Federal Republic of Nigeria

Federal Ministry of Works

Highway Manual Part 2: Maintenance

Volume II:

Maintenance Works

2013

MAINTENANCE WORKS

FOREWORD

The vision statement of the Federal Ministry of Works is to elevate Nigerian roads to a standard where they become National economic and socio-political assets, contributing to the Nation's rapid growth and development, and to make Federal roads functional, safe, pleasurable, and an avenue for redeeming Nigerians' trust and confidence in Government. This vision statement is in tune with the Transformation Agenda of the President of the Federal Republic of Nigeria, His Excellency, Dr Goodluck Ebele Jonathan, GCFR. Based on the foregoing, our mission is to use the intellectual, management and material resources available to the Ministry to make Nigerian roads functional all the time. The principal goal of the Ministry is to drive the transformation agenda by improving road transport infrastructure for the overall socio-economic derivable benefits and development of our great country, Nigeria.

In exercising this mission and in discharging its responsibilities, the Ministry identified the need for updated and locally relevant standards for the planning, design, construction, maintenance and operation of our roads, in a sustainable manner. One of the main reference documents for this purpose is the Highway Manual, which previously included Part 1: Design and Part 2: Maintenance. Both current parts of the Highway Manual were first published in 1973 and 1980 respectively and have been subjected to partial updating at various times since then. The passage of time, development in technology, and a need to capture locally relevant experience and information, in the context of global best practices, means that a comprehensive update is now warranted.

The purpose of the Highway Manual is to establish the policy of the Government of the Federal Republic of Nigeria with regard to the development and operation of roads, at the Federal, State and Local Government levels, respectively. In line with this objective, the Manual aims to guide members of staff of the Ministry and engineering practitioners, with regard to standards and procedures that the Government deem acceptable; to direct practitioners to other reference documents of established practice where the scope of the Manual is exceeded; to provide a nationally recognized standard reference document; and to provide a ready source of good practice for the development and operation of roads in a cost effective and environmentally sustainable manner.

The major benefits to be gained in applying the content of the Highway Manual include harmonization of professional practice and ensuring uniform application of appropriate levels of safety, health, economy and sustainability, with due consideration to the objective conditions and needs of our country.

The Manual has been expanded to include an overarching Code of Procedure and a series of Volumes within each Part that cover the various aspects of development and operation of highways. By their very nature, the Manual will require periodic updating from time to time, arising from the dynamic nature of technological development and changes in the field of Highway Engineering.

The Ministry therefore welcomes comments and suggestions from concerned bodies, groups or individuals, on all aspects of the document during the course of its implementation and use. All feed back received will be carefully reviewed by professional experts with a view to possible incorporation of amendments in future editions.

Arc. Mike Oziegbe Onolememen, FNIA, FNIM.

Honourable Minister

Federal Ministry of Works,

Abuja, Nigeria

May, 2013

ACKNOWLEDGEMENTS

The Highway Manual has been updated by the Road Sector Development Team (RSDT), of the Federal Ministry of Works, with credit assistance from the World Bank's Federal Roads Development Project (FRDP). This update draws upon the original Manual, which was compiled between 1973 and 1980. The new Manual reflects recent developments in Road Design and Maintenance, in addition to latest research findings and updated references. Furthermore, it includes accepted practices that have been developed with the extensive effort of numerous organisations and people involved in the road sector. The assistance of all who have contributed is hereby gratefully acknowledged. Special acknowledgement is due to the following persons, who have been particularly involved and provided specific input that has been incorporated into the Manual:

Review Project Management Team:

Person	**Organisation**
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Public Organisations

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Federal Ministry of Environment
Federal Roads Maintenance Agency (FERMA)
Federal Capital Development Authority
Federal Road Safety Corps
Nigeria Meteorological Agency
Nigerian Geological Survey Agency
Nigeria Police Force (Traffic Division)
Nigeria Hydrological Services Agency
Nigerian Meteorological Agency
Nigerian Society of Engineers
Nigerian Institute of Civil Engineers
Council for the Regulation of Engineering in Nigeria

Private Organisations

AIM Consultants
Aurecon Nigeria Ltd
Axion Consult Engineering Resources Ltd
Ben Mose & Partners
Dantata & Sawoe Construction (Nigeria) Ltd
Enerco Ltd
Etteh Aro & Partners
FA Consulting Services Ltd
Intecon Partnership Ltd
Julius Berger Nigeria Plc
Keeman Ltd
Multiple Development Services Ltd
Mansion Consulting Ltd

Property Mart Ltd
RCC Ltd
Sanol Engineering Consultants Ltd
Setraco Nigeria Ltd
Siraj International Ltd
Yolas Consultants Ltd

This update of the Highway Manual was compiled by the Road Sector Development Team of the Federal Ministry of Works with the assistance of the consultants Royal HaskoningDHV.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

1.1 Purpose of the Manual

In an approach to prolong the lifespan of all roads within the nation and to provide and maintain an acceptable road network standard, which would positively affect travel time and vehicle operating costs, it is imperative that correct and appropriate maintenance procedures be adopted.

The aim of this Manual is therefore to help the maintenance personnel in making sound decisions in the application of acceptable maintenance methods for the maintenance of the over 34,000 kilometres of road network within the Nation. The Manual provides an easy procedural reference book on all aspects of work required in the maintenance and repair of the nation's roads, be it either by own labour or by contractors.

In addition to maintenance methods and procedures, the Manual also covers the issues

- Pavement distress identification
- Pavement management information
- Road user and worker safety procedures

1.2 Structural Overview of the Highway Manual

The Highway Manual consists of two (2) parts, namely

- Highway Manual Part 1: Design;
- Highway Manual Part 2: Maintenance,

Both parts are subdivided into volumes as per Figure 1: Arrangements of Volumes.

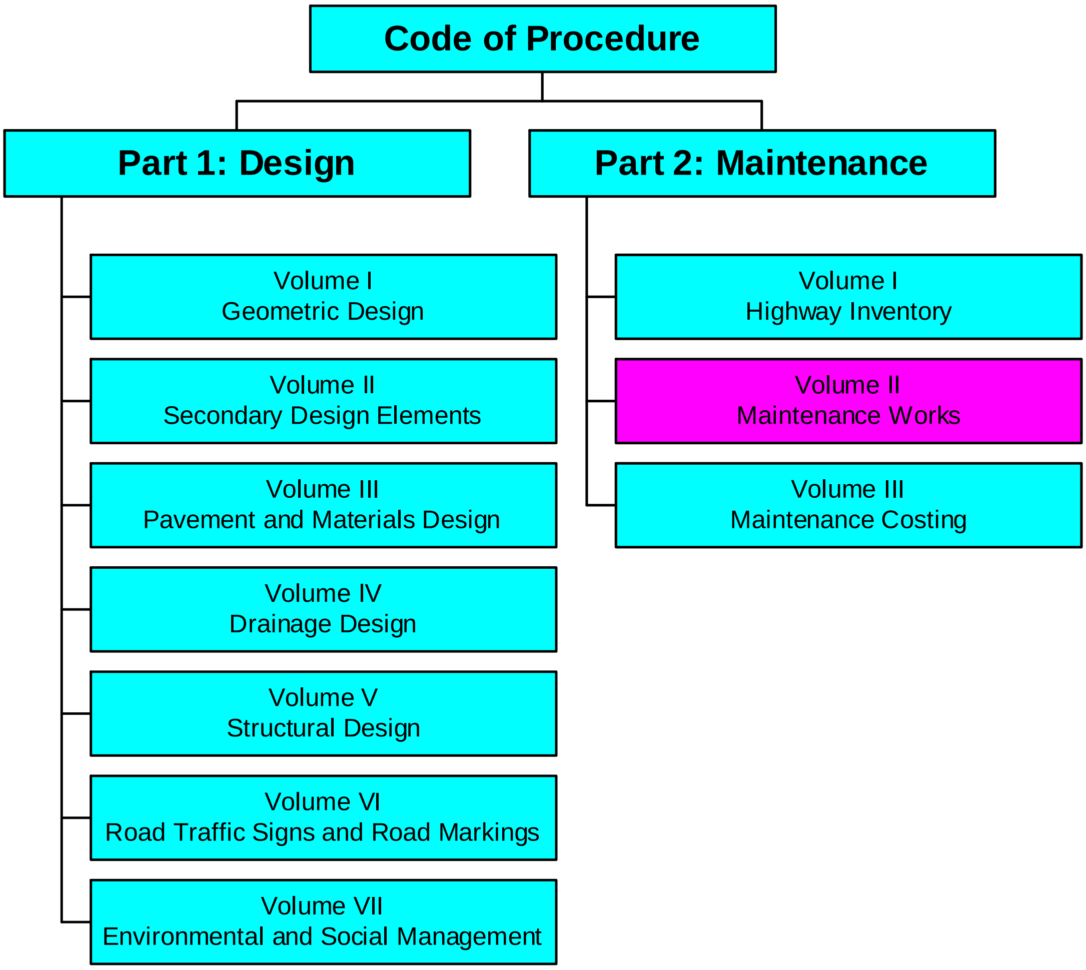


Figure 1: Arrangement of Volumes

Part 1- Design comprises seven volumes:

- Volume I - Geometric Design
- Volume II Secondary Design Element
- Volume III Pavement and Material Design
- Volume IV Drainage Design
- Volume V- Structural Design
- Volume VI Road Traffic Sings and Road Markings
- Volume VII Environmental Management

Part 2- Maintenance comprises three volumes:

- Volume I Highway Register
- Volume II Maintenance Works (This Volume)
- Volume III Cost Accounting for Highway Maintenance

1.3 General Lay-Out of the Manual

a. Volumes

Each volume has been designed as a self-contained independent unit which can be read without cross references to any of the other volumes.

b. Chapters and sub - chapters

As far as possible, each chapter within the individual volumes has been designed to contain information relevant to the subject matter in that chapter only and, with limited cross references to other chapters within the volume.

Furthermore, each chapter is divided into sub-chapters where, as far as possible, each sub-chapter contains instructions on procedures and methods for an individual type of operation or subject only.

c. Amendments

Although the working procedures and methods outlined within each chapter and sub-chapter are by experience found to be the most suitable for use in Nigeria at the time of compilation of the Manual, development in specifications, methods and procedures over time may necessitate improvements and changes to the methods and procedures within the chapters and sub-chapters. To facilitate these changes amendments to the original are issued from time to time.

To facilitate such amendments or additions, the volumes have spring-clip binding covers for easy insertion of any amendments into the Manual. In addition each page within the individual volume is marked at the bottom with the manual number, volume number and date of issue of the page (Highway Manual – Part 2 Volume 2, November 2012).

Thus, amendments marked with a later date than the original page can be easily identified. Amended pages are distributed to all registered holders of the Manual as and when they are made. Periodically a complete list of amendments and additions are issued so that all registered holders of the Manual can insure to have up-to-date copies of the volumes.

1.4 Scope of this Volume

This volume is an upgrade and revision of earlier editions of the Manual and encapsulates improvements to specifications, methodologies and maintenance strategies utilised in the maintenance of the road network within Nigeria.

Although this volume provides guidelines and standards for compliance it is not intended as substitute for sound engineering judgment and should be supplemented by other relevant manuals and books where inadequate information are not supplied. Such information and the use of such codes need to be confirmed by the Department of Federal Ministry of Works, Housing and Urban Development.

1.5 The International Road Maintenance Manual (PIARC)

The Handbook is aimed at those responsible for the maintenance of bituminous or unpaved roads in tropical or moderate climates. It is in four volumes: I, Maintenance of roadside areas and drainage; II, Maintenance of unpaved roads; III, Maintenance of paved roads; and IV, Maintenance of structures and traffic control devices. Volume I also contains a list of terms and a general index for all volumes. General methods are proposed for each activity (with some exceptions) under the headings: The task; Effects; Resources; and Maintenance method. Where appropriate, options are considered for carrying out the work by heavy equipment, tractor based methods or labour based methods. Operations are grouped into routine or periodic. Routine operations are normally small scale or simple and are carried out once or more per year. Periodic operations are normally large scale, requiring specialist skills and resources, and are carried out after a number of years. Emergency work is dealt with as the need arises.

This handbook is a valuable supplement to this Highway Manual Part 2: Volume II – Maintenance. It is published by Crowthorne Transport Research Laboratory, 1994.

2 Highway Maintenance Methods

2.1 Highway Maintenance

Highway maintenance is defined in Nigeria as the preservation of a road in a safe and satisfactory condition for conveyance of traffic at all times. Thus growing traffic demand must be met by growing standards. There are four (4) main types of maintenance activities, namely

- Emergency Repairs
- Routine/Preventive Maintenance
- Periodic/Corrective Maintenance
- Minor Improvement

2.1.1 Emergency Repairs

These are works carried out to repair sudden failures of the road and or structures on the road. These range from the repair of failures affecting traffic flow such as wash-off sections of road or structure, subsidence and slope failures.

2.1.2 Routine/Preventive Maintenance

Routine maintenance may be defined as those treatments that are applied to a pavement in order to keep the pavement functioning properly. As such, routine maintenance is sometimes referred to as “reactive maintenance.” This suggests that it is work that is performed as a reaction to a specific distress. Routine maintenance is performed on pavements as they begin to show signs of deterioration. Filling a pothole is an example of a routine maintenance activity. It cannot be scheduled before the pothole appears and it should not be left unattended once the pothole has developed.

Routine maintenance should be planned and scheduled. The intent is to repair early pavement deterioration, delay failures and reduce the need for corrective or emergency treatments. Although routine maintenance does not include activities that are intended to increase the structural or load carrying ability of a pavement, it does extend the useful life and level of service (e.g. ride). Performing routine maintenance activities on pavements in good condition will be very effective in extending the life. The effectiveness of the treatment is directly related to the condition of the pavement.

Preventive maintenance applies to lower-cost treatments to retard a pavement's deterioration, maintain or improve the functional condition and extend the pavement's service life. With various short-term treatments preventive maintenance can extend pavement life an average of 5 to 10 years. Applied to the right road at the right time when the pavements are mostly in good condition preventive maintenance can improve the network condition significantly at a lower unit cost and also assists the Highways Department in the budgetary process and optimization of available funds. An effective preventive maintenance program depends on adequate funding.

For the Department to have an effective preventive maintenance program all personnel associated with the care and maintenance of our highways need to understand the basis and benefits of such a program and then be able to educate the public.

2.1.3 Periodic/Corrective Maintenance

Periodic maintenance includes activities undertaken at intervals of several years to preserve the structural integrity of the road or to enable the road to carry increased axle loadings. Periodic maintenance is carried out at regular, but relatively long, intervals. As such, they can be budgeted for on a regular basis and can be included in the recurrent budget.

The differences between routine and periodic maintenance occur in the timing and cost. Periodic maintenance is the scheduled and pre-planned maintenance or upgrading of a road surface or pavement structure. A well maintained and implemented routine and preventative maintenance program has a direct influence on the periodic maintenance requirements.

2.1.4 Minor Improvements

Minor improvements are normally defined as improvements, which can be done within the financial capacity of the funds allocated in the budget for highway maintenance such as small improvements to the geometry, replacement or strengthening of small sections of weak pavements or additional overlays of limited thicknesses to existing weak pavement sections.

Improvements such as replacement or strengthening of entire lengths of roads; large realignments or upgrading that are beyond the financial capacity and scope of highway maintenance are major works, which will normally be handled by the Design and Construction Division of the ministry and financed from the capital budget. However, if within the capability of the maintenance organization, they could be carried out and financed from supplementary funds allocated for “Improved Maintenance”.

2.2 Elements of the Highway Structure

Highway maintenance works can be logically divided into ten basic elements, where each will contain a number of functions of both routine and periodic maintenance work. These basic elements are

- Administration
- Drainage
- Shoulders
- Right of way / Road reserve
- Bituminous pavements
- Gravel pavements
- Bases
- Drainage structures
- Highway furniture
- Services and miscellaneous

2.3 Highway Maintenance Works by Maintenance Types

The following lists of works are not exhaustive but contain the basic maintenance functions, which will require inspection, planning, estimating, budgeting, execution and reporting to be done on a regular cycle of operations and will include the training and use and allocation of all staff and should be read in conjunction with Section 3 of the FERMA Operations Manual:

Table 1: Highway Maintenance Activities by Maintenance Types

Administration	
Routine and periodic maintenance	
Budget allocation	
Procurement of materials, plant and equipment	
Prioritizing of work	
Allocation of teams to carry out work	
Daily reporting on work completed	
Cost analysis	
2. Drainage	
Routine	Periodic
Drain cleaning	Cutting new drains
Culvert cleaning	Culvert repair and relaying
Bridge waterway clearing	Repair outlet and inlet channels and structures
Erosion control	
3. Shoulders	
Routine	Periodic
Grass cutting	New grass (including seeding dibbling, turf/sodding , top soiling, etc)
Shoulder cleaning (including light grading and filling)	Build-up and widening
	Surface dressing of hard shoulders

4. Right of way / road reserve	
Routine	Periodic
Bush clearing	Right of way markers (including surveying)
Tree felling	Earthwork
Branch trimming	

5. Bituminous pavements	
Routine	Periodic
Pothole patching (including edge breaks)	Prime (Fog spray) and Seal
Crack sealing (overpainting, etc.)	Single surface dressing (single seal)
Removing sand / silt deposits on roadway	Double surface dressing (double seal)
	Bitumen macadam
	Asphaltic concrete

6. Gravel Pavements	
Routine	Periodic
Pothole patching	Gravel surfacing
Regrading and shaping (including watering and rolling)	
Redressing or re-gravelling (replacement of missing material)	

7. Bases	
Periodic (Please note: If the repair or maintenance of the base is required, the appropriate re-surfacing will also have to be programmed and carried out).	
Lateritic natural gravel base	
Cement stabilized base	
Bitumen stabilized base	
Dry stone base	
Concrete	
Water bound macadam base	
8. Drainage structures	
Routine	Periodic
Minor repairs	Painting steel and timber
Touch painting	New culvert
Riprap repairs	Replacing timber decks
	Major repairs
9. Highway furniture	
Routine	Periodic
Touch-up pavement Marking	New kilometre posts, etc.
Kilometre posts (painting and replacement)	New road signs
Road sign repair (painting and replacement)	Lay-bye construction
	Re-marking and striping

10. Services and miscellaneous
Routine and / or periodic Periodic
Ferry operation
Lighting operation
Escorts and guards
Research and survey

3 Pavement Management Systems

3.1 Pavement condition

The condition of the pavement is considered from two points of view, namely that of the road user and that of the road engineer. Since the road user regards the road as a service, the condition of the pavement is appraised in terms of those characteristics that affect quality of travel, notably comfort, safety and operating costs. The engineer, on the other hand, recognises these functional requirements but also views the pavement as a load bearing structure to be maintained in good time if it is to remain serviceable at optimum cost.

The assessment of the condition of the pavement is therefore based on functional descriptions and descriptions related to the condition of the pavement surfacing and pavement structure.

3.2 Pavement Management System

A Pavement Management System (PMS) is a tool to efficiently manage the continuous evaluation of the existing road network by evaluating the pavement condition of a road where the present serviceability of a road or road section, the cause and rate of pavement deterioration, the pavement loading rate, prediction of optimal time for intervention and the evaluation of the most economic rehabilitation strategy can be determined.

There are two levels of road management:

- Network level
- Project or maintenance level.

3.2.1 Network Level

Pavement management at network level deals with the summary of information related to the entire or a large portion of the network. As such it involves policy and programming decisions.

Examples of network level pavement management is the use of the PMS information to:

- Identify and prioritise projects;
- Establish rehabilitation programmes
- Estimate overall short- and long-term needs
- Establish budgetary requirements for major and maintenance works

3.2.2 Project Level

Pavement management at project level deals with detailed and technical information related to a specific road section or sections.

Examples of project level pavement management, as related to specific road sections, include the following:

- Details of the road pavement structure
- Condition of the road section
- Determine repair or maintenance requirements for the specific road section or sections
- Cost estimates and planning
- Feedback and the documenting of actions taken

Additional information to be collected and documented to form part of the PMS data base, includes the following:

- Geometric data of the pavement such as length, width, etc.
- Pavement structures and layer thickness
- Present Serviceability Index (PSI) of the pavement
- International Roughness Index (IRI) of the pavement
- Road skid resistance
- Accident records
- Maintenance and construction data
- Weather data, etc.

3.3 Functional Condition Analysis

The functional requirements of a pavement are the required standards of those properties of the pavement that affect the service it provides to the road user. They are predominantly those that govern his comfort, safety and speed of travel.

Three of the most important features are:

- Pavement roughness / riding quality
- Skid resistance
- Surface drainage. (Assessed through visual assessments)

3.3.1 Pavement Roughness / Riding Quality

Riding quality is used in the PMS as one index of the functional condition of a section or sections of road pavement. Riding quality can be combined as part of a visual function index or used separately as a trigger value or flag for maintenance and rehabilitation action.

The most widely used method of roughness measurement is the International Roughness Index (IRI). The IRI is defined by the average rectified slope (ratio of accumulated suspension motion to the distance travelled) of a standard ‘quarter-car’ (one wheel) simulation for a travelling speed of 80km/h. Modern technology has developed to the extent where vertical sensors placed at strategic positions (wheel path) on a bar mounted at the front of a vehicle, which measure the undulation or unevenness of a road in mm/m or m/km.

