges. Wedge-holes bored using hammer drill. Two workers in shifts. | Team cuts 3 $m^3$/day, or 1.5 $m^3$/wd |
| | Use of quarry wedges. Wedge-holes made manually. One worker. | Volume cut: 1 $m^3$/wd |
| **Dressing** | | |
| Secondary cutting stage of 0.25 to 0.40 $m^3$ blocks into 14 cm thick slabs. | Use of quarry wedges. Drilling of wedge-holes using hammer drill. Two workers in shifts. | 2.5 $m^3$/day, or 1.25 $m^3$/wd |
| | Use of quarry wedges. Manual boring of wedge-holes. One worker. | 0.8 $m^3$/wd |
| Dressing of large paving-blocks from 14 cm thick slabs. | Use of pneumatic hammer drill fitted with chisel end. Edges dressed by means of chisel. One worker. | 40 paving-blocks/wd |
| | Manual method: grooves cut using grooving-chisel and club-hammer. Edges dressed by means of chisel. One worker | 20 paving-blocks/wd |
| Dressing of edging curbstones. | Edges dressed using chisel, faces corrected using grooving-chisel. One worker. | 4 lm/wd |
| Clearing, over radius of 50 m, of stone debris resulting from squaring of paving-blocks. | Transported by wheelbarrow, loaded by 8-pronged fork. | 1 worker for 20 paving-block masons |
| **Handling** | | |
| Loading and transporting blocks. | Team made up of:<br>· 4 unskilled workers<br>· 1 gang leader | Handling and transport, over 10-20 m, approx. 2 $m^3$/wd |
| Transport of paving-blocks 50 m from dressing site to storage area. | Transported by wheelbarrow. Paving-blocks stacked in piles at storage site. | 400 paving-blocks/wd |

[44] Source: Special Public Works Programmes - SPWP - Stone Paving-Blocks - Quarrying, Cutting and Dressing (ILO - UNDP, 1992, 60 p. )

## 8.16 ULTRA-THIN REINFORCED CONCRETE PAVEMENTS (UTRCP)

An ultra-thin reinforced concrete pavement (UTRCP) is a relatively new construction method for both urban and rural roads, replacing both the conventional base layer and bituminous surfacing. This pavement technology is increasingly proving to be a solution for low-volume road paving problems especially in South Africa in terms of provincial and urban road rehabilitation and surfacing. The South Africa Council for Scientific and Industrial Research[45] (CSIR) institute has designed and successfully applied this technology on several projects.

The UTRCP consists of a 50 mm layer of 30 MPa (1:1.5:3) concrete, with 200 x 200mm grid welded mesh (reinforcing, placed in the centre layer. The concrete pavement is constructed continuously, in strips about 3 m wide, with 400 mm deep anchors at both ends of straight sections. The sections on straight alignments may be up to several hundred metres between anchors.

As there are no transverse expansion joints, as is the case with conventional concrete pavement layers, most of the usual problems with failures at the joints are eliminated.

**Laying of ultra-thin concrete**

The continuous concrete layer functions as a stretched sheet of material, as it is tied in at both ends. This results in less of the wheel load being directly transferred to the underlying layers, as a substantial amount of the load is taken up as tensile forces (by the steel reinforcement), in the concrete pavement. As a result, less layer work is needed with this construction method to achieve the same long-term resistance to traffic as with conventional road construction methods. This is illustrated in Table 8-25:

**Table 8-24 Comparison of conventional pavement with UTRCP**

| Typical Design | UTRCP Design |
|---|---|
| Cape seal<br><br>150 mm imported subbase compacted to 95% Mod. AASHTO<br><br>150 mm in-situ layer compacted to 93% Mod. AASHTO | 50mm UTRCP layer<br><br>150mm subgrade layer compacted to 95% Mod ASSTO. |

The advantage of the thinner layer works for the construction of new slip lanes and lanes widening in urban areas is that the existing utility services, which usually get in the way of road widening, may be left intact and the widening can be built with minimum disruption to these services.

[45] CSIR website: www.cscir.co.za

The reduced impact on the lower layers and the continuous reinforced covering also means that a weak spot in the underlying road layers will be much less likely to develop into a pothole, than with conventional pavements. Production rates are comparable with paver-laid asphalt, when using ready mix concrete and three to four teams of 15 workers.

Further, the UTRCP cost much less than 60 mm block paving and only slightly more than 40 mm conventional hot asphalt to install.

For remote areas where asphalt or even block paving are not available, the 50 mm UTRCP option yields a considerable cost saving. In addition, the reduction of the cost of the base layer makes this option cost competitive in comparison to conventional surfacing.

A further advantage in the longer term is that the concrete does not need continuous rehabilitation, whereas conventional roads require maintenance every 7 to 10 years, owing to the 'drying out' of bituminous surfacing. This construction method has been tested over several years by CSIR and more recently by the Gauteng Department of Public Transport, Roads and Works (Gautrans) and the Tshwane metropolitan municipality. Some extensive testing by Gautrans' heavy vehicle simulator indicated that these roads were extremely robust, taking more than three-million E80's, (standard axle loads), without any sign of failure.

Further advantages are:

- Increase of labour content by an estimated 350%
- Training and skills acquired, e.g. in concrete works can be applied in other sectors
- Community participation
- Reduced layer works required, which reduces amount of work to be carried out by plant
- Reduces depth of layer works (box cut), which limits damage to and need for relocation existing underground services
- Less maintenance required, and more durable
- Investment in equipment fairly low (no barrier to entry)
- Environmental benefits –fly ash, waste product is used
- Reduced reliance on imported material (aggegates and bitumen)
- Reduced construction costs and contract period

**Completed UTRCP sections**

Table 8-25 provides a sumary of labour based sealing types, specifications, indicative costs, advantages, disadvantages and productivities.

**Table 8-25: Sumary of labour based sealing types**

| Seal Type | Specifications | Indicative costs (US$) | Advantages | Disadvantages | Daily Productivity |
|---|---|---|---|---|---|
| Otta Seal | - Binder – MC 3000 cutback bitumen, or; 150/200 Penetration grade, 135 - 180oC at spray rate of between 1.8 to 2.0 litres/ $m^2$ (depending on properties of aggregates used)<br>- Graded aggregates: 16mm - 2mm<br>- Plant/Equipment:<br>o Bitumen tanker<br>o Pneumatic roller<br>o Chippy spreader<br>o Set of handtools | 2.5 - 3.0/ $m^2$ (single seal, excluding prime) | • Durable (+/- 14mm compacted thickness single seal, proven 9 -11 years' service life with single sand cover seal)<br>• High labour content<br>• Does not require priming (except to prevent base damage by traffic)<br>• Same day re-open to traffic (at controlled speed) helping compaction<br>• Relaxed aggregate strength, grading, dust content, particle shape, binder adhesion requirements.<br>• Accommodates use of locally available natural aggregates. | • Hot bitumen poses potential health & safety hazard.<br>• Application requires bitumen tankers<br>• Requires long stretches of formed base which may be damaged by traffic<br>• May be looked upon as inferior seal during first 4 months of construction due to unappealing look (use of natural gravel appears as dirt road).<br>• Screening of aggregate from natural material is expensive.<br>• Prolonged and expensive after-care | • 90m²/wd (Group task with team of 60 completing 5,500m² in spotting and spreading of aggregates) |
| Sand Seal | - Binder - Cationic spray grade emulsion (65% bitumen and 35% water) sprayed at 60 oC. Spray rate of 1.6litre/$m^2$<br>- Sand with grading between 6.7 and 0.15 mm at 0.007./$m^2$<br>- Plant/Equipment:<br>o Motorised hand sprayer<br>o Pedestrian vibratory roller<br>o Set of handtools | 1.5 - 2.0/ $m^2$ (excluding prime at 0.6litre/$m^2$) | • High labour content<br>• Seal as you go with small plant & machinery<br>• Relatively simple and inexpensive to construct depending on the availability of sand.<br>• Carpet thickness can easily be increased with successive applications.<br>• Maintenance is simple yet must be monitored attentively.<br>• Affords some protection to surface and other pavement layers. | • Single sand seal not very durable. Requires a second seal after 2 years.<br>• Requires priming at additional cost<br>• Can only be opened to traffic until after about one week.<br>• Requires an efficient motorised hand sprayer with controllable delivery. | • 150m²/wd (Group task with team of 20 completing 3,000m² in spotting and spreading of sand |
| Modified Otta seal | - Prime rate: 0.5 - 0.6 litres/$m^2$ anionic emulsion.<br>- Binder: 60% emulsion at 50oC in two application spray rates: 0.6 – 0.7 litres/$m^2$ as tack coat and remaining balance as per calculated binder content, as penetration spray.<br>- Commercial Aggregates: 9.5mm<br>- 0.075mm<br>- Plant/Equipment:<br>o Motorised hand sprayer<br>o Chippy spreader<br>o Pedestrian roller<br>o Set of Handtools | 2.0 - 2.5/ $m^2$ (single seal, excluding prime) | • Durable (+/- 14mm compacted thickness)<br>• High labour content<br>• More labour-friendly than Otta seal. (Seal-as-you-go).<br>• Same day re-open to traffic (at controlled speed) helping compaction.<br>• Requires less aggregates application than Otta seal<br>• Does not require hot bitumen and tanker distributer<br>• Does not require long and expensive after-care | • Requires an efficient motorised hand sprayer with controllable delivery.<br>• Requires only graded commercial aggregates. (Cannot use natural gravel).<br>• Requires high technical design and construction inputs in ensuring correct rate of:<br>o binder application.<br>o aggregates application. | • 90m²/wd (Group task with team of 16completing 3,000m² in spotting and spreading of aggregates |