Measurements of the roughness or ride quality are taken on a yearly basis and are measured in millimetre per metre (mm/m).

Typical surface ratings are as shown below:

Table 2: Typical Surface Rating for Paved Road

S/N	RATING	REMARKS
1	0 – 2	Smooth
2	2 – 3	Rough
3	> 3	Very Rough

3.4 Visual Condition Analysis

The Visual Condition Analysis (VCI) is performed on pavement distress data collected through visual assessments of the pavement surface.

The method of analysis combines the visual pavement condition data for individual distress types into an index representing the general pavement condition. The index is only a representation of the ‘as-is’ condition of the pavement, irrespective of the importance of the road and does not take traffic or functional classification of the road or road section into account.

The reporting of the condition of roads or road sections within the paved road network is shown in Table 3:

Table 3: Pavement VCI Rating for Paved Road

S/N	RATING	REMARKS	INDICATION
1	85 – 100	Very Good	Many years of service. No maintenance required.
2	70 - 85	Good	Many years of service. Minor maintenance required.
3	50 - 70	Fair	Some maintenance required
4	30 - 50	Poor	Extensive maintenance and repairs required
5	0 - 30	Very Poor	Major rehabilitation or reconstruction required

3.4.1 Pavement Distress Identification (Visual Assessment)

Visible distress is an important input in the assessment of the condition of a pavement structure. Distress is described by recording its main characteristics, the so-called attributes of distress, which are namely the type, degree and extent of occurrence. Effective road maintenance requires an understanding of the types of distress found on a highway.

a. Degree:

The degree of a particular type of distress is a measure of its severity. Since the degree of distress can vary over the pavement section, the degree to be recorded should, in connection with the extent of occurrence, give the best average assessment of the seriousness of a particular type of distress. The degree is indicated by a number where Degree 1 indicates the first evidence of a particular type of distress ("slight"), Degree 3 indicates a warning (requires attention) degree and Degree 5 indicates the worst degree ("severe"). The general descriptions of degree of each type of distress are presented in Table 4. These descriptions relate to the possible consequences of each type of distress and also to the urgency of maintenance or rehabilitation. Degree 1 generally indicates that no attention is required; Degree 3 indicates that maintenance/rehabilitation is required in the near future, whereas Degree 5 indicates that immediate maintenance/rehabilitation is required.

Table 4: General Description of Degree Classification

Degree	Severity	Description
0	-	No distress visible
1	Slight	Distress difficult to discern. Only the first signs of distress are visible.
2	Between slight and warning	
3	Warning	Distress is distinct. Start of secondary defects. (Distress notable with respect to possible consequences. Maintenance may be required in near future, e.g. cracks can be sealed.)
4	Between warning and severe	
5	Severe	Distress is extreme. Secondary defects are well developed (high degree of secondary defects) and/or extreme severity of primary defect (Urgent attention required).

b. Extent:

The extent of distress is a measure of how widespread the distress is over the length of the road segment. The extent is indicated by a number where Extent 1 indicates an isolated occurrence (“seldom”); Extent 3 indicates intermittent (scattered) occurrence over most of the length of road and Extent 5 indicates the extensive occurrence of a particular type of distress. The general description of the extent classifications is given in Table 5

Table 5: General Description of Extent Classification

Extent	Description
1	Isolated occurrence, not representative of the segment length being evaluated. (seldom)
2	Intermittent (scattered) occurrence, over parts of the segment length (more than isolated).
3	Intermittent (scattered) occurrence, over most of the segment length (general0, or extensive occurrence over a limited portion of the segment length.
4	More frequent occurrence, over a major portion of the segment length.
5	Extensive occurrence.

The selection of appropriate maintenance strategy will be influenced by the type, severity and extent of the pavement distresses and the structural and roughness condition of the pavement.

Table 6 below gives an indication of possible maintenance measures required for flexible pavements under various distress conditions:

Table 6: Flexible Pavement Maintenance Treatments:

Flexible Pavement Distresses	Frequency of Distress		
	Low	Moderate	High
Alligator Cracking[2]	3,6	6,5	15,13
Edge Cracking	2	2,13	13
Longitudinal Cracking	2,6	2,6	6,2,13
Random/Block Cracking	2,3	2,6	12,6,14

Transverse Cracking	2	2,6	2,6,13
Ravelling/Weathering	3,6,5	6,7	6,12,11
Distortion	13,8	8,13,6,2	8,14,13
Rutting	1	8 + 6	8,14,12
Bleeding	1,6	6,8	8 + 6 or 12

c. Recommended Pavement Treatments:

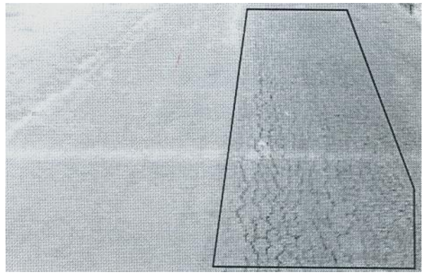
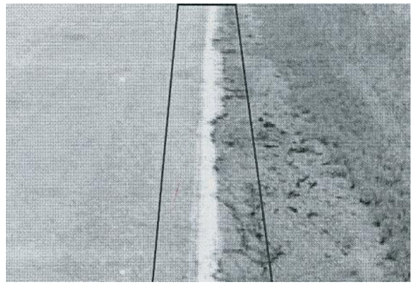
- Do nothing
- Crack fill/ seal
- Fog seal
- Scrub seal (broom seal)
- Slurry seal
- Chip seal/armour coat
- Micro surfacing
- Mill and replace
- Cold-in-place recycle
- Hot-in-place recycle
- Thin cold mix overlay
- Thin hot mix overlay[3]
- Patching
- Thick overlay
- Total reconstruction

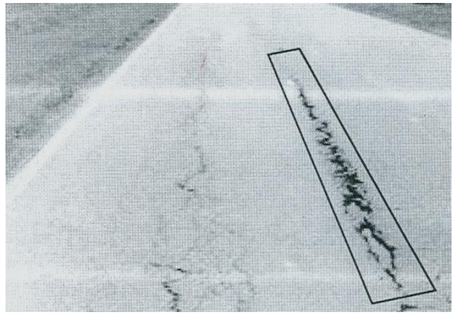
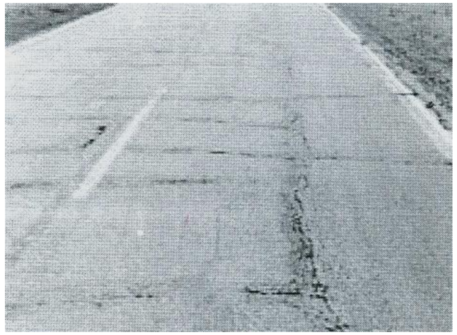
In general, flexible pavement failures are classified into the following five (5) major categories, namely:

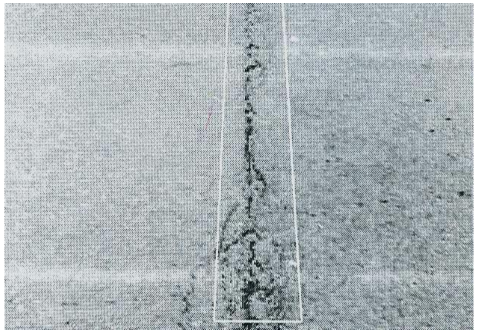
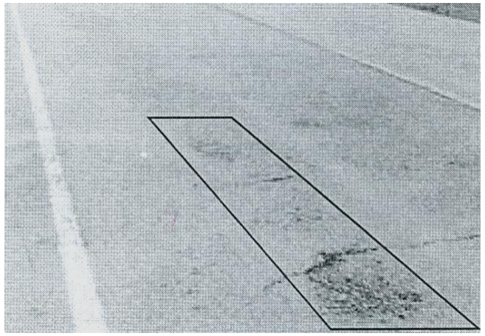
- Cracks
- Ravelling/weathering
- Rutting
- Bleeding
- Distortion

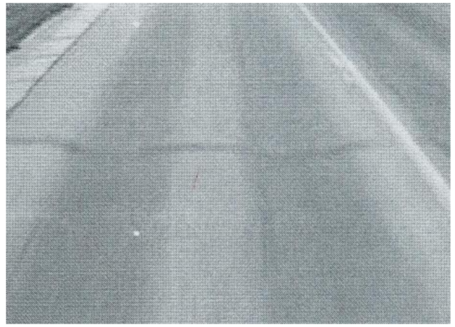
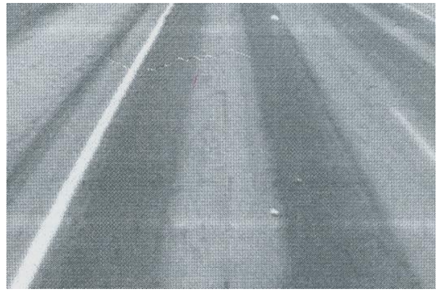
Table 7 below gives a description and pictorial view of these defects with their causes and maintenance strategies to ameliorate them.

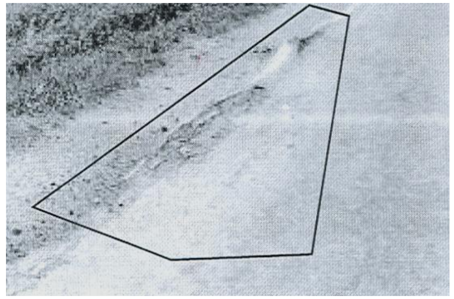
Table 7: Pavement Defects, Causes and Maintenance Methods

S/N	DESCRIPTION	CAUSES	MAINTENANCE METHOD	PICTURES
1.	**CRACKS**			
(a)	***Alligator Crack*** Alligator crack is a series of interconnected cracks in an asphalt layer forming a pattern, which resembles an alligator's hide or chicken wire. The cracks indicate fatigue failure of the asphalt layer generally caused by repeated traffic loadings thus allowing water to penetrate the surfacing materials and subgrade, and furthers the damage. Alligator crack, also called fatigue crack, usually first begins as a single longitudinal crack in the wheel path	• Aging and traffic loading • Insufficient pavement • structure • Poor base drainage • Inadequate base support	• Scrub Seal • Slurry Seal • Thin Cold Mix Overlay • Thin Hot Mix Overlay • Fog Seal • Patching • Chip Seal/Armour Coat	 Alligator Crack on a Flexible Pavement.
(b)	***Edge Crack*** Edge crack is similar to alligator crack but located within 0.6m of the edge of the pavement and progresses towards the wheel path. Pavement edge distress can result in worsening of the wheel path condition and allow moisture into the subgrade soils and base materials. Edge crack also includes the longitudinal crack associated with concrete base course widening	• High Shoulder • Holding Water • Traffic Loading • Construction Related • Low Shoulder • Environmental factors	• Thin Cold Mix • Overlay • Crack Fill • Shoulder Maintenance	 Edge Crack on a Flexible Pavement.

(c)	***Longitudinal Crack*** Longitudinal crack denotes cracks that run predominantly parallel to the centreline. These cracks may be in the wheel paths, between wheel paths and/or at lane joints such as centreline or shoulder/surface	• Reflection Cracks • Traffic Loading (wheel path cracks) • Poor Drainage • Environmental (frost action) • Improper Construction Practices (joint cracks)	• Scrub Seal/Armour Coat • Crack Seal/Fill • Patching	 Typical Longitudinal Crack on a Pavement
(d)	***Random/Block Crack*** Random or block cracks divide the pavement into rough, approximately rectangular pieces and typically occurs at uniformly spaced intervals	• Aging • Environmental factors (Thermal)	• Crack Seal/Fill • Chip Seal/Armour Coat • Fog Seal • Scrub Seal • Thin Cold Mix Overlay • Thin Hot Mix Overlay • Slurry Seal	 Typical Random Crack on a Flexible Pavement

(e)	***Transverse Crack*** Transverse cracks are those considered to extend three-fourths of the width of the pavement or more, generally perpendicular to centreline	• Environmental factors (Thermal) • Swelling or shrinkage of the subgrade • Reflection cracks • Settlement trench, backfill	• Crack Seal/Fill • Fog Seal • Scrub Seal • Chip Seal/Armour Coat • Mill • Patching • Slurry Seal	 Transverse Crack on a Pavement
2.	**RAVELLING/WEATHERING** Ravelling is the progressive wearing away of the pavement from the surface downward caused by the loss of asphalt binder and the dislodging of aggregate particles	• Asphalt hardening due to aging • Improper construction methods • Insufficient asphalt content • Poor mixture quality	• Fog Seal • Scrub Seal • Chip Seal/Armour Coat • Thin Cold Mix Overlay • Thin Hot Mix Overlay • Slurry Seal	 Typical Ravelling on a Pavement

3.	**RUTTING** A rut is a surface depression of the wheel path due to the deformation of the pavement layers or subgrade as a result of traffic load.	• Insufficient support • Improper construction procedures • Poor mixture quality	• Chip Seal/Armor Coat • Mill • Thin Cold Mix Overlay • Thin Hot Mix Overlay • Do nothing	 Rutting on a Typical Pavement.
4.	**BLEEDING** Bleeding also called flushing is a free film of bitumen on the surface of the pavement that creates a smooth, shiny, greasy and reflective surface. It is usually found in the wheel paths and becomes quite sticky when hot	• Improper construction practices • Paving over excess asphalt Mixture problems (bad oil, stripping aggregate, low air voids, high AC content, etc.)	• Chip Seal/Armor Coat • Mill • Thin Cold Mix Overlay • Thin Hot Mix Overlay	 Bleeding of a Flexible Pavement.

5.	**DISTORTION / FAILURES** Distortion is defined as that distress in the pavement caused by densification, consolidation, swelling, heave, creep or slipping of the surface or foundation	• Thermal and moisture stresses (freeze-thaw) • Static load (depressions) • Soft AC (shoving) • Loss of bonding between base layer and surface layer • Inadequate support or overloading	• Crack Seal • Chip Seal /Armor Coat • Mill • Thin Cold Mix Overlay • Thin Hot Mix Overlay • Patching	 Shoving and major changes in pavement profile that requires vehicles to slow from normal speeds.

4 Safety in Highway Maintenance

Safety during highway maintenance operations can be separated into three categories:

- Safety of the highway users
- Safety of the maintenance personnel
- Safety of the highway maintenance work

4.1 Safety of the Highway Users during Maintenance Operations

Every maintenance operation performed on the highway structure and its immediate surrounds imposes an obstruction to the smooth flow of traffic. As such it is the duty of the maintenance engineer to ensure that the safety of highway users is protected by adequate information display and control of traffic movements.

It should be borne in mind by all levels of management from engineers to overseers that the absence of warning and safety devices may be quoted in a court of law as being tantamount to negligence. It is therefore in the interest of all personnel to understand and apply the advice and recommendations given in this chapter.

The means of providing the necessary information to highway users and the methods of traffic control and guidance may be summarized as:

- Signs
- Lamps
- Barriers
- Signals
- Diversions

4.1.1 Temporary Signs

Temporary Signs are not restricted to signs such as “Road Works Ahead”, but may include any of several standard dangers, prohibitory or mandatory signs, which are temporary in time and location for the duration of the maintenance operation. Typical examples of such use are, ***“Slippery Surface*”, “*Overtaking Prohibited”*** and **“*Diversion*”** In the use of temporary signs it is not sufficient to merely display “***Slow***”, or “***Danger***”. Such signs are frequently ignored by the motorists and it is therefore necessary to be specific in answering the questions, “***what”, “where”*** and ***“why***”. This will assist in getting the cooperation and attention of highway users. Examples of useful temporary signs are given below.

a. Road Works Ahead

The sign shown as Figure 2 is a triangle with an red border and with the symbol in black on a yellow background. The sign is more effective when mounted above a supplementary sign denoting the forward distance to the obstruction, as shown as Figure 3. The supplementary sign has 10 centimetres lettering in black on a white background.

Figure 2: 'Road Works Ahead' Signage

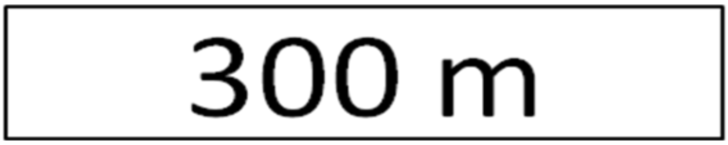


Figure 3: Distance to 'Road Works Ahead'

b. Loose Chippings

The sign mounted 30 metres before the beginning of surface dressing operations is more effective than “slow” signs and flagmen in controlling speed and reducing the risk of broken windscreens.

The sign is shown as Figure 4 below.

Figure 4: Loose Chippings

c. Slippery Surface

The sign mounted 30 metres before the beginning of gravel surfacing or redressing operations.

The sign is shown as Figure 5 below.

Figure 5: Slippery Surface

d. Diversion

Diversion signs should be placed at the commencement of diversions and at any intersection along the route. The sign is shown as Figure 6 and is a blue circle with a white symbol. The supplementary sign has a 10 centimetres lettering in white on a blue background.

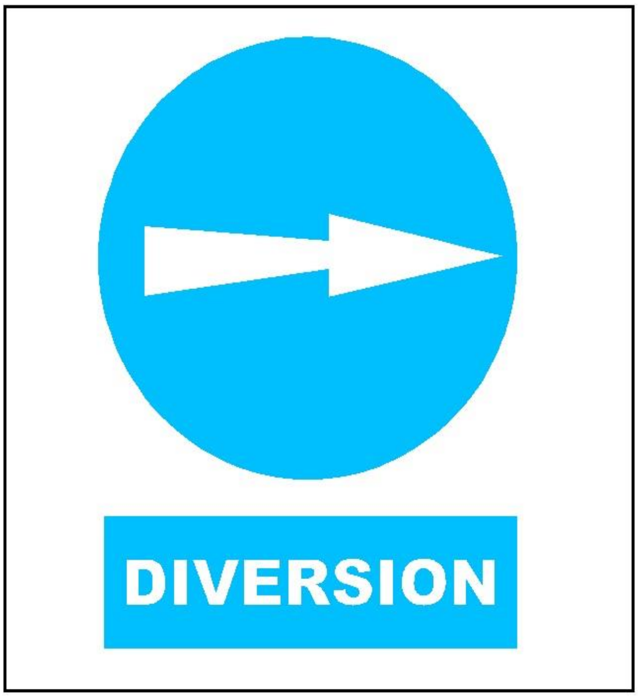


Figure 6: Diversion

e. End of Construction

At the end of the operation site, it is customary to display a sign to signify that the highway is clear of obstruction. The sign is shown as Figure 7 and has 10 centimetres lettering in white on a green background

Figure 7: End of Construction

4.1.2 Lamps

a. Continuous Operation

Where highway maintenance operations are continuous through the hours of darkness the area of the work should if possible be floodlit by portable generating sets or pressure kerosene lamps.

All obstacles and approach barriers should be demarcated by flashing red lamps. Cones, barriers and drums demarcating lane lines should similarly be supported by flashing real lamps.

Highway maintenance machines in operation or parked outside of the barricaded working area, should carry roof mounted flashing yellow lamps.

All signs mounted on the highway and shoulders should be manufactured in reflective materials such as ***"scotchlite"***

All workmen and supervisors within the operation area must wear reflective waistcoats or where these are not available, white shirts. Hand torches should be available to flagmen and supervisors to supplement warning lamps if necessary.

b. Overnight Obstruction

Where highway maintenance operations cannot be completed during the daylight hours and equipment, materials or open working are left upon the pavement overnight, barriers, cones and drums should be closed up to present the minimum length of obstruction to traffic. All relevant reflective signs will be maintained in position. Barriers, cones and drums will be demarcated with red lamps, which will be stationary (non-flashing) where no work is proceeding. All parked vehicles will be brought inside the area of the terminal barriers.

For major sites, two genuine, non-sleeping, watchmen will be provided whose primary task is to maintain all lamps functional. They will be equipped with spare lamps and torches and reflective waist coats.

4.1.3 Barriers

One of the primary means of ensuring traffic safety within a working area is to make adequate segregation of traffic from workmen and machines. The devices used for this consist of:

- Barriers
- Drums
- Cones

a. Barriers

Barriers should be erected at the beginning and end of the work site where they are clearly visible to traffic.

A standard barrier is shown as Figure 8. It is painted with alternate diagonals visible to traffic.