| | | | | | |
|---|---|---|---|---|---|
| Cold Mix Asphalt | - Tack coat : 60% Anionic stable grade emulsion.<br>- Emulsion binder: 65% Cationic premix grade (Tosas KMS 65).<br>- Aggregates : 9.5 – 0.075 mm<br>- Mix proportions (litres) :<br>Mix Volume: 80, 60<br>Aggregate: 80, 60<br>Emulsion: 12, 9<br>Water (litres): 2.5, 1.5<br>- Plant/Equipment:<br>o Concrete mixer, or<br>o Steel trays<br>o Pedestrian vibratory roller<br>o Set of handtools | 4 - 5/m² (excluding prime at 0.6lit/m²) | • High labour content<br>• Seal as you go with small plant & machinery (avoids damage to base)<br>• Suitable for steep sections<br>• Self-sealing of cracks<br>• Durable (thicker layer ~ +/- 18mm compacted)<br>• Minimal handling and health hazards.<br>• Open to traffic same day<br>• Good riding quality with adequate bearing capacity and tyre contact stress transfer.<br>• Easy on-site production - does not require high technical supervision<br>• Affords easy transport of binder to site in 210 litre drums and eliminates all challenges associated with the use of heavy bitumen tankers. | • Higher material transport costs | • 70m²/wd (Group task - Each team of 14 completing 1,000m² in batching, mixing, placing, and screeding the asphalt). With more mixing trays and teams employed, the daily output can be multiplied many times. |
| Segmented Paving Blocks | - Strength: 50 MPa<br>-Thickness: 60mm<br>- Bedding Sand: 20mm thick Grading: 4.75 – 0.075mm<br>- Jointing sand: Grading:1.18 – 0.075mm<br>- Plant/Equipment:<br>o Flat plate vibratory roller<br>o Set of handtools | 12 - 15/m² | • Can use labour to manufacture blocks on site<br>• Laying/placing done by hand<br>• Cost savings in base layer as pavement also act as base layer.<br>• Easy maintenance – remove, patch and replace.<br>• Long durability<br>• Reduced maintenance and lower maintenance costs | • High initial costs (compensated for by thicker layer as base, and durability).<br>• Noisy for high speed traffic;<br>• Require attention to ensure positive drainage of the bedding sand layer | • 15 -20m²/wd (Group task - Each team of 10 completing 150 - 200m² in laying sand bed and, placing paving blocks). |
| Ultra Thin Reinforced Concrete | - 50 mm layer of 30 MPa (1:1.5:3) concrete,<br>- 200 x 200mm grid welded mesh (reinforcing, placed in the centre layer.<br>- Plant/Equipment:<br>o Concrete mixers<br>o Vibrating screed beam or truss.<br>o Movable bridge for placing and screeding concrete<br>o Bass texture broom<br>o construction joints saw<br>o Sealing joints equipment<br>o Set of handtools | 8 - 10/m² | • Lower whole life cost for comparable design<br>• Does not rut, shove or pothole<br>• Reduced maintenance and low maintenance costs<br>• Labour friendly and therefore suitable for LBM<br>• Skills acquired are not limited to road construction but are transferable to the wider building and construction industry<br>• Existing subgrade and alignment can be used<br>• Only simple inexpensive equipment needed | • Possibly increased initial cost<br>• Increased material transport costs in remote areas<br>• Cracking potential during construction<br>• Some concrete skills needed | • 20m²/wd (Group task - Each team of 20 - 25 completing 400 - 500m² in batching, placing and screeding concrete). |

From the foregoing it has been shown that high quality low-volume sealed roads can be successfully constructed using employment-intensive approaches. With the adoption of more appropriate design specifications and locally derived techniques in the use of locally available resources, construction of low-volume sealed roads can be more cost-effective and certainly more sustainable way of paving low volume roads..

# References


Anderssen C. Beusch A. and Miles D. (1996). Road Maintenance and Regravelling (ROMAR) using Labour-Based Methods: International Labour Organization, ISBN 1-85339-348.

Andreas Beusch, Marie Winsvold, (2002). Site Supervisor Course for Labour-Based and Community-Managed Upgrading of Urban Low-Income Settlements – Supervisor's Site Reference Handbook, Geneva, International Labour Office, ISBN 92-2-112813-X.

Arora K. R. (1992). Surveying Volume 1, 3rd Ed. 1705-A, Nai Sarak, Delhi 110006: Standard Book House.

Arora K. R. (January 1993). Surveying Volume 2, 2nd Ed. 1705-A, Nai Sarak, Delhi 110006: Standard Book House.

Asare A.(September 2011). Production of In-situ Cold Asphalt using Steel Pans - A Cost-effective Alternative to Application of Employment Intensive Approaches in Sealing of Low-volume Roads: 14th ILO Regional Seminar for Labour Based Practitioners:

Asare A., Kidanu A., Hlaing H. and Tshabalala D. (2007). Expanded Public Works (EPWP) Operational Level Guidelines. Pretoria: Seriti Printing

Bentall, P., Beusch, B, and deVeen, J. (1999). Green Guide: Employment- Intensive Infrastructure Programmes: Capacity Building for Contracting in the construction Sector Guidelines, ISBN 92-2-111 581X, ILO.

Bergh A. O. and Mckay A. H. (April 2009). CSIR Contract Report on Trials of Asphalt Surfacing with a Bituminous Emulsion Binder Using Labour Supported by Light Plant. Pretoria.

Bergh A. O. and Mckay A. H. (July 2006). CSIR Contract Report (CSIR/BE/CON/ER/2006/052/B) on Construction of Trial Sections of Penetration Seal and Emulsion Bound Asphalt Surfacing. Pretoria.

Bjorn Johannessen. Building Rural Roads (2008). ISBN 9789221209775.: International Labour Organization, Regional Office, Asia.

Bjorn Johannessen (July 1998). Technical Manual, Labour-Based Road Construction Methods: Ministry of Rural Development, Cambodia.

Blokhuis F. and Tembo S. (2001). Manual for Supervision of Labour Based Road Rehabilitation Works: ILO.

Concrete Manufacturers Association. Concrete Block Paving for Steep Slopes, Technical Notes.

Construction Industry Development Board (CIDB), 2005. Labour-based methods and technologies for employment-intensive construction works, Best Practice Guideline – Part 1. ISBN 0621355658.

Department of Rural Roads (2003). Technical Manual for Low Volume Roads Upgraded and Constructed Using Labour-Based Methods in Lesotho.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) 2009. Cobblestone Sector Guide for Ethiopian Cities.

Giummarra G. J. (August 1995). Sealed Local Roads Manual. Guidelines to Good Practice for the Construction, Maintenance, and Rehabilitation of Pavements. ISBN 0 86910 6899. 500 Burwood Highway, Vermont Soutgh Victoria, 3133: Australian Road Research Board Transport Research Limited.

Hongve J. (October 2006). Bituminous Surfacing Options for Low Volume Roads Constructed by Labour-Based Methods: ILO.

Ministry of Transport and Energy, Department of State Roads, Zimbabwe (June 1994). Field Manual for Labour Based Rural Feeder Roads Rehabilitation and Maintenance.

Ministry of Works, Transport, and communications, Roads Department, Botswana (June 1999). The Design, Construction and Maintenance of Otta Seals Guideline No. 1. ISBN 99912-0-285-4. Allkopi AS, Oslo: Norwegian Public Roads Administration (NPRA).

Øverby Charles (June 1995). A Guide to the Use of Otta Seal. Publication No. 93, ISBN 82 - 91228 - 03 - 5.: Norwegian Public Roads Administration.

Overseas Road Note 3, (1993). A Guide to Surface Dressing in Tropical and Sub-tropical Countries. 4th Ed., ISBN 0951-8987.

Overseas Road Note 31, (1993) A Guide to the Structural Design of Bitumen-surfaced Roads in Tropical and Sub-tropical Countries. 4th Edition, ISBN 0951-8987.

Singh, G. C and Singh J., (August 1993). A Textbook of Estimating Costing and Valuation. 1705-B, Nai Sarak, Delhi 110006: Standard Publishers Distributors.

Singh, G. C and Singh J., (January 1991). Highway Engineering. 3rd Ed. 1705-B, Nai Sarak, Delhi 110006: Standard Publishers Distributors.

Southern Africa Transport and Communications Commission (SATCC) (July 2003. Guideline, Low-Volume Sealed Roads. ISBN 99912-0-456-3. Gaborone: South African Development Community (SADC).

Special Public Works Programmes - SPWP - Stone Paving-Blocks - Quarrying, Cutting and Dressing (ILO - UNDP, 1992, 60 p.)

Technical Recommendations for Highways (TRH 13) 1985. Cementitious stabilisers in road construction. ISBN 0798836474.

Technical Recommendations for Highways (TRH 14) 1985. Guidelines for road construction materials. ISBN 0798833374

Tshabalala D., Asare A., Kidanu A., and Hlaing H. (2011). Labour Intensive Construction Guidelines for Water Provision, Sanitation, Solid Waste, and Building Works. ISBN 978-0-620-46146-7. Pretoria: Seriti Printing.

**Websites:**

South Africa Construction Industry Development Board(CIDB): http://www.cidb.org.za

South Africa Council for Scientific and Industrial Research (CSIR): www.csir.co.za

South Africa Expanded Public Works Programme (EPWP): www.epwp.co.za

Benzene International: http://www.benzeneinternational.com/emulsions.html

The University of Southern Queensland (2000)  Transition Curves: www. usq.edu.au

# APPENDICES

## APPENDIX 1: TERMS AND TERMINOLOGY

### Road Servitude Terms

For the purpose of common understanding, a cross-section of a typical low-volume road has been provided below in Figure A-1 which indicates the main road components :