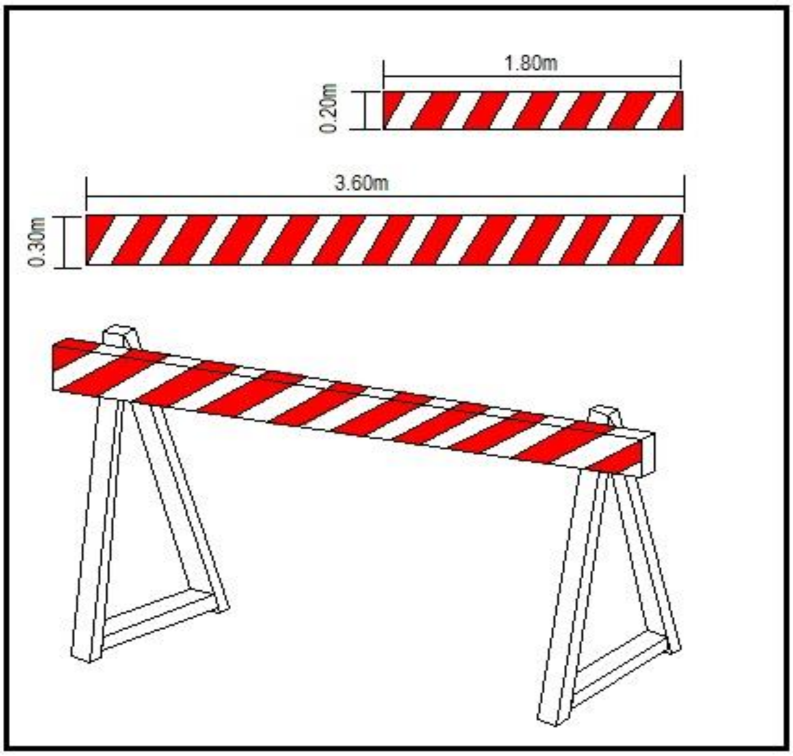


Figure 8: Barriers

b. Drums

Drums provide good demarcation to corners of worksites, provided that there is sufficient room to accommodate them. They also make excellent bases for lamps and stop-go boards.

The drums are painted white with a red band across as shown on Figure 9.

If the drums are to be maintained in position during the hours of darkness, the drums should be painted with reflective paint, or reflective tape should be applied to the drums.

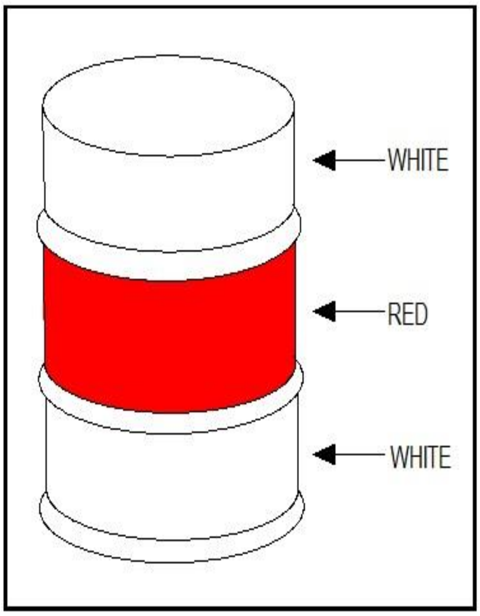


Figure 9: Drum

c. Cones

Standard orange plastic highway cones should be liberally used wherever lines are required for reduction to single lane traffic.

Cones may also be usefully employed to demarcate the centreline when segregating traffic from half width working operations since they occupy very little space on the highway.

4.1.4 Signals

To control traffic in single lane openings and in single lane diversions, signals are required and the training of staff in the efficient operation of them is essential.

a. Traffic Lights

On major highways and particularly in built-up areas, portable traffic lights and generator sets are a great asset since they draw greater respect and obedience from motorists.

b. Stop Go Boards

When portable electrically operated traffic signals are not available, it is customary to control traffic with a manually operated ***"Stop-Go"*** board.

The signal board is shown on Figure 10. It is a circular blue board with 23 centimetres lettering in white.

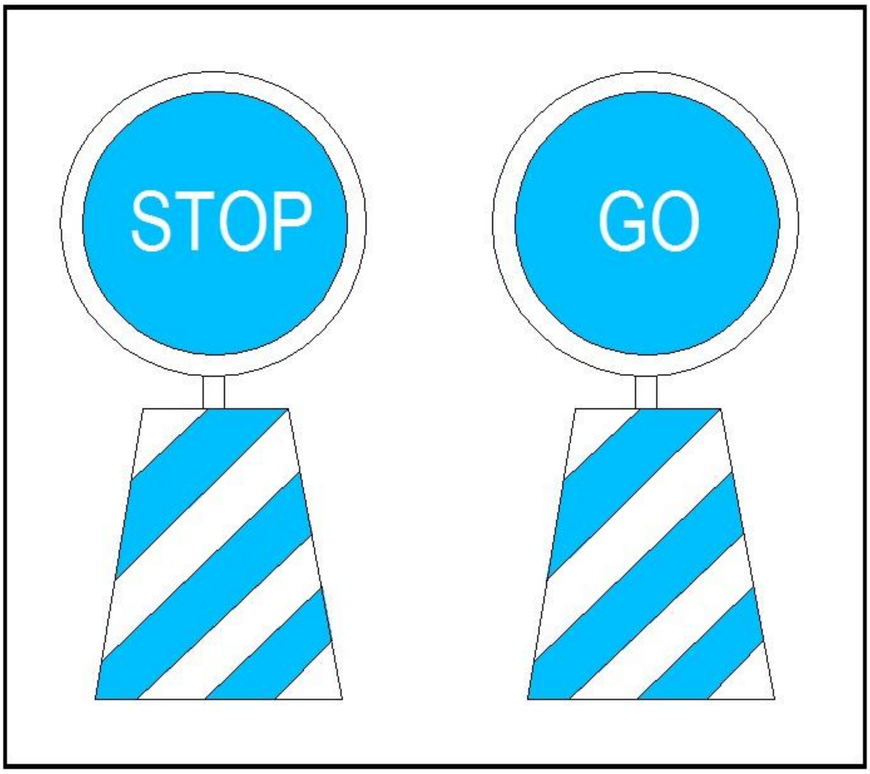


Figure 10: Stop and Go Signs

c. Flagmen

On smaller operations and occasionally in support of traffic lights and stop-go boards it is necessary to employ flagmen.

It is desirable that flagmen should wear distinctive reflective type waist coats as uniforms to enhance their authority. They should always be polite and cheerful, never argue with highway users and merely report to their overseers the registration numbers of vehicles ignoring signals.

4.1.5 Diversions

Wherever possible on localized operational sites where work is likely to extend over several days, as in bridge or culvert repair works, a diversion route or access road should be provided. This is the most efficient means for segregation of traffic from workmen, materials and machines. It is therefore the safest way providing that it is properly signposted, controlled and maintained.

4.1.6 Layout of Safety Design

a. Single Lane Obstruction (Major)

Major single lane obstructions are caused by most periodic operations to the highway pavement. A typical layout of safety devices for such an operation is shown as Figure 11.

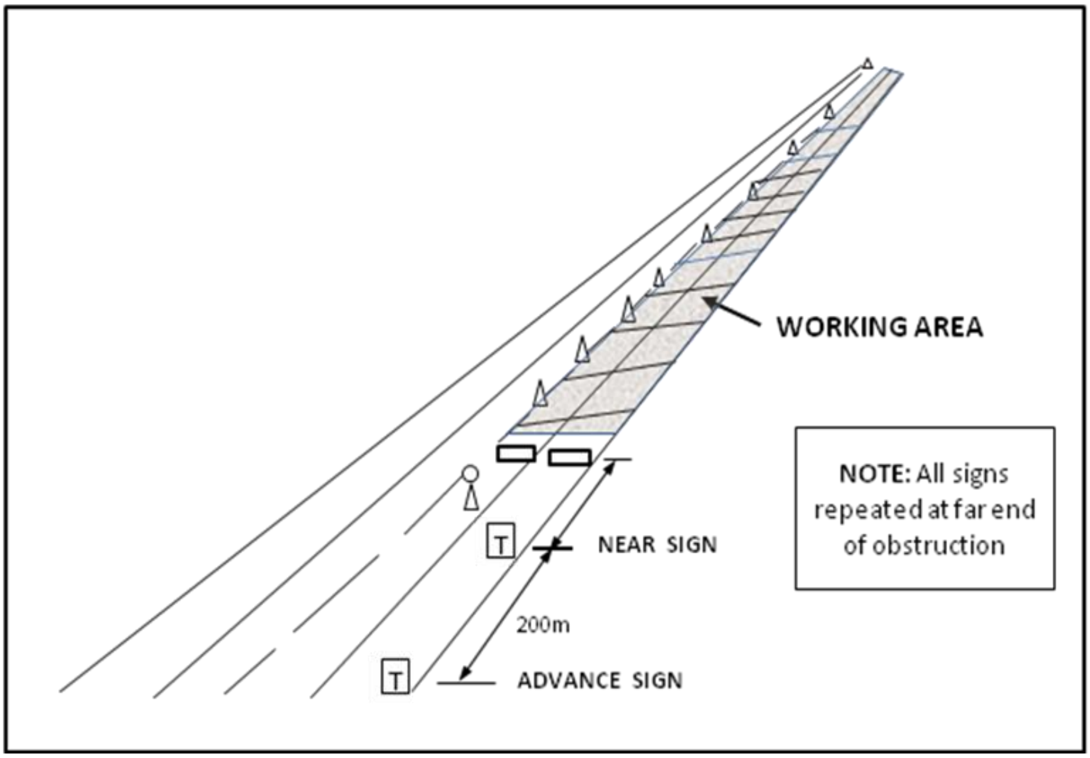
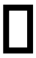


Figure 11: Single Lane Obstruction (Major)

The symbols used in this and the succeeding figures are as follows:

Temporary signs	
Standard cones	
Standard drum	
Signals, Flagmen	
Standard barrier	

b. Single Lane Obstruction (Minor)

Minor single lane obstructions are short duration or travelling obstructions such as potholes patching operations. The simple and more easily transportable sign layout is illustrated at Figure 12.

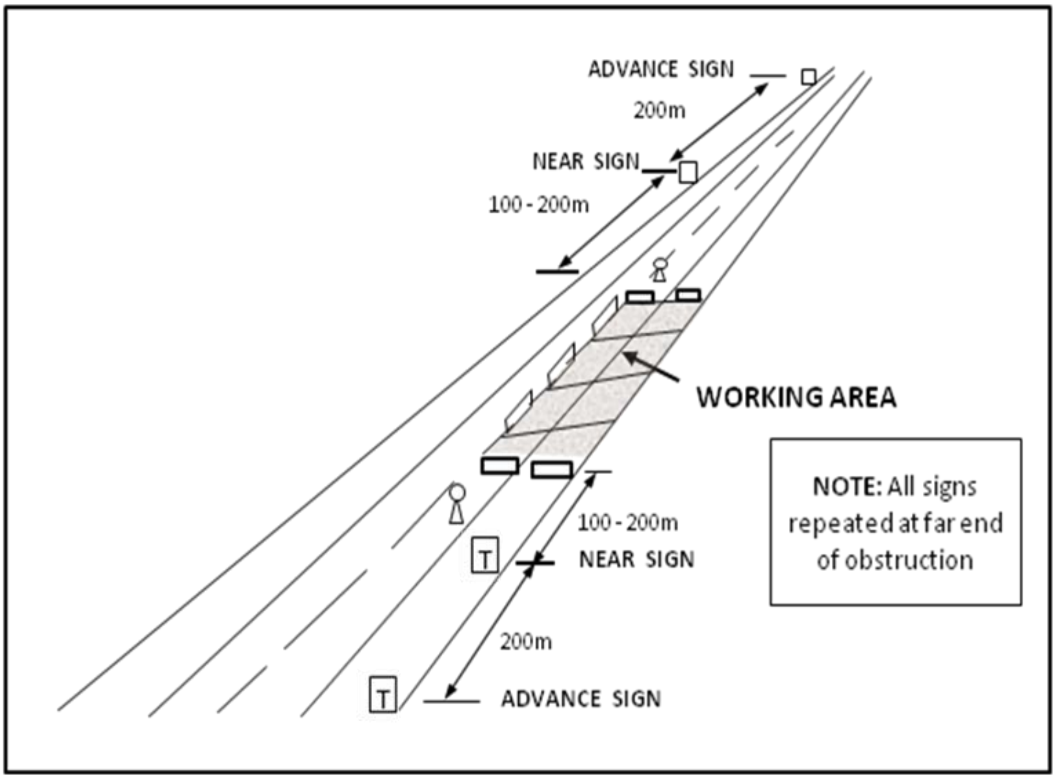


Figure 12: Single Lane Obstruction (Minor)

c. Double Lane Obstruction

For major bridge repairs, or culvert construction causing a long duration localized obstruction, it is advisable to construct a temporary diversion.

The layout of signs and safety devices is shown as Figure 13.

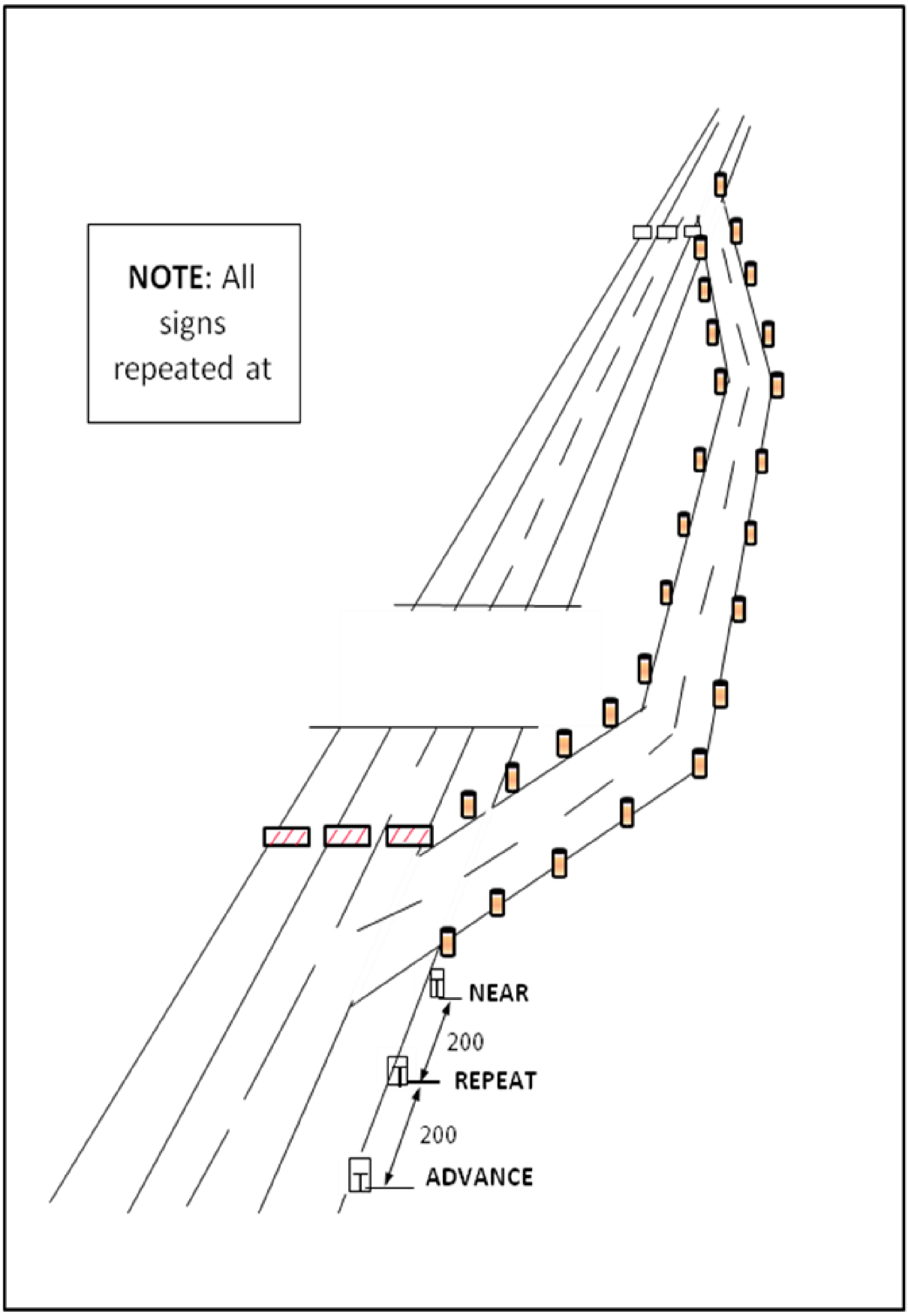


Figure 13: Layout for Diversions

Where space permits the construction of only a single lane bypass, signals and flagmen must be added to the layout with the provision of advance warning signs in respect to single lane and signals. The layout of signs would then be similar to that shown in Figure 11.

d. Peripheral Works

Heavy moving operation, repairs to shoulders, drain laying and tree cutting operations do not directly obstruct traffic lanes on the highway. Such works adjacent to the pavement edge can however provide a hazard to traffic if adequate advertising and demarcation is not provided. A line of cones should be placed along the pavement edge spaced at 20m interval for the length of the works plus 40m either end. The layout of signs, etc. is shown in Figure 14.

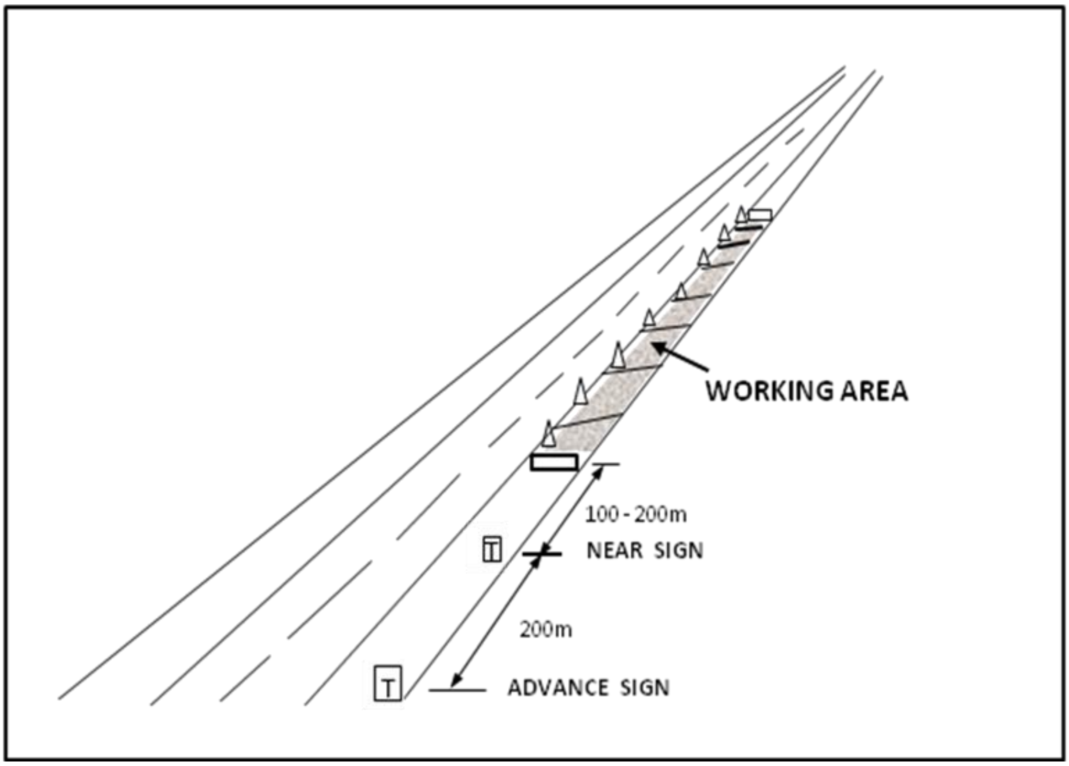


Figure 14: Peripheral Works

4.2 Safety of Highway Personnel during Maintenance Operations

Primarily, every workman on an operational site is responsible for his own safety. The sailor‘s axiom of ***“one hand for the ship and one hand for yourself***” is equally true for work on the highways. The entire active labour force must be trained to know what dangers may be expected from traffic, machines and materials and must be continuously alert to minimize risk. Some basic assistance and care is required in areas of high risk and these are summarized below:

4.2.1 Protection from Traffic

From the foregoing sections of highway users, the principle of segregation of highway users from maintenance workers was established and the employment of signs, signals, lamps and barricades was discussed. These are the first lines of defence. Additional safety measures may be required.

a. Guards

Where workmen are operating in excavations for operations such as culvert laying or base reconstruction they may not be able to see on-coming traffic in order to assist in their own safety. In such circumstances, it is customary to position an additional flagman or guard equipped with a whistle whose primary duty is to alert workmen of impending danger.

b. Distinctive Clothing

All workmen, equipment operators and junior supervisory staff employed on highways maintenance operations should be provided with a light weight sleeveless waist coat of a distinctive and easily visible colour such as yellow or orange. These waist coats shall have stripes of reflective material for those personnel who are expected to work during the hours of darkness.

c. Torches

Supervisory staff and employees whose work necessitates their movement across or near to traffic lanes (e.g. flagmen, paving assistants and overseers) should be provided with torches for work during the hours of darkness

4.2.2 Protection from Machines

Highway maintenance operations are mechanically assisted, which means that on the majority of operational sites machines and manpower are working together in close proximity. During these operations, drivers and operators of equipment have their own specialized and often exacting tasks requiring high levels of concentration upon the accuracy of the work they are performing. It is not reasonable therefore to expect such operators to give full time consideration to the safety of workmen around them. It is essential therefore that all manpower employed on highway maintenance operations be fully trained to be acquainted with the nature of the machine, the job it does and how it performs that job. In particular, for each and every machine, the training will underline the dangers that exist for attendant workmen from failures of brakes, frayed ropes, mishandled controls etc. Attention should be given in planning operations to the following specific precautions.

a. Protective Clothing's

Workmen, required to assist machines such as cranes off loading pipe culvert sections into trenches, should be provided with safety helmets. Workmen, required handling wire ropes in recovery operations, should be provided with heavy leather gloves.

b. Guard Attendants

Equipment working on loading, off loading, tree felling and similar high risk operations should be provided with a ground attendant, who may be a trainee driver, to whom the operator will look for guidance and for whom the safety of associated workmen is a primary concern.

c. Protection of Excavations

Equipment excavating trenches or loading heavy materials into excavators should not be permitted closer than the natural angle of repose of the soil unless the shoring has been specially designed to accommodate these superimposed loads. Where heavy machines are working adjacent to excavations light railings or barricades should be erected at the limit of safe working.

4.2.3 Protection from Tools

Accidents involving the use of tools occur either from their improper use or lack of maintenance of the tools. It is essential therefore that all personnel liable to use tools be thoroughly trained in their proper use and that all tools returned to store be adequately inspected and repaired prior to re-use. Dangers involving the use of tools emanate primarily from the following:

a. Blunt Cutting Edges

Grass cutting knives, axes and saws with blunt edges cannot perform their work efficiently and result in operators exerting unnecessary efforts with resultant inaccuracy. All cutting tools must be regularly inspected and maintained in a high quality condition.

b. Loose Handles

Pick axes, axes and sledge hammers develop loose handles usually due to improper use as rammers, which damages the eyes of the tools. Regular inspection is essential and damages tools should be returned to the workshop for repair and rebuilding.

c. Power Tools

The replacement of cutting bits on rotary grass cutters, the adjustment of power saws, etc. must not be undertaken on site without first disconnecting the sparkling plug. Only fully trained operators should be permitted to use power tools.

4.2.4 Protection from Materials

Dangerous materials used in highway maintenance operations include fuels, chemicals and bituminous products. Safety is therefore mainly insurance against burns and fire risks.

a. Fuelling Points

It is frequently necessary to refuel vehicles on site as in the case of rollers, which cannot economically return to district headquarters for fuelling and larger groups of equipment on major periodic maintenance operations. Whether this work is undertaken by a fuelling tanker or from drums, standard fire risk precautions are necessary. Strict ***"No Smoking"*** rules shall be observed, CO_2 foam extinguishers shall be available and all unnecessary personnel shall be kept clear of the site. Bitumen kettles and distributors shall extinguish their heaters prior to receiving fuel.

b. Protective Clothing

Operators of bitumen kettles, distributors and pavers shall be issued with heavy leather gloves and boots. All assistants to distributors and pavers shall be issued with boots. Distributor spray bars must be enclosed with an anti-splash curtain. The lighting of heating units of bitumen kettles and distributors is always liable to result in a blow-back. Only trained operator shall perform this task and they must use the standard torches provided and stand well clear to one side of the heater.

Should any bituminous material catch fire, it should be fought with CO_2 foam, sand or soil. The only method of extinguishing bitumen fires is by smothering. Water must never be used.

4.2.5 Protection from Personnel

A major source of danger on all worksites comes from incompetence or carelessness of fellow workmen. Such behaviour can be due to disability, fatigue, boredom or lack of understanding of the job requirements.

a. Disability

Employees reporting for work in operational teams with disabling sickness, drunkenness or under medication which impairs their alertness must not be employed in active roles. Their lack of efficiency or speed or reaction in emergencies could endanger the lives of their colleagues.

b. Fatigue

Junior management and engineers when considering the use of overtime to complete priority works must study the alertness of the labour force at their disposal. Although most employees are keen to earn overtime payment and genuinely strive hard to merit it, accident frequency is at its highest in late afternoons and evenings when concentration is liable to fade.

c. Boredom

Carelessness and accidents are frequently caused by lack of concentration resulting from boredom in uninteresting repetitive tasks.

There is sufficient variety of routine maintenance work to be undertaken to enable overseers to rotate the allocation of unskilled and semi-skilled tasks. The main weapon in fighting boredom amongst all levels of maintenance employees is the encouragement of pride in the quality of product. This can be stimulated by competition for the best kept or most improved highway section.

d. Lack of Understanding

Accidents may occur due to a lack of knowledge or appreciation of the task of fellow workmen. It is most essential therefore that every member of a team be fully acquainted with the nature of the work performed by every other member of that team. To ensure that the team works efficiently and safely every time there must be:

- One correct way to perform an operation
- One correct way to operate a machine or tool
- One correct way to handle and use materials

Accidents may be prevented when these correct ways are:

- Known and practiced by workmen and operators
- Known and enforced by supervisors
- Known and planned accordingly by management

4.3 Safety of Highway Maintenance Work

The quality of maintenance works performed on the highway is most susceptible to damage during construction and prior to completion of compaction, setting and bedding of materials. Provided that the correct machines are used, that the operational plan is correct and that personnel have been adequately trained; then such early damage is most likely to be caused by traffic. The precautions listed in ***Section 4.1 SAFETY OF HIGHWAY USERS*** above will go a long way towards control of traffic to the extent it is possible and segregation of it from the works being constructed. However, it will be seen in the following chapters that it is frequently necessary to pass over newly completed works and occasionally over partially completed works.

Under these conditions, damage to the work can be minimized by reduction of traffic speed to the lowest practical level. These basic methods are employed for this purpose.

4.3.1 Speed Humps

Artificially created humps are frequently employed to reduce vehicle speed on entry to single lane work sites of a long duration such as bridge repairs and culvert laying operations. The humps are generally made of premixed paving materials, thick wooden planks or shaped baulks of wood. In general, these are the least satisfactory of all control devices since they result in annoyance of the highway user and lessening his desire to cooperate. They can also constitute a genuine danger unless they are well signposted, supported by flagmen and illuminated at night. Maintenance engineers are advised to avoid the use of humps wherever any alternate solution is permissible, since they can result in:

- Unnecessary damage to vehicles and passengers
- Imposition of impact loads to pavement
- Loss of steering control.

No hump should be placed on a public highway unless it is supported by an advisory sign showing the safe speed at which it can be negotiated.

4.3.2 Intermediate Flagmen

Where operational sites are of medium to long length, additional flagmen should be placed at intermediate positions to maintain slow speed. This is usually adequate for all but the most aggressive of drivers.

4.3.3 Pilot Vehicles

On longer length operational sites and particularly on single lane operations such as surface dressing, it is advisable to release streams of traffic behind a pilot vehicle. A light pick-up is ideal for this purpose of controlling the convoy speed from the front. One pilot vehicle is sufficient to shuttle convoys alternately from either direction.

5 Highway Maintenance Crews

5.1 Basic Parameters

Section 2 listed the basic maintenance functions to be carried out under a programme of routine and periodic maintenance. In broad terms, the routine maintenance works would normally be undertaken by resident general purpose crews; and that periodic maintenance works would be undertaken by mobile specialist crews.

This Chapter further expands the analysis of work required and lays down the basic parameters of maintenance crew duties, staff and equipment holding. The parameters are approximate and may well require adjustment from district to district to compensate for variations of work load and degree of mechanical assistance available.

The Tables included in this section, list the functions and composition of the twelve different permanent highway maintenance crews. Other crews may however be created as required on a temporary basis to carry out emergency duties.

5.1.1 Number of Crews per District

In general, the number of mobile specialist crews will depend upon the condition of the roads and work load required. Permanent crews, however, should not exceed the numbers shown in Table 8 to Table 19 below. An excess of potholes initially can be met by temporary assignment of work, for e.g. to the painting crew, since obviously no centreline painting can be undertaken under these conditions.

5.1.2 Productivity

The productivity figures as given in Table 8 to Table 19 are a guide to team planning.

5.1.3 Equipment

Table 8 to Table 19 also list the equipment and vehicles assigned to each crew type.

No attempt has however been made to quantify the holding of tipping trucks by specialist teams, since these vehicles may either operate under the control of the material production crew delivering gravels, stones, etc.

5.1.4 Basic Parameters of Maintenance Crew Duties, Staff and Equipment

Table 8 to Table 19 are given as an indication of the different maintenance crews required, the functions within the maintenance type as well as recommended labour and equipment requirements.

Table 8: "A" – Section Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Drain cleaning 2. Culvert cleaning 3. Bridge waterway clearing 4. Erosion control 5. Cutting new drains 6. Grass cutting 7. Shoulder clearing 8. New grass planting 9. Bush clearing 10. Tree felling 11. Branch lopping 12. Pothole patching gravel roads 13. Assistance to specialist crews	One crew per road section of approx. 40km.	Varies with functions	• 2 Grass cutting machines • 1 Tipping truck ***or*** • 1 Tractor and trailer • Miscellaneous hand tools	• 1 Overseer • 1 Driver • 15 Labourers

Table 9: “B” - Patching Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Pothole patching 2. Over painting (sealing of cracks)	One crew will normally be sufficient provided it is fully mechanised for use of pre-coated stone preferably designed to B.S. 1621 Table 2.	Up to 25 tons per day of pre-coated stone	• 1 Flatbed Lorry • 1 Vibratory • 1 small compressor and air tools • 1 small batching plant – at depot • Various hand tools	• 1 Overseer • 1 Driver • 3 Operators • 6 Labourers

Table 10: “C” - Grading Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Cutting new drains 2. Grading shoulders 3. Preparing surfaces for prime & seal re-grading 4. Redressing 5. Assist with bitumen stabilized base construction	1 – 3 crews depending on extent of gravel road holding	Up to 8 km per day depending on extent of corrugation and rutting for simple re-grading. At the higher output additional rollers are required.	• 1 Grader • 1 6-ton Roller • 1 4½-ton Roller • 1 Tractor • 1 Water-bowser • 1 Pulvimixer	• 1 Overseer • 1 Driver • 2 Operators • 2 Labourers

Additional labour as required will be drawn from the “A‘Crew in whose section the work is being undertaken.

Table 11: "D" - Bridge Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Erosion control – assistance to "A" crew 2. Culvert repairs and relaying 3. Manufacture of R.O.W. Markers 4. Minor repairs to structures 5. Touch painting 6. Rip-Rap repairs 7. Painting steel and timber 8. New culvert installation 9. Replacing timber decks 10. Major repairs to structures 11. Manufacture of kilometre posts	1 Crew	Varies with functions	• 1 Light Vehicle (4x2) • 1 Backhoe and Tractor • 1 Concrete mixer – usually at depot • Various hand tools	• 1 Overseer • 1 Driver • 2 Operators • 4 Tradesman • 2 Labourers

Table 12: "E" - Surface Dressing Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Sealing Hard shoulders 2. Prime & Seal 3. Single surface dressing 4. Double surface dressing 5. Lay-bye construction	1 Crew	1 kilometre per day of 2 – lane highway	• 1 Chip spreader • 1 Pneumatic tyred roller • 1-2 6-ton tandem rollers • 2 Bitumen heaters-usually at depot • 1 Bitumen distributer • 1 Tractor • 1 Power Broom	• 1 Overseer • 2 Drivers • 8 Operators • 4 Labourers

Additional labour as required will be drawn from the "A" Crew in whose section the work is being undertaken.

Table 13: "F" - Gravel Surfacing Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Rebuild and widen shoulders 2. Sealing hard shoulders – Assist Crew "E" 3. Gravel surfacing 4. Lateritic gravel bases 5. Cement stabilised bases 6. Bitumen stabilised bases 7. Lay-bye construction	1 Crew	0.5 to 1.0km per day, depending on extent of damage and depth of gravel added	• 2 Graders • 2 6-ton rollers • 2 Water bowsers • 2 Tractors	• 1 Overseer • 2 Drivers • 4 Operators • 2 Labourers

Additional labour as required will be drawn from the "A" Crew in whose section the work is being undertaken.

Table 14: "G" - Painting Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Pavement markings 2. Kilometre post painting 3. Road sign repair and painting 4. New kilometre post painting 5. Manufacture of new road signs	1 Crew	Varies with function	• 1 Light vehicle (4x2) • 1 Road line painting machine • Miscellaneous hand tools	• 1 Driver • 1 Operator • 1 Artisan Grade 1 • 2 Painters • 2 Labourers

Table 15: "H1" - Material Production (Gravel) Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
To support Maintenance Crews "A, C & F"	1 Crew	200-500 cubic metres (m^3) per day	• 1 Loader shovel • 1 Dozer (part time use)	• 1 Overseer • 1-2 Operators • 2 Labourers

Table 16: "H2" - Material Production (Stone) Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
To support Maintenance Crews "D, E & H3"	Normally not more than one (1). In some locations, districts may be supplied from outside their borders depending on material availability	30,000 tons per year	• 1 Crushing and screening plant • 1 Gravel washing plant • 1 Dozer (part time) • 1 Weighbridge • 1 Compressor • 2 Benchers • Miscellaneous drilling ancillaries	• 1 Overseer • 7-9 Operators • 1 Blaster • 2 Drillers • 1 Mechanic • 8 Labourers

Table 17: "H3" - Material Production (Premix) Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
To support Maintenance Crews "B and I"	Normally not more than one (1). Initially one (1) mobile crew should be provided in each state to undertake pre-planned programmes working from stockpiles prepared by Crew "H2"	Approx. 35-40 tons per hour	• 1 Batch-mix plant • 1 Bulk bitumen tank • 2 Bitumen heaters • 1 Weighbridge • 1 Loader shovel (Usually at depot)	• 1 Technical assistant • 1 Overseer • Operators • 6 Labourers

Additional semi-skilled labour can be drawn from "E" Crew at depot

Table 18: "I" - Paving Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Paving with bitumen macadam 2. Paving with asphaltic concrete 3. Laying bases	Normally not more than one (1). Initially one (1) mobile crew should be provided in each State to undertake pre-planned programmes working from stockpiles prepared by Crew "H3"	Not less than 40 tons per hour	• 1 Paver • 1 Pneumatic tyred roller • 1 6-ton tandem steel wheeled roller • 1 4½-ton three wheeled roller • 1 Emulsion trolley	• 1 Technical assistant • 1 Overseer • Operators • 8 Labourers

Additional labour for signalmen to be drawn from “A” Crew in whose section work is undertaken.

Table 19: “J” - Survey Crew

Functions	No. of Crew per District	Productivity	Equipment	Labour
1. Placing kilometre posts and R.O.W. markers 2. Pavement measurement 3. Drainage survey 4. Bridge investigations 5. General survey assistance to crews	1 Crew	Varies with function	• 1 Theodolite • 1 Level and staff • 1 Light vehicle (4x4) • Miscellaneous small instruments and tools	• 1 Surveyor • 1 Technical assistant • 4 Labourers

6 Maintenance and Control Sections

Each district is divided up into a number of Maintenance Sections for operational purposes and each Maintenance Section is divided up into a number of Control Sections for administrative purposes.

6.1 Maintenance Sections

As discussed in Section 2 of this manual, the routine maintenance works required on highways are undertaken by resident section crews, as summarised in ***Section 5, Table 8,*** which also defines the area of responsibility of one section crew.

A maintenance section is that length of road, or lengths of roads, which is, or are, the limit of responsibility of one section crew.

To provide the basis for planning of section crews, their numbers, locations and extent of responsibility, this Chapter lays down the parameters by which the limits of maintenance sections are defined.

6.1.1 District Road Maps

- The first step in planning is to obtain or prepare a district road map to as large a scale as is available.
- The second and most important step is to become thoroughly familiar with the road network by repeated touring.

Figure 15 shows a hypothetical road map of a typical district, with a network of some 460 kilometres of road in various pavement and terrain types. This is used to illustrate the parameters defined in 6.1.2. below.

6.1.2 Parameters

The parameters defining the extent, limit and content of a maintenance section are:

- Optimum overall length
- Centre of operation
- Type of roads
- Classification of roads
- Type of pavements
- Control section relationship
- Inclusion of bridges
- Local authority limits

a. Optimum Overall length

Both equipment and labour force have been designed to maintain, on average, a road length of 40km.

This can be reduced if the road condition is poor or the terrain difficult. Thus in the mountainous Section No.4 with its large number of culverts and drain erosion problems the maintenance road length for a section crew is only 34km long; whilst in the relatively easy and well kept Section No.8, between Shabomi and Gbagba, the maintenance road length for a section crew is 49km long.

The practical limits are not less than 30km, where labour holding becomes uneconomic and not more than 50km, where daily inspection by the Overseer becomes difficult and probably neglected.

b. Centre of Operation

The centre point of the m aintenance s ection should be the place of residence of the section crew for efficiency of transport and ease of meeting emergency calls.

Where possible, this should be near or at a town or village, for economy of provision of housing and for human reasons such as the availability of shops, schools and clinics (e.g. Sakwa for Section No.9).

Where this is not possible, a road camp should be sited as near as possible to the mid-point of the road network and preferably on a stream or potential well-point (e.g. km 40 for Section No. 10).

c. Type of Roads

A maintenance section may include roads and branch roads and need not necessarily confine itself to the limits normally defined for control sections for cost-accounting purposes. Thus, because of the desire to house labour and centre operations in Shabomi, Section No.1 extends to Km 10 on the Shabomi-Burutu road and includes 15km of the northern riverine road 15km of the Shabomi-Gbagba road.

d. Classification of Roads

A maintenance section may include both Trunk Roads “A” and Trunk Roads “F” since both classifications of roads are maintained from the same head and sub-head of the estimates. Section No. 11 to the east of Shabomi is a typical example of this.

e. Types of Pavements

A maintenance section may include lengths made up of any pavement type, since the functions of routine maintenance consigned to a section crew are basically identical on all roads irrespective of pavement type. An example is Section No.1, based in Shabomi, which contains elements of the premix paved road to Burutu, the surface dressed road to Gbagba and the gravel surfaced northern riverine road.

f. Control Sections

The road network and maintenance sections can be divided up into control sections for the purpose of cost accounting.

Details of the parameters ruling the establishment of control sections are dealt in the following sub-sections, but it is necessary to bear in mind two major considerations:

- Firstly, control sections are of maximum value in providing cost statistics if they are kept to the maximum possible length.
- Secondly, all control sections within a maintenance section may only be maintained by one section crew in order to simplify the input of data.

Thus maintenance section No.2 is ideal in that it contains one trunk road uniform terrain with identical pavement throughout its length. The length of the control section here is equal to the length of the maintenance section. Conversely, maintenance section No.1 at Shabomi is the most undesirable situation since it contains four small control sections.

However, in actual practice in this particular district, it has been possible to plan 6 of its 11 maintenance sections to coincide exactly with control sections. Such a situation will be rare and a balance must be struck between optimum efficiency in the layout of the maintenance sections together with maximum uniformity of road within the maintenance section.

g. Inclusion of Bridges

All bridges, ferries and weighbridges included within the territorial area of the maintenance section will become part of that section and part of the responsibility of the section crew resident there. Thus, the major bridge within Shabomi town, although a separate control section, still forms part of the responsibility of section No.1 crew.

Similarly, the ferry crossing the river estuary at Gbagba is part of the responsibility of section No.7 crew. Here however, the section crew would be provided with additional labour for the operation of the ferry.

h. Local Authority Limits

Where a City or Municipal Council exists, the responsibility for maintenance of all roads within the gazette limits of the council area is usually vested in the council. Under these conditions those parts of trunk Roads “A” and “F” passing through the council area would be excluded from the responsibility of the section crew.

Had Shabomi been created a Municipal Council (which fortunately it has not) then maintenance section No. 1 would have been reduced to 12km of the northern riverine road and 12km of the Gbagba road. Under these conditions the section would have been too small and re-planning would be required.

6.2 Control Sections

In sub-chapter 6.1, reference was made to control sections. This sub-chapter (6.2) expands on the basic purpose of the sub-divisions of highways into control sections and the parameters defining their establishment.

The use of these control sections is detailed in Volume 3 of the Highway Manual: Cost Accounting for Highway Maintenance.

6.2.1 Cost Accounting

Cost Accounting is a specific form of accountancy adopted in highway maintenance for the purpose of:

- Monitoring the cost and efficiency of highway maintenance operations.
- Developing cost-indices for specific types of road, specific types of work and related labour, material and equipment usage.
- Utilization of cost-indices for estimating, planning, programming and budgeting purposes.

Cost Accounting is carried out in parallel with Government‘s financial accountancy process, which it does **not** replace.

6.2.2 Definition

In order to develop cost-indices for specific types of road as defined above, it is necessary to sub-divide the highway network into lengths of road with constant common features. These sub-divisions are called control sections.

A control section is therefore a typical length of highway where the elements of work required for its maintenance are relatively constant both in nature, tasks and frequency of operation. A control section will thus be a typical length of highway on which the cost of operation is normally constant.

6.2.3 Parameters

To ensure uniformity of elements of work within a control section, the parameters defining its limits are:

- Pavement type
- Geography
- Geometry
- Traffic
- Exclusion of major structures
- Exclusion of ferries
- Exclusion of branch roads
- Exclusion of major urban areas

Further to simplify the collection and processing of data, a control section shall terminate at:

- An administrative boundary – A district boundary
- A maintenance section boundary

Having the above parameters in mind, the value of the data collected and analyzed within a control section will be best and most accurate where control section limits provide:

- The maximum length of road possible

6.2.4 District Road Map

Using the parameter listed above, control sections are plotted on the district road map already developed and showing the maintenance sections.