Cross-Section Terms

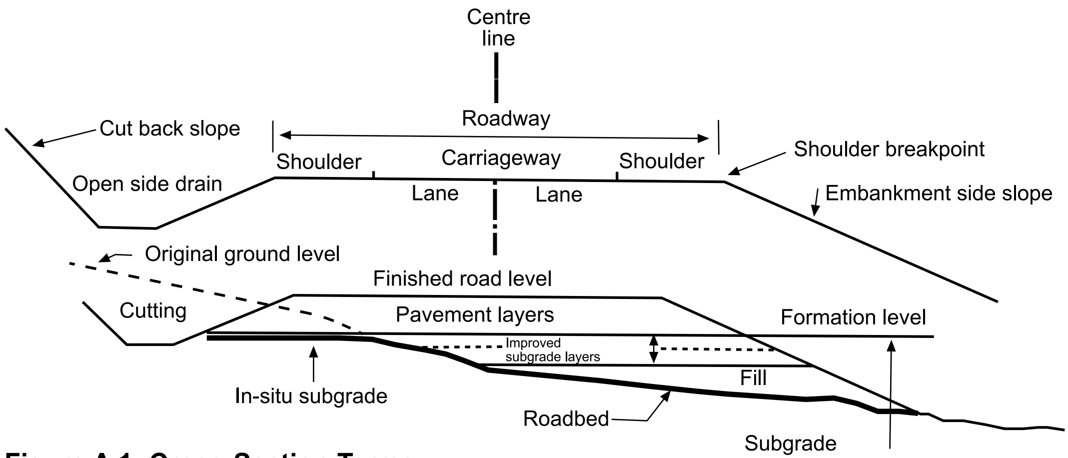



**Figure A 1: Cross-Section Terms**

1. Roadway
Width of road available for traffic, including shoulders.

2. Formation Width
Full width of road, including drains and embankments.

3. Carriageway
Paved width of the road.

4. Shoulders
Paved or unpaved width of road next to the edge of the carriageway adjacent to the ditch or embankment slope.

5. Camber
A cambered road has a cross-section like a ¨Roof¨ to drain the rainwater away from the carriageway to the side drains.

6. Gravel Course
A layer of compacted gravel which forms the surface (or pavement) of the carriageway.

7. Embankment
Compacted earth fill below the roadway.

8. Cut
Excavation into the natural ground on the hill side of the road usually with graded slopes. The suitable dug out material is used to create a fill on the valley side of the road.

9. Subgrade Surface
Upper layer of the soil (natural material) supporting the roadway including embankment slopes.

10. Side Drain
The side drains run along the road and collect the water from the carriageway and adjoining land and transport it to a convenient point of disposal.

11. Original Ground Level
The natural surface of the cross-section before construction.

12. Back Slope
The outer slope of the side drain with an appropriate angle to prevent the soil from sliding into the ditch.

13. Ditch Slope
Inside slope from the shoulder to the side drain.

14. Embankment Slope
Natural material slope on embankment.

15. Shoulder Break Point
The junction of the carriageway shoulder with the drainage ditch

16. Crown
Peak or highest point of the camber.

17. Road Centre Line
Line running along the centre of the road (important in surveying and setting out the road alignment). Longitudinal sections usually run along the road centreline.

18 Chainage is a term frequently used for describing distances measured along the centreline of a road and are shown written on pegs or boards which are fixed in the road reserve.

**Drainage Terms**

Good drainage is vital if roads are going to survive heavy rains. The following definitions help to understand the discussions on drainage. Figure A-2 shows where the major drainage elements are located.

1. Side Drains
The side drains run along the road and collect the water from the carriageway and adjoining land and transport it to a convenient point of disposal.

2. Mitre Drains
Mitre drains (or turn out drains) lead water out of the side drains and safely disperse it on adjoining land. Mitre drains should be provided at regular intervals to avoid water accumulating in the drains and causing erosion to the drains and adjoining land.

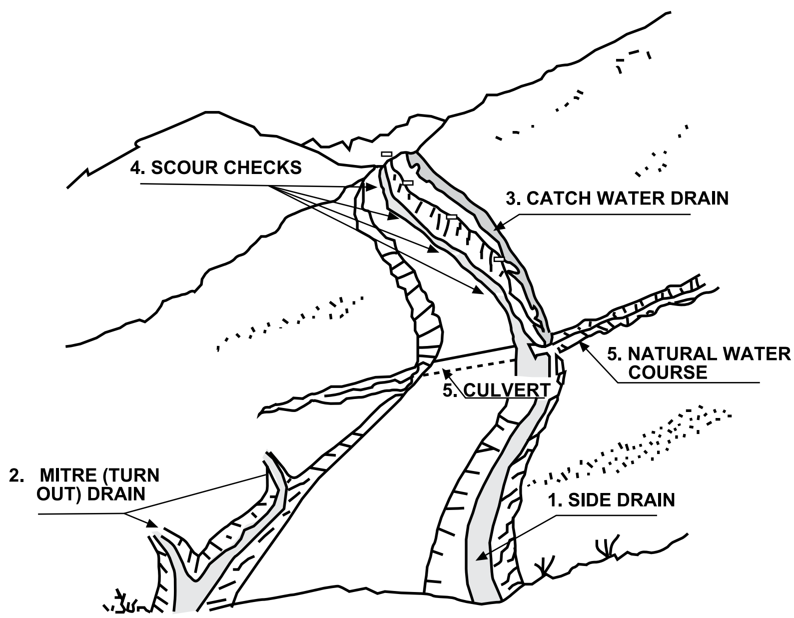



**Figure A 2: Drainage Elements**

3. Catch Water Drains
Where the road is situated on a hill side a significant amount of rainwater may flow down the hill towards the road. This may cause damage to the cut face (backslope) of the road and even cause landslides. Catch water drains catch or intercept surface water flowing towards the road from adjacent land, and lead it away.

4. Scour Checks
Scour checks prevent erosion in side drains on steep gradients by slowing down the water (steps). Scour checks are usually built using locally available material, such as wooden sticks or stones.

5. Culvert
The culvert is a transverse drain built under the road and its function is to lead water from the upper or uphill side of the road to the lower or valley side of the road. Roads in areas with high rainfall may require three to four culverts per kilometre. Culvert rings are usually made of concrete or prefabricated steel rings (e.g. Armco culverts).

**Culvert**

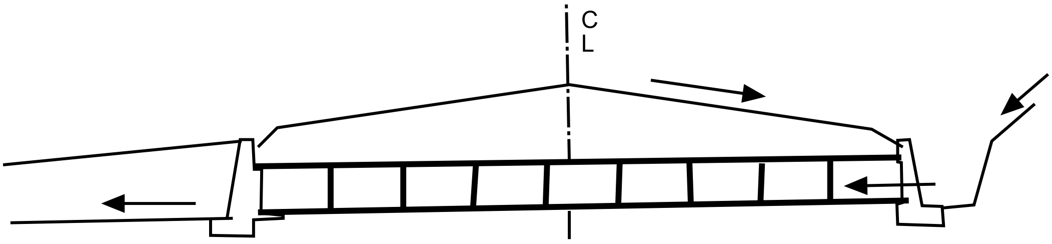
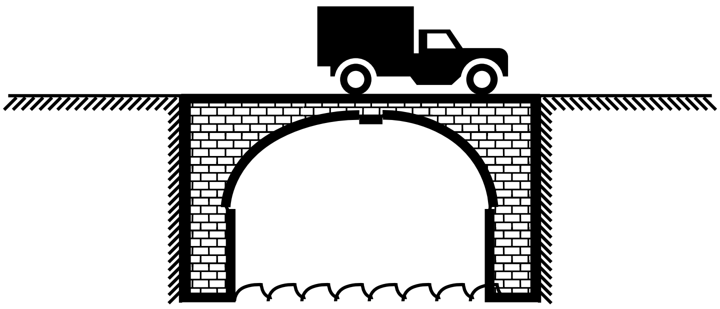



**Figure A 3: Culvert**

**Major Structure Types**

1. Bridge / Box Culvert
A designed structure that allows natural water courses like rivers including runoff during periods of high rainfall to pass under the road.

**Bridge**



**Box Culvert**

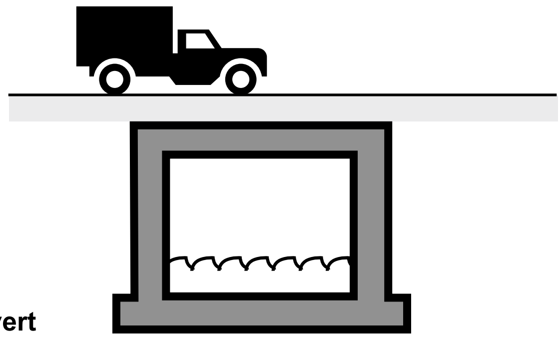


**Figure A 4: Box Culvert**

2. Drift or Splash

A low level crossing over which constant or seasonal water collected from the ditches and / or natural water courses can flow.

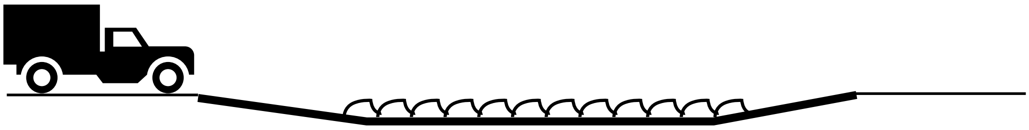


**Figure A 5: Drift / Splash Drain**

3. Vented Ford (or Vented Drift)

A medium level stream or river crossing through which the normal flow of water can pass but which is designed to be over-topped during periods of heavy rainfall.

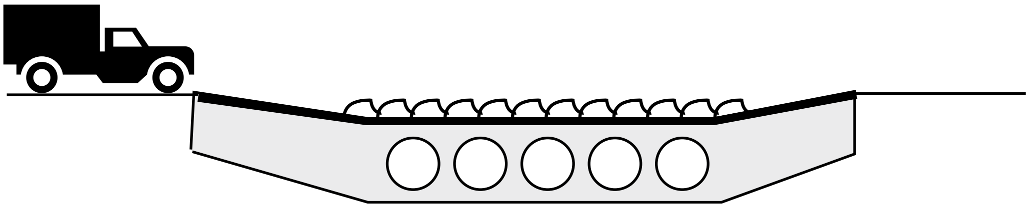


**Figure A 6: Vented Ford**

## General Terms

1. Construction
The process by which a road is actually built according to established design standards and construction plans.