Figure 15 is an example of this district road map, with control sections plotted to illustrate the analysis of control section given below. To facilitate description of the parameter the control section limits are shown on the map by means of small pins numbered 1 to 31 and summarised in Table 20.

6.2.5 Analysis of Control Section Limits

The following notes expand the definitions of the parameters defining the limits to control sections as assistance for the establishment of control sections in each district.

a. Pavement Type

Only one part pavement type may be included in any one control section. Thus, maintenance section No.11 to the east of Shabomi contains one control. Section from pin (1) to pin (31) on a premix, paved road and one control section from pin (30) to pin (29) on a gravel surface road.

b. Geography

Geographically roads may lay in country that is mountainous, hilly, rolling, flat, or marshland. Any one control section should not contain more than one such geographical feature. Thus maintenance section No.4 contains one control section from pin (14) to pin (13) in hilly country and one control section from pin (13) to pin (11) in rolling country. Similarly, the road from Gbagba to Sakwa is divided into two control sections by pin (25) separating marshland from flat countryside.

c. Geometry

A control section should contain roads built to one homogenous set of geometric criteria. The most common example of this is a change in pavement, which causes a major change in periodic maintenance cost. No visible examples occur on the map, except the change in design radii of horizontal curves in maintenance section No.4.

d. Traffic

A control section should contain similar and uniform annual daily traffic over its length as this will determine the frequency of application of periodic maintenance and ideal choice of pavement type. Generally, an observance of parameters (g) and (h) will satisfy this condition.

e. Exclusion of Major Structures

Generally all drainage structures are included within the control section in which they are situated – unless their routine maintenance and/or repair materially affect the costing of the control section. Major structures, which are likely to create such an effect, are not included and given a separate control section number. An example of this can be seen in maintenance section No.1 where a major bridge carries the main road over the river in Shabomi from pin (1) to pin (2). Separate control sections should be estimated for:

- Temporary bridge minimum 15 m overall span
- Permanent bridge minimum 30 m overall span

f. Exclusion of Ferries

All ferries must be given a separate control section number which shall include the ferry terminal structure. An example of this is seen on the Gbagba to Sakwa road from pin (23) to pin (24) within maintenance section No.7.

g. Exclusion of Branch Roads

A control section shall include only one route and shall exclude any branch roads. This will ensure compliance with parameters (a), (c) and (d) above and enable accurate overall route costing. An example of this is seen in maintenance section No. 11 where the branch road is a control section from pin (29) to pin (30) and the main road is a control section from pin (1) to pin (31).

h. Exclusion of Major Urban Areas

In major townships non-standard conditions occur frequently. Traffic is frequently distorted by local buses and taxis and roads are paved to additional width to allow for parking. Gravel roads are sealed to alleviate dust nuisance, cycle tracks and footpaths are frequently added, street lighting probably exists and abnormal breaking loads are applied at intersections. It is normal therefore to consider each road length within major urban areas as separate control sections.

An obvious example is the main road of a town such as Shabomi in maintenance section No. 1, which will be so affected and therefore becomes a separate control section from pin (2) to pin (6). However, in this instance the town has little effect on the road east of the river, so no separate control section has been established between pin (1) and pin (31). This could be done at a later stage if the demographics of this section of road should change by widening or the installation of lights, etc.

Similarly in the example map, the gravel road to the north of Shabomi is provided with street lights and concrete drains from pin (5) to pin (4) and is therefore a separate control section from the rural road length from pin (4) to pin (3).

i. Termination at Administrative Boundaries

Where the road passes out of the control of an administrative authority and into that of another authority the control section must terminate. Such boundaries are state boundaries, Provincial boundaries and autonomous local or city council boundaries.

j. Termination at District Boundaries

Control sections shall also terminate at district boundaries for simplification of data input.

k. Termination at Maintenance Section Boundaries

Control Sections shall terminate at maintenance section boundaries for simplification of data input. The design of labour, statistics input forms would be unnecessarily complicated if two or more “A” – Section crew overseers were contributing to its compilation.

l. Maximum Length of Road in Control Sections

One of the primary objectives of Cost Accounting is to develop cost-indices for typical types of roads and typical types of work. The accuracy of these indices and their use in planning and estimating is greatly increased with increased length of road under analysis. Realistic planning of control sections must avoid therefore the tendency to over-fragment roads into a mass of small control sections. The basic question that needs to be asked is “does this change in geometry, etc., really affect the cost, nature, or frequency of operations?”

6.2.6 Temporary Control Sections

It may be that the collapse of a small timber, the washout of a length of highway, or widening of a length of pavement, will throw a temporary unrealistic cost onto a controls Section. Should this occur, the area of activity can be designated a temporary control section number for the purpose of costing the corrective operation as emergency maintenance.

6.2.7 Special Control Sections

Where specialist crews are operating on permanently established material resources sites (e.g. Quarries), these sites shall be designated as control sections.

Examples of these are the operations of “H2”- Material Production (Stone) crew and “H3”- Material Production (Premix) crew. This does not necessarily apply to gravel production, which in most instances will be undertaken by a crew temporarily working on a gravel pit within a maintenance section exclusively for the use of that “A” - section crew.

6.2.8 Control Section Numbering

Control section numbering will be based primarily on maintenance sections. Whilst there may beand usually are more than 10 maintenance sections in a district, there cannot (practically) be more than 10 control sections in any one maintenance section. Thus, a three digit code will be used where the first two digits identify the maintenance section and the third digit identifies the control section.

Table 20 shows a schedule of controls Sections and their parameters in the district shown on the map of Figure 15.

Table 20: Schedule of Control Sections and their Parameters

MAINTENANCE SECTION	CONTROL SECTION	FROM – TO PIN	PARAMETERS
01	011	1 - 2	e
	012	2 - 6	a, d, g, h, k
	013	5 - 4	a, d, h
	014	4 - 3	a, d, j
	015	7 - 8	a, d, k
02	021	6 - 9	a, d, g, j
03	031	10 - 12	a, d, g, j, k
04	041	11 - 13	a, b, d, k
	042	13 - 14	a, b, d, k
05	051	15 - 16	a, d, k
06	061	17 - 18	a, d, j, k
07	071	18 - 19	a, d, k
	072	20 - 22	a, d, g, k
	073	21 - 23	a, d
	074	23 - 24	f
08	081	22 - 8	a, d, k
09	091	24 - 25	a, b, d
	092	25 - 26	a, d
	093	27 - 28	a, d, g, j
10	101	28 - 29	a, d, k
11	111	29 - 30	a, d, k
	112	1 - 31	a, d, g, k

6.2.9 Control Section Signposts

A signpost is to be erected on the boundary line between two adjacent control sections facing the road and on the right side of the road, i.e. in such a way that a person travelling in the direction of increasing kilometres will see the sign on his right hand.

Figure 16 shows the lay out and dimensions of a control section signpost.

The sign is divided into 4 parts. The right side of the sign is reserved for the control section the person is leaving, showing in the top part the initials of the state and the number of the district and in the bottom part the number of the control section. The left part is reserved for the control section the person is entering showing in the top part the initials of the state and the number of the district, in the bottom part the number of the control section.

In cases where two adjacent control sections are situated in the same district, the left and right upper parts of the sign will read the same. In cases where two adjacent control sections are situated in different districts within the same state, the left and right upper part will have the same state initials but different district numbers.

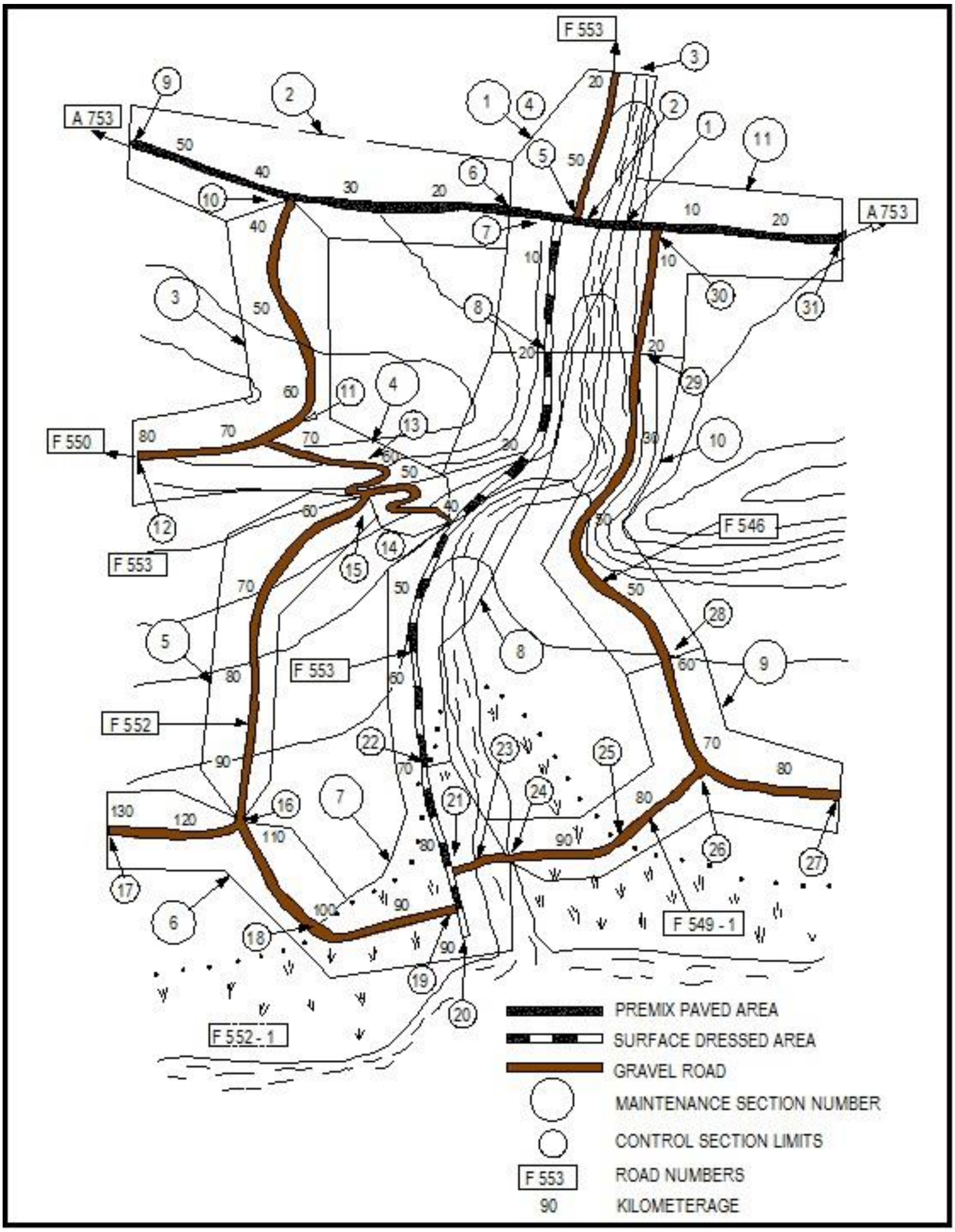


Figure 15: District Road Map

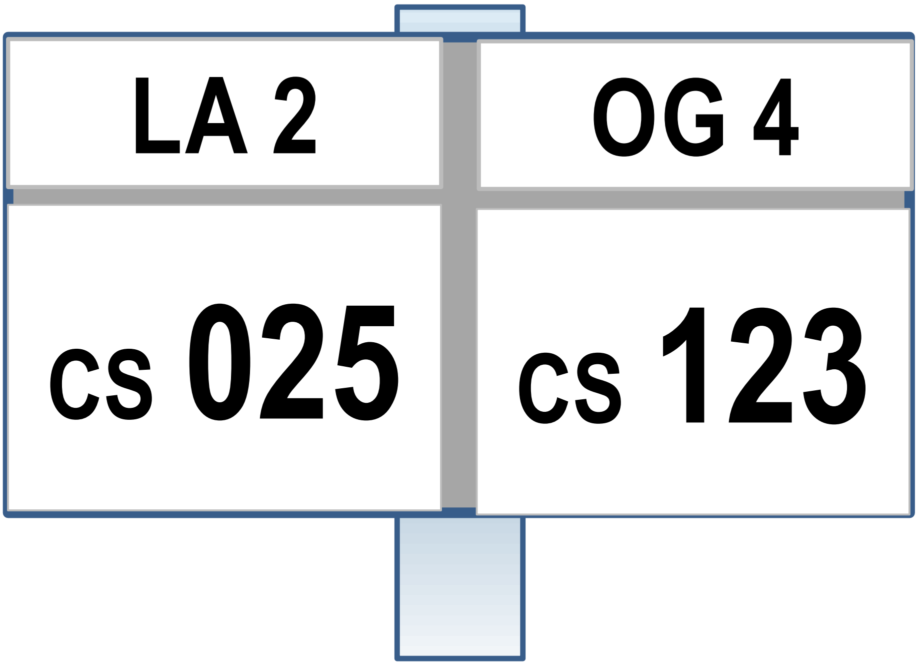


Figure 16: Layout and Dimensions of Control Section Signposts

7 Routine Maintenance Operations

The principal operations of routine maintenance are listed in the left hand column of ***Table 1 of Section 2*** of this volume. The operations are described below under their element headings and in the same sequence as used in Cost Accounting for allocating task numbers.

7.1 Duties of Sections Overseers

As previously stated a section overseer is allocated responsibility for the routine maintenance of a road section, or sections, amounting to approximately 40 kilometres. The section overseer will also be responsible for identifying the need for operations and the planning and performance of works.

Within the section the overseer will have a road camp which is his depot for storage of a minimum quantity and range of raw material sand for parking of his basic equipment and tools.

7.1.1 Daily Inspection

The section overseer will inspect daily his highways by travelling over them and observing defects in the elements of their structure. These defects he will note for:

- Immediate repair
- Less urgent repair work that can be programmed for repair
- Repair by specialist teams

He will form his observations, where applicable, note also size of team required, equipment required and approximate material requirement. He will consequently be carrying out the basic 4 M planning equation of:

- Manpower,

- Materials,
- Machines plus his own element of
- Management.

He is not involved at his level of management with the fifth M of money.

7.1.2 Allocation of Daily Task

There are everyday tasks of good housekeeping such as grass cutting and drain cleaning. There are also emergencies such as bush clearing of lesser urgency, pothole repair of greater urgency or bridge de-snagging of immediate urgency, which must be fitted into a day‘s programme of work. The relative degrees of urgency are outlined below – Routine Maintenance Operations.

Depending upon their urgency the section overseers will allot labour, equipment and material to priority operations, identified on today‘s inspection, for tomorrow‘s work. He will programme the remainder of his resources to every-day operations.

He will plan to allocate labour, equipment and materials for less urgent operations into succeeding days maintaining a balance between urgent, less urgent and every-day work throughout the week.

The section overseer will also plan his own work for the next working day, allocating those hours available to general inspection of his highways, visits to working sites and standing supervision on the urgent priority works.

The s ection o verseer will review and where necessary re-plan his programme for the next four to five days every evening, in the light of his daily inspection and progress on all works during the day.

7.1.3 Reports

a. Weekly Report

The section overseer will submit a routine report to the technical officer every week, summarizing only the routine maintenance, operations of urgent or immediate categories, which remain outstanding.

The format of this report is shown in Figure 35 at the end of this section.

Note: The weekly report is a reminder to more senior management levels of operations of work NOT undertaken and which, if delayed, may cause accelerated deterioration of the highway structure.

b. Monthly Report

The section overseer will also submit a routine statistical report to the technical officer every month in the form of a ***"Monthly Labour Allocation***" sheet. This is a cost accounting document that shows the allocation of labour to control sections and tasks. From this document and others received monthly from the supply and mechanical sections of the district, the cost accounting staff can compile historical records of work performed in each section. There is therefore no necessity for any other statistical report covering work actually undertaken by the section overseers. The format of this report is shown and fully described in ***Chapter 4 of Volume 3 "Cost Accounting".***

7.1.4 Requests

a. Request for Materials

The section overseer will carry in his depot small stockpiles of fast moving materials such as gravel, crushed stone and premixed pothole patching material.

Replenishment of stockpiles will be requested by use of a" ***Road Materials Requisition and Issue Voucher"*** which is shown and fully described in ***Chapter 4 of Volume 3 "Cost Accounting".***

From time to time the section overseer will also need specialist materials such as pipe culverts and material timber for direct use in the operations. Such materials will be requested by use of a ***"Store Requisition and issue Voucher".***

b. Request for Tools

Request for tools and replacement of defective tools will be made by use of a ***"Stores requisition and issue voucher"*** for new tools and a ***"Stores exchange voucher" for*** replacements.

Note: Tools are issued on a borrow basis, so that the persons are responsible for the tools until they are returned to the Warehouse.

c. Requests for Assistance

Frequently during the course of inspection and planning programme of work the section overseer will encounter operations which are beyond his capacity to handle with the limited resources at his disposal. This may be due to any one or combinations of the following reasons:

- Specialist tools or equipment required; such as pavement marking
- Specialist technology required; such as redressing a soil aggregate deficient in fines
- Specialist labour required; such as repair to timber bridges
- Too large a job size; such as storm damage erosion or extensive or deep potholing
- Periodic maintenance operation.

Where the need for assistance arises the section overseer will make out a ***"Request for Assistance"*** form and dispatch it immediately or urgently to the technical officer for his inspection, evaluation and action.

The format of the request is shown at Figure 36 at the end of this section.

<u>Note:</u> All requests given a priority rating of ***"Immediate"*** should be dispatched immediately by hand in the first available vehicle to district headquarters. Less urgent requests may be dispatched as convenient and appropriate to the priority accorded to them.

7.2 Drainage

7.2.1 Drain Cleaning

a. Routine Cleaning

Side (longitudinal) drains fulfil two primary functions of channelling surface water run-off away from the formation and maintaining the permanent water table sufficiently low to enable the structural layers of the pavement to develop their full strength. Should side drains become silted the drain will lose capacity to deal with run-off, which can result in flooding and the pavement base layers will become saturated and weak. This situation is illustrated below.

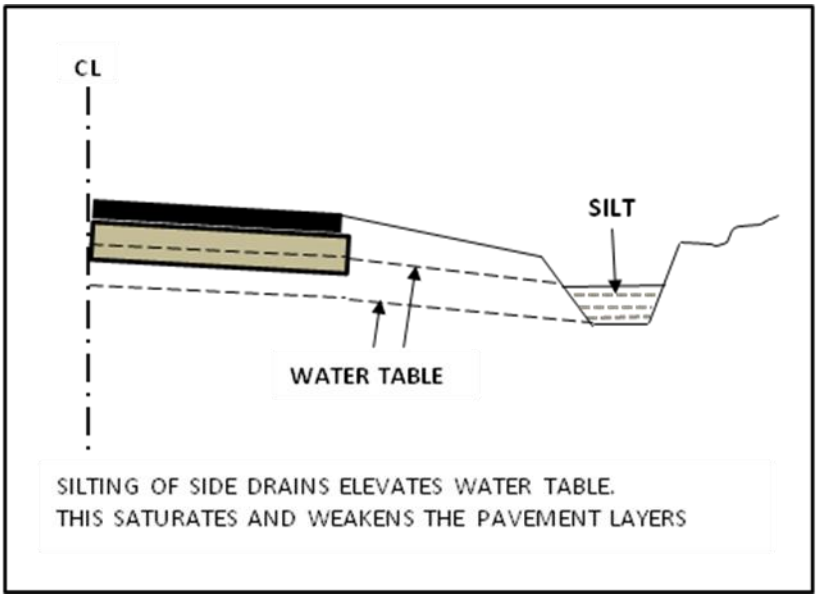


Figure 17: Silting of Side Drains

It is essential therefore that the section overseers continuously inspect side drains and keep them under constant maintenance. Similarly, outfalls drains and cut-off drains over embankments must be regularly checked and where necessary cleaned.

It should be noted that material removed from drains is largely silt and is useless anywhere in the road structure. Such material must be removed totally from the highway area and spread in low ground areas within the Right of Way or in old borrow pits.

b. Obstructions

Side drains can become blocked by falling soil, falling trees or man-made obstructions. These must be immediately cleared to enable free flow drainage gradients to be maintained. Man-made obstructions most commonly encountered are: drains deliberately filled to give vehicle access to private property. After clearing the obstruction the section overseer must immediately report the occurrence to his technical officer in order that planning permission can be given for the provision of a permanent culvert access.

Note: Treat this operation as Priority: ***"URGENT"***

7.2.2 Culvert Cleaning

During wet seasons silt is frequently deposited in culvert, pipes and on culvert floors. Such material left in culverts restricts the water-way opening and its capacity to carry run off from streams and side drains. The resulting increase in velocity on the down side of the obstruction can cause erosion of the outfall. In extreme cases choked culverts can result in flooding and washout of the road down into the side drains and silting through pipes and boxes.

Small diameter pipe culverts can be cleaned with rods, augers and dragline cones on pull-through ropes.