2. Rehabilitation
Activities which improve the existing road and restore its geometric characteristics to the original recommended design standards.

3. Upgrading
The process by which the standard of an existing road is altered to allow the achievement of an increased capacity for the safe use by a greater volume of traffic.

4. Maintenance
The work which is required to retain the original standard of the road.

**Horizontal Alignment**

The direction of the centreline of a road in plan.

**Horizontal Curve**

A curve in plan.

**Transition Curve**

A curve, whose radius changes continuously along its length, used for the purpose of connecting a straight with a circular arc or two circular arcs of different radii.

**Transition Length**

The length of the transition curve.

**Shift**

The lateral displacement of a circular curve, measured along the radius, consequent upon the introduction of a transition curve.

**Compound Curve**

A curve consisting of two or more arcs of different radii curving in the same direction and having a common tangent or transition curve where they meet.

**Reverse Curve**

A composite curve consisting of two arcs or transitions curving in opposite directions.

**Intersection Angle**

The internal angle formed by two successive straights.

**Deviation Angle**

The external angle formed by two successive straights measuring the angular change of direction.

**Deflection Angle**

Successive angles from a tangent subtending a chord and used in setting out curves.

**Vertical Alignment**

The direction of the centreline of a road in profile.

**Vertical Curve**

A curve on the longitudinal profile of a road. There are two types of vertical curves:

- Crest Curve - A convex vertical curve with the intersection point of the tangents above the road level.
- Sag Curve - A concave vertical curve with the intersection point of the tangents below the road level.

**Gradient**

A rate of rise or fall on any length of road with respect to the horizontal. It is usually expressed as a percentage.

**Longitudinal Profile**

An outline of a vertical section of the ground, ground data and proposed works along the centreline.

**Superelevation**

The inward tilt or transverse inclination given to the cross-section of a carriageway throughout the length of a horizontal curve to reduce the effects of centrifugal force on a moving vehicle. It is expressed as a percentage.

**Design Speed**

A speed selected for purposes of design and correlation of those features of a road, such as curvature, superelevation and sight distance, upon which the safe operation of vehicles depends.

**Surfaced road**

A surfaced road is a road which has been provided with an all-weather riding surface. For the purposes of this presentation two surfacing options will be considered, viz.:
- A Bituminous seal utilizing a bituminous emulsion binder, and
- An asphalt surfacing manufactured with a bituminous emulsion binder.

**Bituminous Seal**

A bituminous seal consists of aggregate of a specified size (or grading) held in place with a bituminous emulsion binder, penetration grade or cut back bitumen binder. For the purposes of these guideline three types of seal will be discussed. These are:
- Sand Seal
- Cape seal
- Modified “Otta” seal or Penetration Seal

**Sand Seal**

A Sand seal comprises a single or double seal of aggregate (river sand, crusher dust or grit) held together with a bituminous binder. For a permanent wearing course at least a Double sand seal would normally be required. A single sand seal can be used as a temporary seal until the permanent seal can be applied.

**Penetration seal (Modified Otta Seal)**

The penetration seal was developed to provide a more labour friendly alternative to the “Otta” seal. A Penetration seal comprises a graded aggregate held in position with a bituminous binder. The binder is applied in two applications in the form of a tack coat followed by a penetration application.

**Asphalt surfacing**

Asphalt consists of a mixture to predetermined proportions of aggregate, filler and bituminous binder prepared off the road under controlled conditions. The asphalt described in the guidelines makes use of a bituminous emulsion as binder.

**Aggregate**

Aggregates (coarse aggregate) for bituminous seals as a rule consist of approved inert hard rock type material which has been crushed and/or screened to comply with certain specifications and requirements. Crusher sand or washed natural sand, used in the manufacture of slurry, is also classified as an aggregate (fine aggregate). The grading of the sand used in the manufacture of slurry will determine the texture of the slurry

**Average Least Dimension (ALD)**

This expression is used as one of the characteristics for aggregate used in bituminous seals for surfacing e.g. Cape seal, penetration seal etc., and is of importance when determining the rate at which the aggregate must be spread to prevent over or under application of the aggregate as well as determining the application rate of the bituminous binder.

The ALD can be described as follows:

Any particle of aggregate is not perfect in shape – a 19mm aggregate is not 19mm in all directions, it has long and short sides.

**Average Least Dimension of aggregate (ALD)**

If dropped on a surface it will always fall on the surface with its smallest dimension vertical to the plane of the surface. It does not matter what the shape of the particle of aggregate is, it will always fall on the road with d1 and d2 (Figure A-7) i.e. the least or smallest dimension vertical to the road surface; e.g. a sample if dropped in the road will never come to rest on the road in this position where d the maximum dimension is vertical to the road surface.

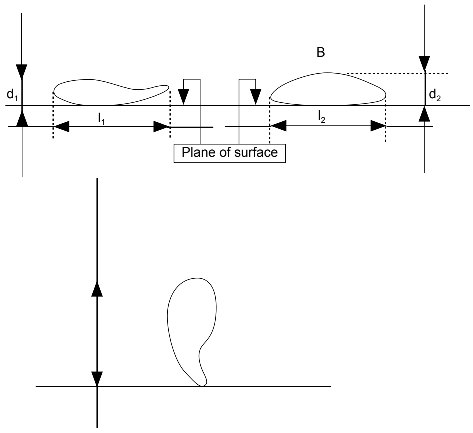



**Figure A 7: Average Least Dimension of aggregate (ALD)**

**Aggregate Crushing Value (ACV)**

The aggregate crushing value (ACV) of an aggregate is the mass of material, expressed as a percentage of the test sample which is crushed finer than a 2.36 mm sieve when a sample of aggregate passing the 13.2 mm and retained on the 9.50 mm sieve is subjected to crushing under a gradually applied compressive load of 400 kN.

**Bitumen**

Bitumen which is a by-product of the petroleum industry is the cementing (binding) agent used in bituminous seals or asphalts. The viscosity[47] (stiffness) of bitumen is given in terms of a penetration. The penetration value of bitumen is the distance a standard needle will penetrate a sample of the bitumen at a certain standard temperature.

**Bituminous emulsion**

A bituminous emulsion is a liquid mixture of small droplets of bitumen suspended in water with the assistance of an "emulsifier" An emulsifier is an agent included in the bitumen water mixture to distribute the bitumen droplets in the water and regulate its stability and "breaking" time. There are a variety of bituminous emulsions either anionic or cationic, spray grade, mix grade or stable grade. The correct emulsion must be used for the correct application. For instance, Anionic emulsions rely on the evaporation of the water component for breaking the emulsion and are generally most suitable for use with basic aggregates e.g. dolerites, whereas the Cationic emulsions rely on a chemical reaction for breaking the emulsion and are most suitable for use with acidic aggregate e.g. granites. The types and grades of emulsion referred to in this guideline are listed below.

**Anionic spray grade emulsion (60/40)**

This is an emulsion of 60% bitumen and 40% water and is used to bind the aggregate in the construction of bituminous surfaces such as the Cape seal.

[47] Viscosity is a measure of resistance to flow at a certain temperature

**Cationic spray grade emulsion (65/35)**

This is an emulsion of 65% bitumen and 35% water and is used to bind the aggregate in the construction of seals. This grade emulsion is commonly used with Sand Seal and Cape seal.

**Anionic stable grade emulsion (60/40)**

This is an emulsion of 60% bitumen and 40% water and is used in the manufacture of seals such as the slurry in the Cape seal and the tack and penetration coats in the penetration seal.

**Cationic mix grade emulsion (65/35)**

This is an emulsion of 65% bitumen and 35% water and is used in the manufacture of the asphalt. This product is specially prepared for the manufacture of cold mix asphalt in a concrete mixer.

**Rate of application**

The rate of application of a product or material is the amount of that material or product applied over a certain area.

Examples of rates of application are:

| Activity | Unit |
|---|---|
| Spraying of Bituminous binder or emulsion | Litres per square metre ($l/m^2$) |
| Spreading of aggregate for surfacing | Cubic metres per square metre ($m^3/m^2$) |

**Bearing Ratio**

The load required to produce a certain penetration using a standard piston in a soil, expressed as a percentage of the load required to force the piston the same depth in a selected crushed stone. Bearing Ration values are normally determined using the California Bearing Ratio (CBR) text method.

**Liquid Limit (L.L)**

It is the minimum moisture content at which the soil will flow under its own weight when tapped 25 times in Atterberg's Liquid limit device. This indicates limit where soil changes from plastic to liquid state.

**Plastic Limit (P.L)**

The Plastic Limit indicates the percentage of moisture at which the soil sample changes, with decreasing wetness, from a plastic to a semi-solid state. It is the maximum water content at which the soil can be rolled into threads approximately 3mm in diameter without breaking. It is the lower limit of the plastic state.

**Shrinkage Limit (S.L)**

It is the moisture content, expressed as a percentage, at which volume change ceases. The sample continues to shrink with decrease in moisture content during drying, until the shrinkage limit is reached, but its volume remains constant with further drying.

**Plasticity index (P.I)**

The plasticity index of a soil is defined as the liquid limit of a soil minus its plastic limit:
Plasticity index (P.I) = Liquid limit (L.L) - Plastic limit (P.L). It is the range within which soil exhibits plastic properties is called the plastic range.

**Grading Modulus (G.M)**

The Grading Modulus is defined as the sum of the percentages retained on the 75µm, 425µm, and 2.36mm sieves divided by 100.

**Plastic Product (P.P)**

This is defined as the plasticity index (P.I) multiplied by the percentage passing the 0.425mm sieve.

## Notes

## Notes

## Notes

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