7.2.3 Bridge Waterway Clearing

During raining seasons, rivers frequently carry downstream trees, branches and debris, which can become embedded in freestanding pile bents of bridge piers. The build-up of debris, once started, is very quick and acts as a localized or surface dam upon the river. The resultant increase in velocity or deflection of the water will rapidly cause erosion of abutments, wing wall sand even the river bed in which piles are seated. During rainy seasons section overseers will carry out daily inspections of bridges of free-standing pile design in suspect rivers. Any snagged debris observed must be immediately cleared. Heavy accumulations of debris can best be de-snagged with grappling irons and Tirfor pullers, or hand winches towards the upstream side of the bridge. Debris removed from the river should be carried up to the top of the bank for subsequent removal and disposal.

Note: Treat this operation as priority: ***"IMMEDIATE"***

7.2.4 Erosion Control

Erosion can be caused by water, traffic, or wind. In this section we are concerned only with the most dangerous form of erosion caused by water. Erosion is likely to occur in the following places:

- In side drains
- On embankment slopes
- On side slopes of cuttings
- At outfall drain and culvert outlets
- At bridge abutments and wing walls

a. Side Drain Erosion

Side drain erosion is caused by high velocity run-off due to too steep gradients and is usually to be found in cuttings. The only satisfactory method of dealing with this problem is to line the drains with concrete precast channel sections or cast-in-situ concrete invert drains. This permanent solution will normally be beyond the capacity of the section overseer and he should therefore request assistance.

Temporary relief of erosion can be obtained by inserting shallow timber weirs into the drain bed every 5-8 metres. On steep gradients temporary relief can be obtained by lining the drain with cascade sheets cut from empty bitumen drums. Such works are only temporary and will survive only one rainy season until permanent assistance works can be made available.

Note: Treat this operation as Priority: ***"URGENT"***

b. Embankment Slope Erosion

Heavy rainfall on formation on embankments, particularly where they are super-elevated in curves, will tend to find the lowest and weakest parts of the shoulder for discharge down the embankment slope. If the embankment is of short length and not in a valley vertical curve, it is possible to raise a small bund (earth dyke) on the edge of the shoulder to channel water back to the cutting outfall drains. Where a discharge over the slope is inevitable it must be provided for with a precast concrete channel cascade drain. Assistance should be requested for this work.

Temporary relief can be obtained using sheets cut from old bitumen drums as described in (a) above. Care should be taken to securely spike the sheets into position with 15 cm wire nails.

Note: Treat this operation as Priority; "***URGENT"***

c. Slide Slope of Cuttings

Erosion of the side slopes of cutting is caused by the spillage of surface water over the hill-top (crest) of the cutting. The first and most essential action to be taken is the installation of a cut-off drain at least 1 metre back from the top of the cutting.

It will probably be necessary to line the drain by priming and sealing to avoid drain erosion as it is carried down to lower levels. Where cuttings have been constructed by terracing, the terraces should be sloped back into the hillside and cut-off drains constructed along their inner edge. This drain will have to be bituminous or concrete lined drain to prevent water logging of the terrace and subsequent slip collapse.

Erosion can be resisted on side slopes by liberal planting of coarse grasses, bamboo and deep rooted small shrubs.

Note: Treat this operation as Priority; ***"URGENT"***

d. Outfall Drains and Culverts

All too frequently outfall drains and culverts are built with inadequate aprons or length of spillway to accommodate the volumes or velocities that are discharged. Resulting erosion in soil channels will undercut the concrete terminal causing collapse of the structure.

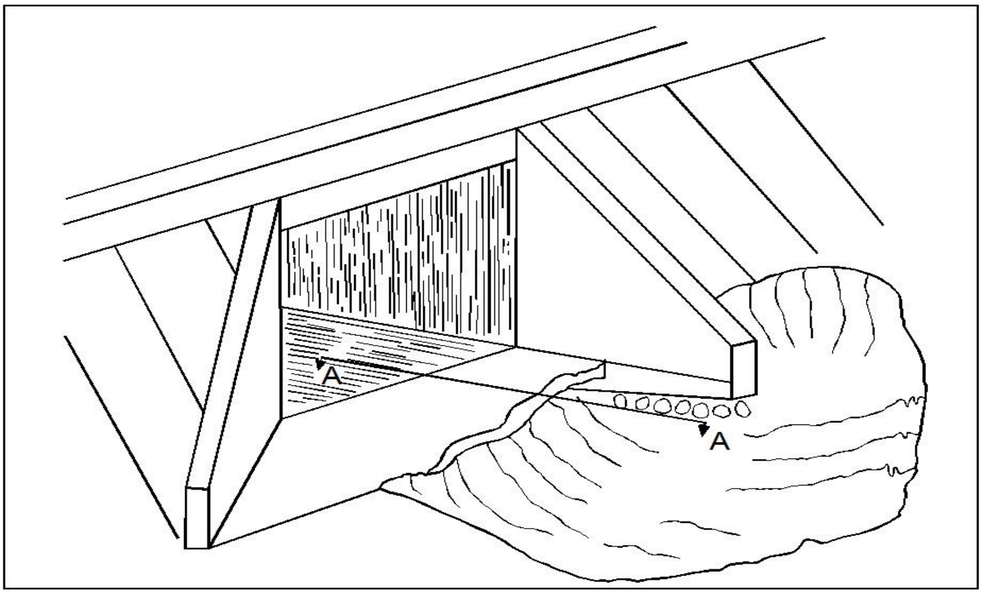


Figure 18: Erosion of Waterway at Structures

The eroded area should be backfilled with stone blocks or rubble and the apron or drain reconstructed as rip-rap in cement mortar. Additional large boulders randomly scattered at the limit of erosion will assist in reduction of velocity as depicted below.

<u>Note:</u> Treat this operation as priority: ***"URGENT"***

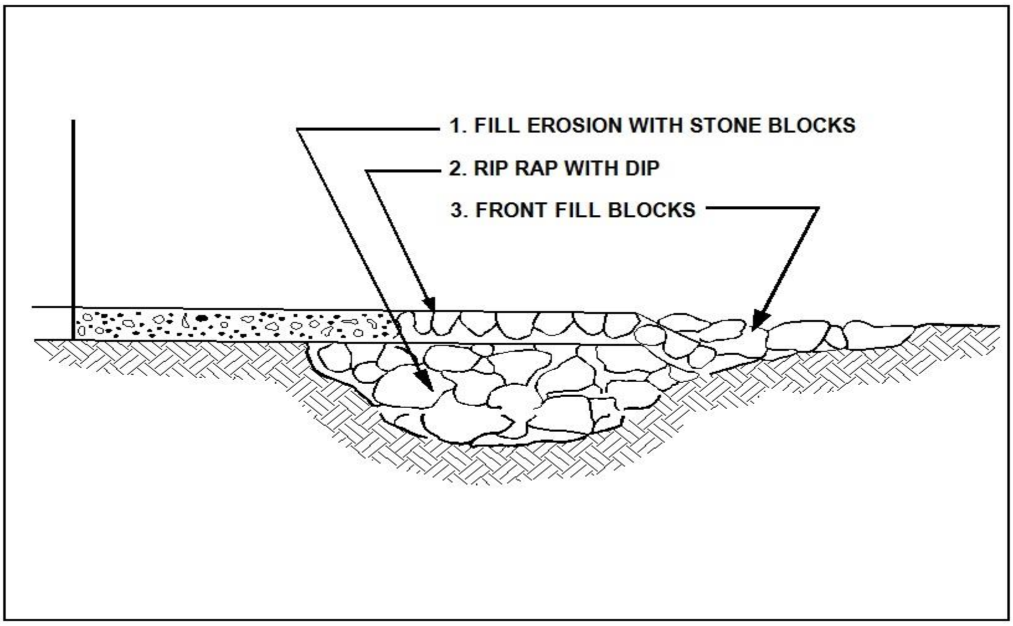


Figure 19: Erosion Repairs

e. Bridge, Abutments and Wing Walls

Erosion can occur at bridge abutments and wing walls due to deflection of streams and rivers caused by snagging, or by man-made or natural interference upstream. Erosion can also occur as a result of flash flooding outside of the parameters of design for the bridge in question. Removal of snagging debris, removal of upstream interference, such as a fallen tree, or a recently constructed jetty or badly designed river wall will prevent further aggravation of erosion. Man-made interference will require a court or council order for removal and must therefore be reported immediately to the technical officer.

Reinstatement, repair and prevention of further erosion are normally achieved by sheet pilling, drains, rip-rap, gabions or boulder-fill. This work is highly specialized and beyond the capacity of a section crew. Assistance must be requested.

Should erosion extend deeply into bridge wings or close to the abutment faces, temporary warning signs should be placed on the bridge approaches showing ***"Bridge under Repair"*** and ***"Slow".***

Note: Treat this operation as Priority; "***IMMEDIATE"***

7.3 Shoulders

7.3.1 Grass Cutting

Soft shoulders are planted with grass as a cover crop to protect them from erosion. Grass will require continual repeated cutting. This is not merely a decorative process to keep the appearance of the highway pleasant and relaxing to highway users. Uncut grass in tropical climates can change in structure to coarse bladed elephant type grasses, which rapidly denude the topsoil of its nutrient and grow to heights where they can obstruct sign lines.

The thick mat of uncut grass on a shoulder presents a dense filter to the path of run-off water leaving the pavement surface.

This causes the water to deposit dust, sediment and wind blow silts onto the shoulder. The slow gradual build-up of sediment on the shoulder can under extreme circumstances result in an increase in the shoulder height by a few centimetres per year.

7.3.2 Shoulder Repairs

Shoulder repairs may be necessitated as a result of three major types of damage:

- Spot or localised damage
- Rutting
- Erosion damage

a. Spot or Localised Damage

Holes and depressions in the shoulder surface, frequently caused by vehicle accident or excessive parking, can result in ponding of water and subsequent softening of the shoulder and even penetration of water into the pavement structure. All holes and depressions should be cut out square and reinstated to level and slope with good quality fill, topsoil and turf. The materials should be watered (in the dry season) and rolled with a hand operated roller.

b. Rutting

The formation of ruts, in both hard and soft shoulders along the pavement edges, is caused by wheels of moving vehicles. It is usually indicative of inadequate width of the pavement and should therefore be reported for consideration of widening of the carriageway in association with the next planned periodic maintenance operation.

Ruts must not be left unattended during rainy seasons, since the ponding of water will result in weakening of the base and subsequent failure of pavement edges.

Ruts will be cut to square trenches and reinstated with good quality fill, topsoil and close turfing. The materials will be watered (in the dry season) and compacted with a hand operated roller

c. Erosion Damage

Erosion of both soft and hard shoulders, apart from rutting as described above, can occur as a result of excessive quantity and velocity of surface water run-off, flooding and loss of cover crop in soft shoulders as a result of damage. The erosion may appear as corrugation of the shoulder (particularly unpaved gravel shoulders) and may be accompanied by erosion of the side slope in the form of a washout or a series of minor rivulets. For soft shoulders, patching should be carried out as described above for rutting, except that turf establishes on side slopes shall be pegged into position with 15 cm long split bamboo spikes. Hard shoulder should be graded, watered and rolled. Major washouts shall be rebuilt from the bottom upwards in layers not exceeding 15 cm thick in square cut terraces.

7.3.3 Shoulder Clearing

All rubbish, waste, surplus materials and even broken down vehicles must be cleared from the shoulders continually. Apart from being unsightly, any form of debris inhibits grass growth, blocks natural drainage lines and constitutes a hazard to traffic.

7.4 Right Of Way / Road Reserve

7.4.1 Bush Clearing

Small bushes and ornamental shrubs, provided that they do not encroach upon drainage lines, are attractive and desirable within the right of way. Large bushes may obstruct visibility and if they do, they should be grubbed out.

7.4.2 Tree Felling

Trees are not normally desirable within the right of way since they are likely to obstruct sight lines and their roots, sooner or later, are likely to interfere with drainage lines. Tree felling, where necessary, should be within the work capacity of a section crew, although assistance may be required for grubbing out larger roots that interfere with drainage.

7.4.3 Branch Lopping or Trimming

There will be frequent instances where a tree cannot be felled owing to their value, beauty, or conditions of tenure of the land within the right of way. This may well occur in areas of rubber estates, fruit orchards and in the suburbs of cities and larger townships. In these latter instances trees may have been deliberately planted along roadsides for shade and beauty. Where this condition exists the tree branches must certainly be cut back or lopped to the edge of the pavement and if possible to the outside edge of the drain. The continual dripping of rain drops onto the same part of the pavement, like from an overhanging branch, will create a pothole in any surface material.

Before embarking on a programme of tree felling or extensive lopping the section Overseer should in the interests of Public Relations seek the advice from the technical officer,

7.5 Bituminous Pavements

7.5.1 Pothole Patching

Potholes are localised structural failures which are generally a secondary form of distress that develops from cracking or extreme loss of aggregate.

Figure 20: Pothole Developing

a. *Causes of Potholing*

(i) Overstressed Wearing Courses (Traffic Induced)

The most common cause of extensive potholing is overstress and distortion of thin wearing courses of surface dressing on flexible bases under heavy traffic. Under these conditions, the repair of potholes alone will not suffice. The wearing course must be thickened and if possible a stronger base of adequate thickness must be introduced.

(ii) Drainage Defects

Potholes in areas of pavement showing signs of depression or upheaval are probably caused as a result of poor drainage. Side drains, culverts outlets and run-off drains should be inspected for silting, blockages and adequacy of depth.

(iii) Progressive Disintegration

Potholes in areas of pavement showing signs of cracking are due to progressive disintegration of the cracked surface and accelerated by entry of water to the base. The primary source of the crack failure must be discovered and corrected if repairs are to be effective.

(iv) Spillage

Spillage of diesel fuel, oil and chemicals from traffic and particularly parked vehicles can result in cutting back the bitumen in open textured pavement material with the eventual growth of a pothole. The more common example of this comes from spillage from construction plants during pavement construction stages.

(v) Defects in Design

Defects in design, or manufacture, resulting in areas of too little bitumen, too much or too little fines in asphaltic concrete, can result in potholing. Usually ravelling of the surface will be visible prior to failure.

b. Pothole Repair

Potholes must be patched the moment they become visible and certainly whilst they are small in size. If due to weather or unavailability of materials, specialist teams or equipment, permanent patching must be delayed and then temporary patches with the best available materials should be first affected. However, when a pothole is patched, the repair will not be effective or permanent unless the root of failure is identified and cured.

Where the cause is due to general weakness of pavement, or design detects, there is little that the s ection o verseer can do, except report the defect and progressively repair the holes as they appear.

Spillage problems are cured as the defective area is cut out and replaced. Potholing created as a result of drainage defect or as a progression from cracks must be cured. The cause must be traced back to its origin. Drains, culverts, outfalls must be reinstated first. Defective material below the pothole must be removed and replaced with sound material and finally a permanent patch placed in position.

c. Pothole Patching

Potholes that are merely cleaned and backfilled without increasing their volume and squaring off the sides will not survive under traffic. Wheel loads invariably create bowl shaped holes and further wheel loads will merely displace the "bowl shaped" plug.

The pothole must be excavated as a square sided hole with a clean horizontal base and vertical sides. The surface area of the hole must be bounded by straight lines whether it is cut in a square, rectangle, or diamond. The base of the hole must be at such a depth as to be founded on good solid undamaged material.

(vi) Depth of Pothole Excavation

Figure 21 below shows the shape of correct pothole excavation in cross-section. Should excavation to the base of the hole show wet and contaminated material in the base, then the excavation must be continued in depth as shown in broken line into the sub-base and sub grade if necessary.

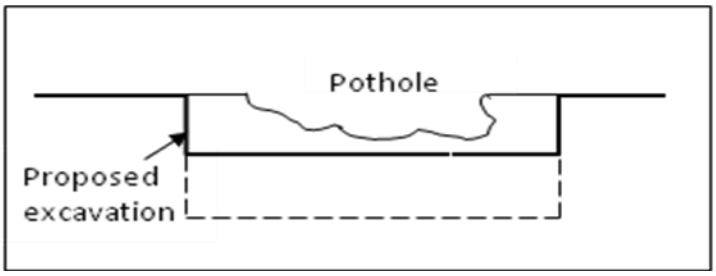


Figure 21: Repair to Pothole – Excavation

(vii) Shape of Pothole Excavation

The sides of the excavated area must be made up of straight lines to provide the maximum support to the asphalt. Figure 22 below shows a typical excavation. The shape shown is a diamond, which, although not obligatory, is probably the best pattern to use since it presents a diamond joint to wheel loads and reduces the tendency to disturbance.

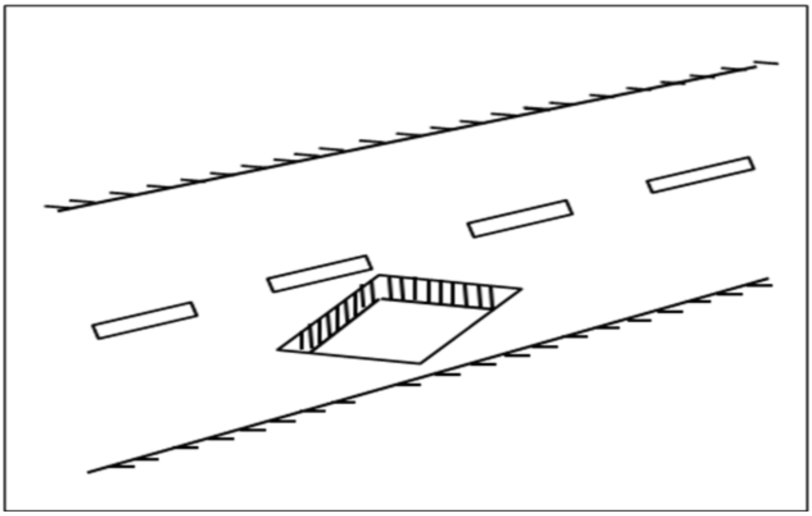


Figure 22: Excavated Pothole Ready for Filling

(viii) Preparation of Excavation

If the bottom of the hole is excavated down to a granular base material, it should first be primed before adding asphalt. For shallow potholes onto old bituminous surfacing material the old surface should be thoroughly cleaned and given a tack coat.

No matter what the depth of the excavation, the sides of the hole must be given a tack coat to ensure good adhesion of the patching material to the rest of the pavement structure.

(ix) Reinstatement

For best result a hot mix of bitumen macadam or asphalt concrete should be used. In practice, the most common material used will be a cold mix that can be stockpiled for use as and when required. For deep patches, the higher stone content and high mechanical strength of bitumen macadam‘s will give the best results. Aesthetically the patch should match the material of the existing surface and with deep patches this can be achieved in two stage construction. The material of the patch should be placed by hand using shovels raked to the profile of the road using a string line or straight edge and thoroughly compacted.

<u>Note:</u> All potholes should be treated as Priority; ***"URGENT "and*** where extensive, assistance should be requested.

7.5.2 Crack Sealing

With the increasing use of hot-mix pavement material the incidence of potholing should decrease and cracked defects will become more frequent in appearance. Cracking may become visible in any of the six descriptive forms listed below:

- Alligator / crocodile cracks
- Edge cracks
- Joint cracks
- Reflection cracks
- Shrinkage cracks
- Slippage cracks

d. Alligator / Crocodile Cracks

Alligator cracks are visible as a pattern of interconnecting lines similar to the pattern of an alligator's skin and breaking the surface up into a series of small blocks.

Alligator cracks normally occur as a result of fatigue failure of surfacing and base layers and are related to the inability of the pavement to carry the traffic load.

Treatment of this defect must be the total removal of the cracked area and the entire affected base and sub-base material. If the alligator cracking is due to inadequate drainage, this must be identified and corrected before valuable replacement material is wasted. A temporary skin patch can be applied if the materials for permanent replacement are not immediately available. Skin patches are thin tack coats of medium curing cut back applied over the cleaned cracked area and blinded with sand or dust-free crusher fines. These should be lightly rolled with a hand operated roller or the rear wheels of a tipper.

Figure 23: Alligator / Crocodile Cracking

e. Edge Cracks

Edge cracks will appear as longitudinal cracks close to the edge of the pavement. They may be accompanied by some small lateral cracking and by a depression or shrinkage of the pavement between the crack and the edge of the road.

The cause of such cracking is either inadequate shoulder support of the formation or failure of the base due to entry of water from the shoulder. This is a frequent occurrence where shoulders have been permitted to stand too high thereby ponding water on the pavement edge.

Repair should be carried out urgently by filling the crack with a cutback bitumen and sand mix. Any depressed area should be brought back to the original profile by regulating overlay. Should the defect have been caused by ponding of water a temporary gully should be cut through the shoulder and action instituted for the early reduction of the shoulder to the correct level and slope.

f. Joint or Longitudinal Cracks

Joint cracks are longitudinal line cracks between lanes of construction in asphaltic concrete wearing courses.

The cause of j oint cracking is a poor bond between successive paving sequences due to either careless work or cold material compaction. Treatment is filling of the crack with a mix of cutback bitumen and sand or dust free quarry fines.

g. Reflection Cracks

Reflection cracks occurring in asphaltic concrete and to a less frequent extent in bitumen macadam overlays are repetition of underlying cracks in the old surface. Reflection cracks become visible as irregular lines less straight than joint or edge cracks.

The repair of reflection cracks which are normally very thin should be undertaken with cutback bitumen squeezed into the crack and blinded with sand.

h. Shrinkage or Stabilisation Cracks

Shrinkage cracks frequently have the appearance of alligator cracking photographically enlarged. The block sizes are larger and the crack pattern more irregular. One of the common causes of such cracking is a volume change in high bitumen content and dense asphaltic concrete.

Another cause is shrinkage of treated (stabilised) pavement layers. These cracks are not confined to the wheel paths. Treatment is filling of the crack with a mix of cutback bitumen and sand or dust free quarry fines.

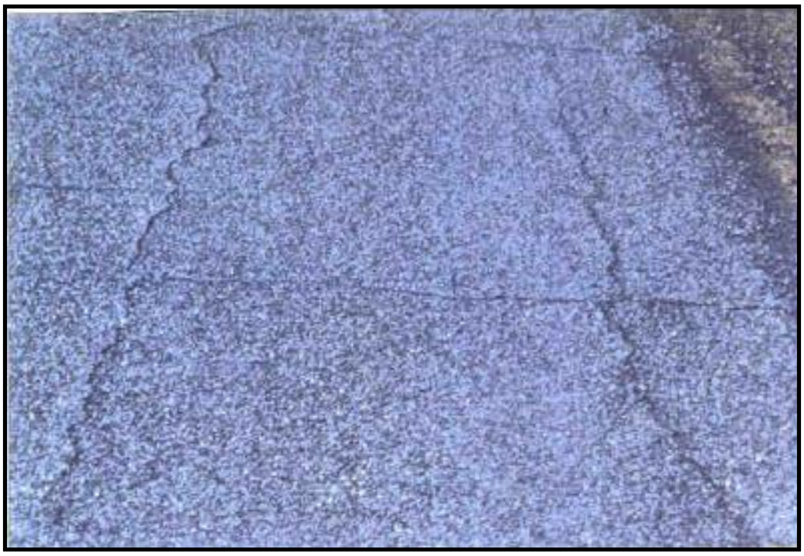


Figure 24: Shrinkage or Stabilisation Cracks

i. Surface Cracking

Asphaltic concrete wearing and binder courses, designed for heavy traffic but receiving little or no usage, frequently develop shrinkage cracks.

Unused stadium car parks and access roads to undeveloped industrial estates are common sufferer of this defect. Since the cracks are very thin the only satisfactory method of repair is a slurry seal over the entire affected area. If surface dressing is effected care should be taken to use sand or dust free quarry fines and the minimum possible bitumen application since the asphaltic concrete surface is likely to be fairly rich.

Figure 25: Severe Surface Cracking

j. Slippage Cracks

Slippage cracks become visible as crescent shaped cracks, frequently supported by a depression and winkles in the asphaltic concrete course. In appearance they look like broken skin blisters.

The cause of this cracking is a loss of bond between the wearing course and the surface on which it was laid or the slipping of the under lying pavement layers close to the edge of an embankment.

Repair should be dealt with in exactly the same method as applied to potholes above.

Note: All cracking of bituminous pavement should be treated as Priority: ***"URGENT"*** and specialized assistance requested.

Figure 26: Slippage Cracks

7.6 Gravel Pavement

Gravel pavements are low cost wearing courses generally constructed of naturally occurring soil aggregates. They can provide excellent riding surfaces but are prone to wear from both weathering and traffic. Defects in gravel pavements, once started, grow rapidly and it is therefore essential that routine maintenance operation be systematically and continuously applied to these pavements.

7.6.1 Gravel Pavement Defects

a. Pothole

Potholes are bowl shaped depressions in the pavement surface.

Generally in the early stages they are not as uncomfortable to motorists as the sharp edge potholes associated with bituminous pavements. However if they are not attended to, they can become very dangerous.

Both, traffic and weather, cause rapid deepening and enlargement of potholes to the level at which they become a hazard to traffic. Potholes must therefore be identified as early as possible and be repaired as a matter of extreme urgency.

Figure 27: Potholing of Gravel Roads

(i) Causes of Potholing

- *Depression*

Low spots left in the pavement surface after grading or resurfacing will pond water during the wet season, weakening the surface and permitting traffic to cause further weakening and enlargement of the hole.

- *Segregation*

Segregated oversized aggregates left undetected or uncorrected after grading or resurfacing will rapidly develop into potholes as the unstable material is first loosened and finally thrown out by traffic movements.

- *Sub grade Weakness*

Localized failure of the sub grade due to poor compaction or drainage failure can result in settlement of the gravel pavement and subsequent growth of potholes. In these instances groups of potholes will tend to grow due to uneven settlement usually associated with this type of failure.

- *Overhanging Trees*

The repetitive dripping of rain from overhanging trees is an all too frequent and unnecessary cause of damage to gravel pavements. Gravel surfaced roads will accept a certain proportion of rain into the material varying with the soil aggregate graduation and the camber of the pavement. In this condition the pavement is weakened and needs to release the surplus moisture as quickly as possible. Overhanging trees will shade the pavement and delay the vital drying out of the surface thereby exposing the material to unnecessary repetition of load in a weakened condition. Pothole development under these conditions is highly probable.

(ii) Repair of Potholes

All potholes in gravel surfaced pavements develop a bowl shape as wheel loads break down the edges. If repair is carried out by merely filling this shape, the bowl shaped plug has little or no resistance to displacement by subsequent wheel loads. The repair sequence that must be followed is therefore:

- Excavation
- Preparation
- Reinstatement
- Compaction

- *Excavation*

The potholes must be excavated with vertically cut sides into the shape of a square, rectangle or diamond, with a horizontal and clean base, as explained and shown in Section 7.5 for bituminous pavements. Since standing water plays a part in the formation of most potholes, it is likely that the bottom of the excavation will be wet and may well be a slurry of fines. If this is the case then the excavation must be carried down until firm well graded dry material is encountered. This may well entail excavation into the sub grade. All damaged material must be removed and thrown to waste.

- *Preparation*

When the excavation has been completed down to good quality material the base should be compacted thoroughly with a rammer and if still in the gravel surfacing material lightly watered prior to compaction.

- *Reinstatement*

The volume of the excavation is now ready to receive a patch, made of the identical material to that used in the gravel surfacing. Where surfacing material is an artificially blended material, it is advisable to retain a stockpile of the individual components for repair works.

The soil aggregate material should first be moistened to raise its moisture content to the optimum for compaction and then placed into the excavation and levelled with rakes should the depth of the excavation be greater than 15 cm the patch must be constructed of two or more layers, each being compacted prior to placing the succeeding layer.

- *Compaction*

Compaction of the patch is best carried out with a hand operated vibrating roller worked laterally across the reinstated area. The surface should be checked to conform accurately to the profile of the pavement, with a string-line. Care must be taken to avoid a depressed patch since this will immediately cause the formation of yet another pothole. If a vibrating roller is not available compaction can be achieved with the careful hand rammers or the rear wheel of a tipper.

b. Rutting

Rutting is the formation of longitudinal wheel troughs as shown in Figure 28. This condition is most frequently encountered on narrow single lane gravel surfaced highways.

Figure 28: Rutting of Gravel Roads

(i) Causes of Rutting

- *Abrasion by Traffic*

The most common cause of rutting is by abrasion and is usually accompanied by clearly visible windows of coarse material along the sides and between the ruts.

Repeated passages of wheel loads first remove the fine grained binder fraction of the gravel surfacing thereby exposing and loosening the coarser material. Continued wheel loads follow in the same path; brush the loose coarse material to either side and thus enabling the wheels to attack once more the newly exposed fine grained material. Progressively the wheel paths get lower as higher windows of coarse material are built up.

- *Deformation by Traffic*

Rutting may occur by the lateral displacement of gravel surfacing material while it is in an excessively wet condition and without decomposition of the soil aggregate. Again this will occur most frequently on single lane highways or highways with neglected shoulders and edges forcing vehicles to follow a single central path.

Deformation of this type is most common where there is fine fraction. Usually clays are very high and where the camber of the highway is too low to permit rapid run-off of surface water. Localized rutting will also occur in areas where drainage defects exist.

(ii) Repair of Rutting

Ruts are parallel depressions of the surface in the wheel tracks. They generally form as a result of loss of gravel from the wearing course by traffic abrasion and less commonly by deformation (compaction) of the sub grade and compaction of the wearing course

The methods available for repair work depend upon the extent of rutting and its character. Wherever possible the defect should be identified early to enable the easiest and cheapest corrective operation to be employed.

- *Shallow Rutting*

Where rutting is in its earliest stages of development and where little or no segregation of material is evident the profile of the pavement may be returned to its correct shape by simple blading. This process is described below in subsection ***"7.6.2 – BLADING"***.

- *Deep Rutting*

Where rutting is deep, blading will be insufficient to restore the pavement to its correct profile. Some segregation will undoubtedly be present due to probable water ponding in the ruts. Provided that this segregation is not excessive the corrective procedure to adopt is re-grading. This process is described below under ***"RE-GRADING".***

o *Segregated Rutting*

Where rutting is accompanied by visible segregation as is caused by abrasion due to traffic, re-grading will return the pavement to profile but leave it in an unbalanced and decomposed condition in which it will be susceptible to further rutting or corrugation. Under these conditions, the gravel surfacing material will require addition of the missing fractions before re-grading. This process is described below under ***"GRAVEL – REDRESSING"***.

c. Corrugation

Corrugation is a series of lateral waves or ridges on the surface of the pavement. The height of the ridges and their wave length are usually peculiar to the soil aggregate grading. Corrugated surfaces are most uncomfortable for light vehicles causing vibration in the suspension and a loss of steering control.

Figure 29: Corrugation of Gravel Surface

(i) Causes of Corrugation

Corrugation is a direct result of traffic action upon a soil aggregate material of incorrect gradation. Corrugation may occur on gravel surfaced roads with excessive high clay content in very wet conditions. However, the most frequent occurrences of corrugation are with soil aggregates that are deficient in fines. The loose particles of gravel and sand size are moved by wheel action in the same way as the wind builds sand dunes in the desert.

(ii) Removal of Corrugation

The methods used for correction of corrugated surfaces of gravel surfaced pavements depend upon the severity of the defect. Every effort should be made to detect and eliminate the defect as early as possible. Since the defect will be more readily felt by faster moving vehicles, the drivers of tippers and pick-ups should be encouraged to report any corrugation vibration felt in driving over gravel surfaced highways.

d. Dust Control

Road dust is the dry solid matter consisting of clay and silt-sized particles that is entrained by wind, the wind shear forces created by vehicles and the interaction of vehicle tyres with the road. It disperses and remains in suspension for a period of time before eventually falling back to the earth's surface. The aerodynamic shape, tyre size and number of wheels on trucks imply that dust generation by heavy vehicles is more severe than light vehicles.

Dust is undesirable from a number of points of view including safety (loss of visibility), economic (accelerated gravel loss as a result of the loss of fines), comfort of vehicle occupants, health (respiratory diseases), vehicle damage (filters and exposed moving parts), damage to road side vegetation (crops) and environmental impact (air pollution). Dust is generally considered unacceptable by the travelling public when the vehicle generating the dust cannot be seen by a following vehicle.

It is not possible to prevent gravel surfaced highways from dusting. It is however possible to reduce the volume of dust brushed off by traffic.

Figure 30: Dust Problems

(i) Severe Dust

Should the gravel surfacing show heavy dusting it will be indicative either of excess clay fraction present or advanced decomposition of the soil aggregate. In either case samples should be taken from the surfacing material for laboratory analysis, so that a correction can be made to the soil aggregate gradation.

(ii) Light Dusting

If the gravel surfacing shows only dusting during the dry season, it may be assumed that the soil aggregate grading is close to the ideal. It may be preserved in this condition and dusting reduced to the minimum with occasional watering and rolling. A light application of water followed by a single pass of a pneumatic tyred roller or steel wheeled tandem roller in the early morning should be sufficient to reduce dusting for 2-5 days, depending on traffic density.

e. Analysis of Defects

Gravel roads are not capable of carrying high density traffic. Below is a guide to traffic densities at which gravel roads should be considered for upgrading either from earth roads to selected gravel roads or from selected gravel roads to surface dressed roads.

(i) 0 - 30 ADT (Average Daily Traffic)

These traffic densities can be carried on earth roads economically and without causing excessive defects

(ii) 30 - 100 ADT

At these traffic densities earth roads are no longer economical to maintain and should be upgraded to selected gravel roads

(iii) 100 - 200 ADT

Selected gravel roads are economical to maintain but should be surface dressed through villages to avoid excessive dusting.

(iv) 200 - 300 ADT

Selected gravel roads are economical to maintain but should be surface dressed on steep sections with gradients over 4%.

(v) 300 - 500 ADT

Selected gravel roads are not economical to maintain if natural gravel pits are distant from site and should be upgraded to surface dressed roads.

(vi) More-than 500 ADT

All gravel roads carrying more than 500 ADT should be upgraded to surface dressed roads as it is not economical to maintain them.

Note: The borders lines given above are not firm since the frequency with which defects occur are dependent upon the gradation quality of the gravel available.

7.6.2 Blading

a. *General Theory*

(i) Definition

Blading consists of a light shallow grading of gravel surfaced pavements to correct minor defects in the profile. It performs only a geometric correction and does not mix or blend material which has become segregated.

(ii) Functions

Blading when applied to a gravel surfaced pavement corrects minor defects and:

- Restores the camber
- Restores riding quality

b. *Application*

Blading may be applied to any natural gravel or soil aggregate where the following conditions apply:

- Shallow rutting
- No visible segregation

The process is repeated in the second lane, making adjustment to depth and angle of crown to avoid resulting windrows or depressed areas

To achieve the final resultant shape shown in Figure 33, it may, on occasions when rutting is deeper, be necessary to make a third pass down the centre-line with a square blade to distribute the resulting windrows.

c. *Strength*

Blading does not affect the strength of the pavement since it utilizes only the existing road materials.

d. *Equipment*

(i) Drag- Blade

Blading may be performed by a grader or, more ideally, by a drag-blade. This consists of an axle and tow-bar supporting a light grader blade, circle and controls and an operator's seat. The assembly is towed behind an industrial tractor.

While two operators are required for tit's use, it has the major advantage of the grading operator being close to the pavement level for accurate eye-judgement of the very shallow cuts and fills required.

(ii) Rollers

Either one (1) steel wheeled tandem roller or one (1) pneumatic tyred roller is required for compaction of the thin layer of soil aggregate bladed and shaped by the drag-blade.

(iii) Water Bowser

Should water be required to assist compaction a tractor and water bowser unit will be used.

e. *Construction Methods*

Figure 31 illustrates an exaggerated representation of shallow rutting requiring blading.

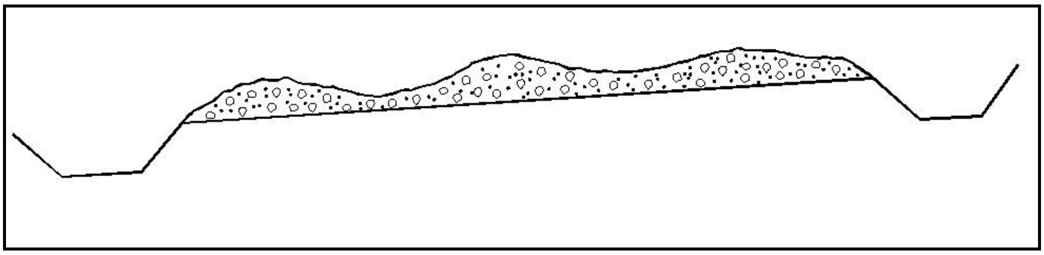


Figure 31: Rutting Requiring Blading

(i) Blading

The first pass of the drag-blade will be made in one lane with the grader blade set to the appropriate angle of camber and approximately 10º inwards of square to crowd surplus material from the outer edge towards the centre-line. The depth of cut will be adjusted by the operator to result in the minimum residual overspill windrow at the centre-line.

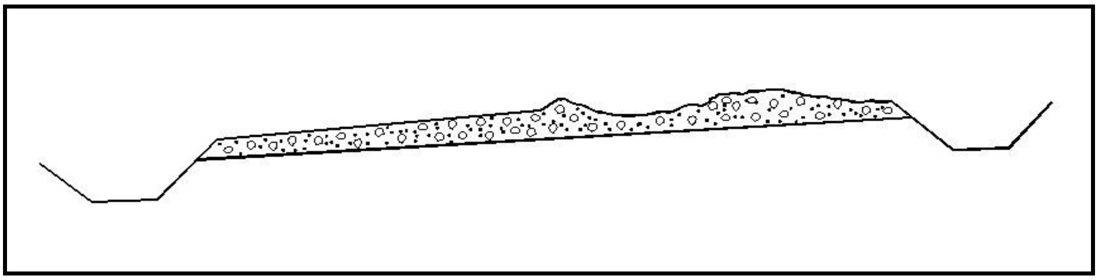


Figure 32: First Pass of Blading

The process is repeated in the second lane, making adjustment to depth and angle of crowd to avoid resulting windrows or depressed areas. To achieve the final resultant shape as shown in Figure 33 below, it may be on occasions, when rutting is deeper, be necessary to make a third pass down the centre-line with a square blade to distribute the resulting windrows.

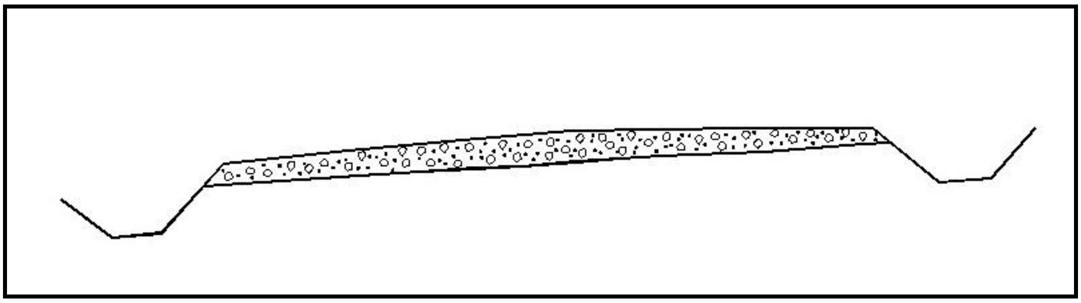


Figure 33: Completed Blading

(ii) Compaction

After the addition of light watering if necessary, compactions can be achieved with a single pass of a 6-8 ton steel wheeled tandem roller. Rolling should commence at the outer, lower edge and proceed towards the centre-line.

f. Defects

The only major defect resulting from this blading operation on soil aggregates free from segregation is likely to be due to overcutting. A natural reaction of most operators in ensuring that they have sufficient material on the blade is to cut too deep on the outer edge, thereby setting-up too high a camber and therefore create unequal thickness across the pavement.

Continuous checking with camber boards can insure against this risk.

7.6.3 Gravel Re-Grading

a. General Theory

(i) Definition

Gravel re-grading is the process of mixing, shaping and compacting soil aggregates in wearing courses, which have become deformed and/or segregated.

(ii) Functions

Gravel re-grading when applied to a soil aggregate wearing course fulfils the following functions:

- It corrects geometric effects in profile
- It re-blends those portions of the aggregates that have become segregated
- It improves the riding quality
- It retards decomposition of the soil aggregates

b. Application

Gravel re-grading may be applied to any soil aggregate wearing course showing signs of deformation of profile and segregation where:

- Deformation is too great to be corrected by blading
- Segregation is not so far advanced as to lead to decomposition of the soil aggregate and thereby necessitates redressing

c. Strength

Gravel re-grading does not make any addition to the strength of the pavement since it utilizes only the existing materials on the road.

d. Equipment

Equipment requirements consist of one (1) grader, one (1) water bowser and tractor and one (1) 6 to 8-ton steel wheel tandem roller, all of which are standard units available within districts.

e. Construction Methods

(i) Inspection

It is desirable that the section to be worked be carefully inspected to ensure that all ancillary works involving repair or reinstatement of drains, shoulders, culverts and accesses be noted for prior execution. An example of an assessment form that can be utilised is given in Figure 37.

It is also desirable that samples of the soil aggregate in the wearing course be sent to the laboratory for analysis if any signs of segregation are visible. The laboratory test will confirm whether the soil graduation lies within the range of acceptability to ensure that it can be compacted and remain stable.

Since water will be required for compaction a suitable source within range of the equipment available must be located.

(ii) Planning

Gravel re-grading operations can only be satisfactorily undertaken on full width pavements if segregation of aggregate is present. The problem of traffic disruption, diversionary routes and traffic control must be considered in association with the normal planning sequences. These will cover the following steps:

- Optimum moisture content for compaction
- Water quantity requirements
- Distance of site from water source

- Sequence of operations
- Length of sections to be worked
- Breaks in sequence of operation for traffic movement
- Traffic control

(iii) Safety

Safety considerations must cover:

- Safety of road users
- Safety of labour force
- Protection of work from damage during construction

This is not a high risk operation since no hot or corrosive materials are in use.

(iv) Operation

- *Mixing*

With the surface in a condition such as that illustrated in Diagram 1 of Figure 34 there is almost certain to be some segregation with loose coarse aggregate particles lying in the three windrows created by rutting.

Should the material be in a hard compacted condition it may be necessary to first scarify the surface to the depth of the gravel surfacing course.

The first pass of the grader in the mixing process is illustrated in Diagram 2 of Figure 34. The objective is to blade the maximum quantity of material available in the first lane into a windrow on the centre-line.

The second grader pass is performed returning in the second lane repeating the process of blading the maximum quantity of material available onto the windrow on the centre- line as shown in Diagram 3 of Figure 34.

The third and final grader pass in the mixing operation is performed with the blade set square and level evenly distributing the material in the windrow across the full width of the pavement. The material available should now be evenly blended.

- *Watering*

With the gravel surfacing in a loose condition and shaped as shown in Diagram 4 of Figure 34 water should be added with a water bowser to bring the moisture content up to the optimum for compaction.

- *Shaping*

Two further passes of a grader, one in each lane with the blade set to the appropriate angle of camber between 3.5 and 4.0 percent and set square or retarded 5-10 degrees, are required to shape the surface to profile.

The blade should not overspill and grader operators will vary in their ability to maintain this condition with individual preferences of angle of retarding towards the centre line. These two passes are illustrated in Diagram 5 of Figure 34.

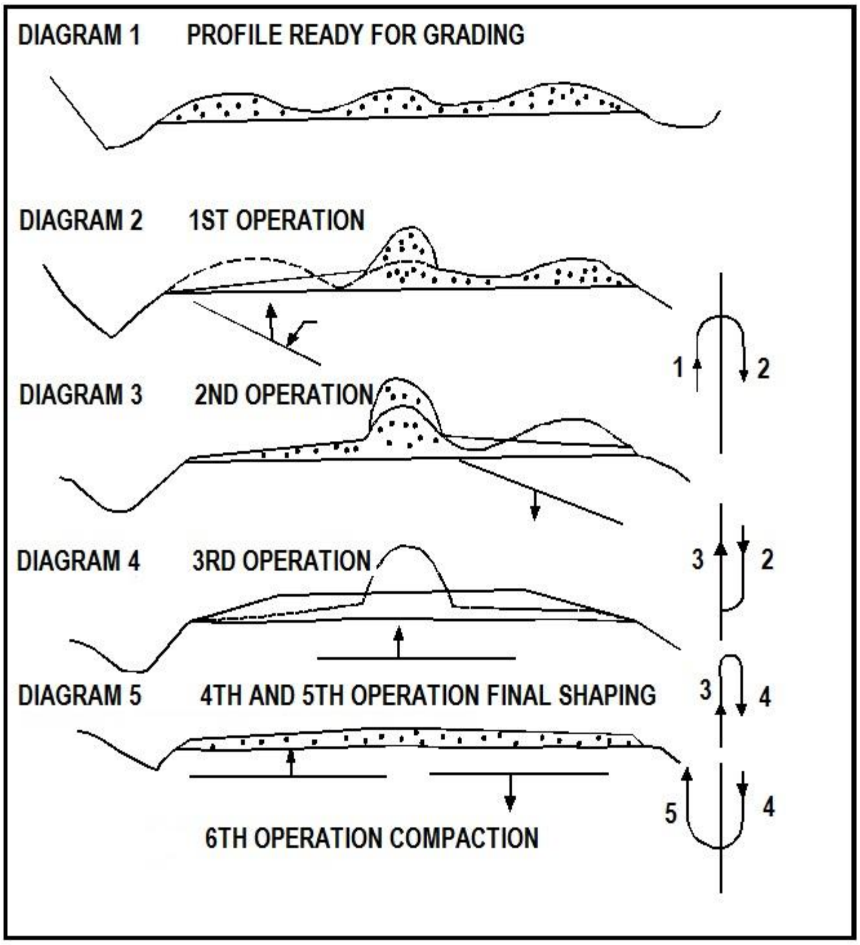


Figure 34: Grading of Gravel Roads

- *Compaction*

Compaction will be achieved with 3-4 passes of a 6-8 ton steel wheeled tandem roller. Rolling will commence at the lower edges and overlap progressively towards the centre line.

- *Length of Section and Traffic Accommodation*

Where traffic movements must be maintained during gravel regarding operation it is advisable to work the grader on relatively short lengths of pavement. Traffic movements may be permitted over the completed shaped profile after the first pass of the roller.

7.6.4 Gravel Redressing

Gravel redressing is part of the normal range of routine maintenance operations. However, it contains a number of highly specialized and precise factors which make it a difficult operation for performance by routine maintenance equipment and labour available to section overseers. These specialist factors are primarily:

- Laboratory testing and design of blended aggregates
- Exact precision in the quantities of aggregates to be placed on the pavement
- Specialist equipment requirements
- High level of measurement and supervision of the operation

It will therefore be necessary for section overseers to call upon their technical officers for specialist assistance in design, construction and supervision of their operation. This work has therefore been included under the periodic maintenance part and is fully described in the following chapter.

7.7 Bases

Routine maintenance operations will not normally include work on base courses of the pavement structure, except where they are exposed in repair to potholes. Where this occurs the base should be reinstated either in the material of which it was originally constructed or in penetration macadam or bitumen macadam. Where bases are reconstructed in bitumen macadam or patches are laid to full depth in hot or cold mix materials, the cleaned part base or sub-base material should first be primed.

Where part only of a dry stone base has been removed, reinstatement should not be attempted in crusher-run aggregates since these cannot be satisfactorily compacted in depths of less than 11cm.

Note: Repair to potholes involving damage to bases should be treated as Priority: ***"URGENT"*** and specialist assistance requested.

7.8 Drainage Structures

7.8.1 Minor Works

Works within the capacity of section crews not requiring the use of specialized tradesmen may be summarized as traffic damage to:

- Steel or timber handrails
- Minor concrete parapet damage
- Culvert headwalls
- Displaced running boards on timber bridges

Where damage is more than minor, assistance should be requested. Damage must always be reported and treated as Priority: ***"URGENT"***

7.8.2 Touch Painting

Semi-skilled painting is within the capacity of labour employed in section crews. Works falling within the scope of touch painting are:

- Over-painting scratches and defacement caused by traffic damage
- Re-painting of lettering on informative signs
- Painting barriers and road crew safety signs
- White-washing parapets, culvert head walls, kilometre posts, guide stones
- Temporary markers on hazards such as trees within the formation

Paint and whitewash are applied to structures both as preservatives and aids to the recognition by road users. The quality and cleanliness should therefore be maintained at a high standard at all times even though these operations are classified as routine.

7.8.3 Rip-Rap Repairs

Rip-rap is a mattress of stone boulders of approximately 30cm size set in cement mortar to protect bridge abutments, culvert outlets and watercourse banks from erosion. Damage caused by impact, undercutting or slips should therefore be made good at the earliest possible opportunity. If the damage consists of displacement of a small area or loss of bond in mortar, the repair work can be dealt with by the semi-skilled labour available in section crews. Major damage and failure due to embankment slips are beyond the capability of section crews and assistance should be requested.

Note: These operations should be treated as Priority: ***"URGENT"***

7.9 Highway Furniture

7.9.1 Pavement Marking

Although replacement and repairing of pavement markings are a routine maintenance task, the work requires a degree of skill and accuracy beyond the capacity of section crews. A pavement marking machine is required for the task. Inspection of highways should include loss of legibility of existing markings and need for new markings. A request for assistance should be made as an aid to planning at more senior levels.

7.9.2 Kilometre Posts

The regular repainting and repair of kilometre posts is a routine task required for section crews. Broken and missing kilometre posts will be installed by section crews with new standard posts supplied by district headquarters.

7.9.3 Road Sign Repair

Repainting and repair of temporary signs may be carried out by section crews. Sings broken beyond repair by traffic accidents and vandalism must be reported with a request for assistance. A temporary timber sign should be erected immediately until a new sign can be supplied and erected.

Note: Replacement sign operations will be treated as Priority: ***"URGENT"***

7.9.4 Temporary Hazard Signs

Where temporary hazards occur that cannot be rectified immediately, temporary hazards signs must be erected and district headquarters should be notified on a request for assistance form. Temporary hazards include landslides, slips and floods. In the case of floods, a flood warning sign will be erected 200 metres before either end of the flood point indicating maximum depth. The edges of the pavement will be demarcated through the entire length of the flood area with black poles at 20-40 metre spacing.

Note: Temporary hazard operations will be treated as Priority: ***"IMMEDIATE"***

State: ……………………………………………………………………… **WEEKLY REPORT FOR WEEK ENDING**

Control Section No: ……………………………………………

From: …………………………………To…………………………

Road Overseer: …………………………………………………

Note: Only Unfinished Work to be Reported on this Form

TASK AND LOCATION	DATE WORK STARTED	% COMPLETED	REMARKS

……………………………………………………
ROAD OVERSEER'S SIGNATURE

……………………………………………………
TECHNICAL OFFICER'S SIGNATURE

Figure 35: Format of Weekly Report

TASK AND LOCATION	**PRIORITY:** 1 = Immediate 2 = Urgent 3 = Routine	REMARKS

………………………………………………… …………………

ROAD OVERSEER'S SIGNATURE **DATE**

………………………………………………… ………………...

TECHNICAL OFFICERS SIGNATURE **DATE**

Figure 36: Format of Request for Assistance

UNSEALED ROAD ASSESSMENT FORM

Evaluator		Date	
Road No		Section	
Start km		End km	

Segment No		Start km		End km	

General performance	1	2	3	4	5	Moisture		Wet		Dry
Gravel quantity	1	Plenty	2	Sufficient	3	Isolated exposures	4	Extensive exposures	5	None
Gravel quality	1	Very good	2	Good	3	Average	4	Poor	5	Very poor
Influencing factors		Clay		Sand		Gravel/stones				
Road profile/shape	1	Very good (4%)	2	Good (2%)	3	Flat	4	Uneven	5	Very uneven
Drainage from the road	1	Well above ground	2	Slightly above	3	Level with ground	4	Slightly below	5	Canal
Riding quality/safety	1	Very good (>100 km/h)	2	Good (100 km/h)	3	Average (80 km/h)	4	Poor (60 km/h)	5	Very poor (40 km/h)
Dust	1	Acceptable	5	Unacceptable						
Trafficability	1	Acceptable	5	Unacceptable						

Influencing factors	Corrugation	Loose material	Stoniness	Potholes	Ruts	Erosion
Isolated problems	Potholes	Subgrade exposure	Transverse erosion	Longitudinal erosion	Rough area	Slipperiness
Maintenance action	Local repairs	Routine blading	Heavy blading	Regravelling	Reshaping	Drains

Comments (Not captured in the system)

Inventory check

Material	Basic Crystalline	Acid Crystalline		High silica	Arenaceous		Argillaceous		Diamictite
	Metaliferous	Carbonate		Pedocrete	Fer	Cal	Gyp	Sil	Transported
Road width	<8 m	8-10 m	>10m	Road type	Gravel		Earth		Treated

Figure 37: Gravel Roads Assessment Form

8 Periodic Maintenance Operations

The principle operations of periodic maintenance are listed in the right hand column of "Highway Maintenance Functions" in Section 2.3 of chapter 2 of this volume.

Periodic maintenance consists of known and planned replacement or renewal of the working parts of the highway structure. Wearing courses have a foreseeable life depending on their type, quality of construction and volume of traffic usage. Similarly, paint has a known life under weathering and even road signs are limited in the number of times they can be repaired and repainted.

The periodic maintenance operations described below are not an exhaustive list of civil engineering trades and techniques. They represent the major works suitable to highway maintenance in Nigeria and for which equipment is provided.

8.1 Duties of Overseers

As previously stated periodic maintenance operations are carried out by specialist crews with specialist equipment. Each crew is headed by an overseer who is responsible for the performance of work. This involves planning of the practical execution, while planning of work programmes rests with the technical officer (Periodic Maintenance) at the district. The specialist crews are not staffed with many labourers, as they may use section crew labour to supplement their own staff.

8.1.1 Inspections

Before start of a periodic maintenance operation the overseer of the specialist crew in question shall inspect the site, together with the section overseer in whose section the work is to take place, in order to ensure that all necessary preparatory work has been carried out by the section crew.

8.1.2 Allocation of Daily Tasks

The specialist overseer will programme his resources for each day's operation one week in advance. Every evening, depending on the work process during the day, he will review and where necessary re-plan his programmes for the next four-to-five days..

8.1.3 Reports

a. Weekly Reports

The specialist overseer will submit a report to the technical overseer every week summarizing the work progress done during the week, in order that the district can review the work programmes and re-plan where necessary.

b. Monthly Reports

The specialist overseer will also submit a routine statistical report to the technical overseer every month in the form of a ***"Monthly Labour Allocation Sheet"***, as shown and fully explained in Chapter 5 of Volume 3 "Cost Accounting".

8.1.4 Requests

Requests for materials, etc. are done in the same way as explained in ***Section 7.1.4*** of the previous Chapter.

8.2 Drainage

The most important single factor in highway maintenance is the establishment of an efficient drainage system and its continual upkeep in an efficient working condition.

A highway drainage system can be defined as the means for speedy and safe collection and removal of surface water, together with the control and prevention from encroachment of ground water.

8.2.1 Drainage Systems

Highway drainage systems are made up of three basic forms of drainage works, namely:

- Surface water drainage
- Ground water drainage
- Transverse drainage

a. Surface Water Drainage

Surface water drainage consists of collection and control of rain precipitated onto the surface area of the highway formation and its supporting earthwork structures. These consist of the cuttings and embankments on which the formation is founded. Surface water drainage also consists of the interception, collection and diversion of surface water attempting to enter or overspill upon the formation and it's supporting earthwork structures.

b. Ground Water Drainage

Ground water primarily is in a static condition and does not create the erosion damage associated with surface water. It can however lie too close to the surface of the highway formation causing saturation and therefore weakening of the pavement layers. It can also become dynamic where natural surface conditions have been altered as in cuttings, resulting in the collapse of cuttings through seepage.

Ground water drainage systems / drains are designed to control water table levels and thereby protect the highway from encroachment of water from below.

c. Transverse Drainage

Rivers, streams and artificial drainage channels cross the alignment of highways. The safe conduct of these water courses through and below the highway structure is that part of the drainage system called transverse drainage. Operation involving the maintenance of such drainage structure is detailed below under ***Culvert and Bridges***.

8.2.2 Surface Water Drainage

Surface water is dynamic. It moves from the pavement surface, the shoulders and adjacent faces of cutting into drains which in turn conduct it into streams and rivers. In the processes of these movements water will pick up clays, silts and even sands as its velocity increases. Similarly it will release and deposit these materials as its velocity subsequently decreases. Thus, at higher levels, uncontrolled water movements will erode drains, shoulders, cuttings and even highway formations while at lower levels water will deposit silts resulting in choked drains and culverts with the risk of floods and washouts.

Surface water drainage is therefore not merely a question of designing the correct size of drain but of controlling velocity of flow and minimizing erosion and silting to manageable proportions.

The basic elements that make up a surface water drainage system are:

- Side drains
- Cut-off drains
- Outfall drains

There may also be the need to incorporate culverts as additional elements of transverse drainage within the outfall element

a. Side Drains

(i) Responsibility

Side drains are the primary collectors of surface water and have a limit of task for collection of surface water run-off of rain falling on the highway formation and the side slopes of cuttings within the right of way as defined by the width “w” in Figure 38 below.

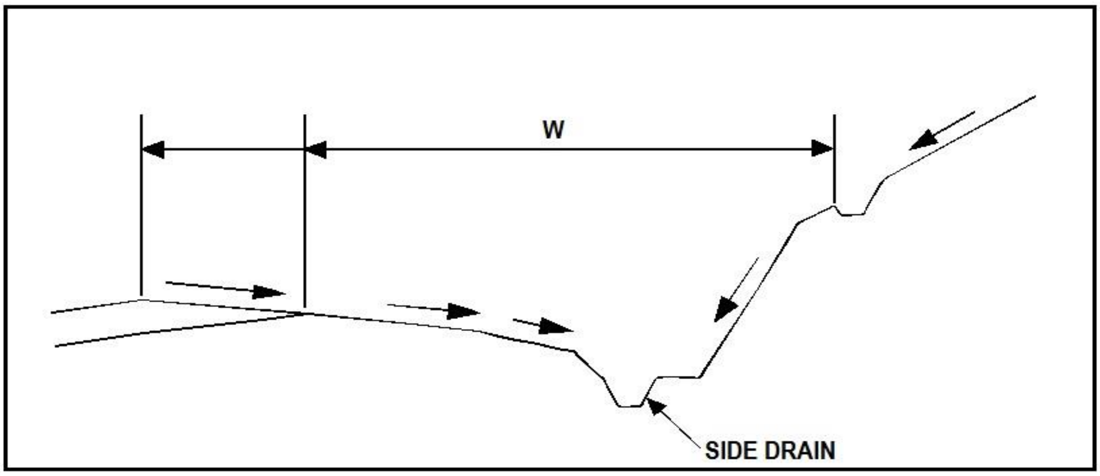


Figure 38: Surface Water Run-Off

Side drains have additional tasks for maintaining the water table in a depressed condition through the formation in order that the pavement layers shall not become saturated. This is illustrated in Figure 39 below.

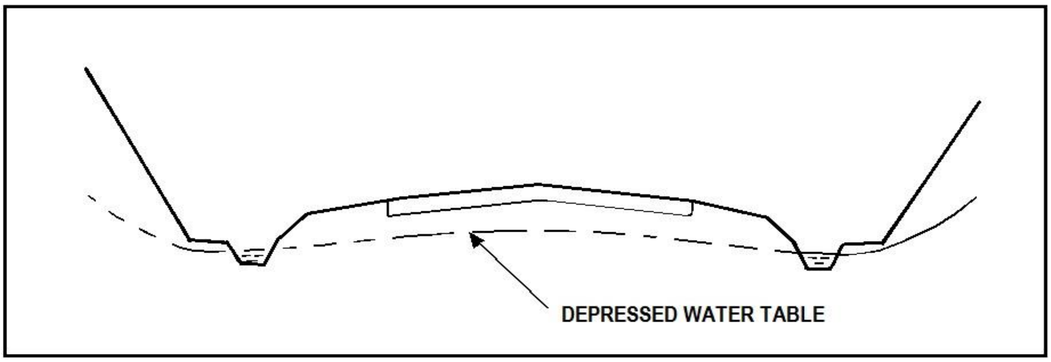


Figure 39: Desirable Level of Water Table

(ii) Dimensions of Side Drains

In order to be able to fulfil their responsibilities side drains must have a basic minimum cross-sectional area and a basic minimum depth.

The capacity of the side drain is dependent upon:

- Surface water run-off
- Size of drain

- Gradient of drain
- Distance between outfalls

Surface water run-off is normally calculated on the basis of rainfall intensity, duration and frequency data. This may be taken for this purpose as an approximate standard for Nigeria. The gradient of the drain will normally be fairly closely related to that of the highway and will vary from section to section. The distance between outfalls will be dependent upon the availability of water courses to receive outfalls.

Thus, the normal practice is to dimension a standard drain, define the limits between outfalls and specify a proportional increase in dimensions where the limit between outfalls is exceeded.

Figure 40 below illustrates the dimensions of a standard side drain cut with side slopes of 1:1 with a minimum base width of 60cmand a minimum depth of 60cm below the edge of the shoulder.

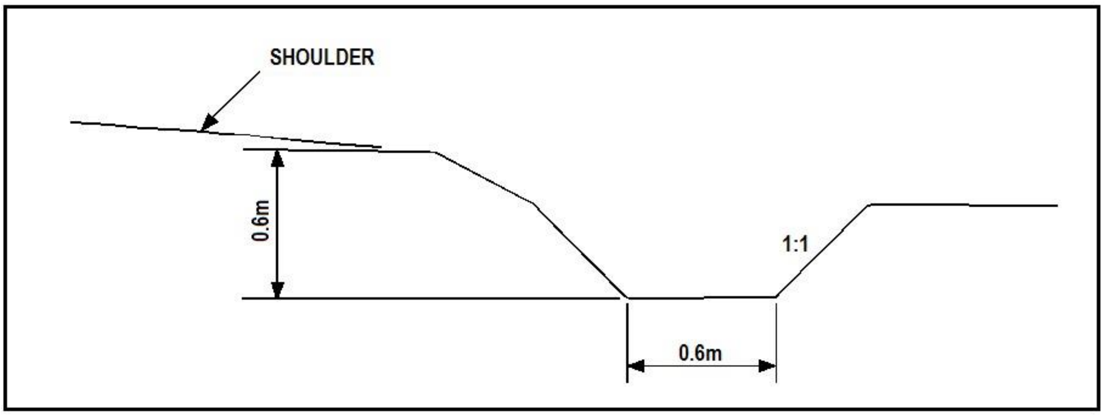


Figure 40: Side Drain Dimensions

Such a side drain will be capable of carrying peak rainfall run-off under the following gradient conditions and outfall spacing’s

Table 21: Side Drain Spacing

Gradient	Distance between outfalls
0.5%	100 – 200 metres
1.0%	100 – 200 metres

Where the distance between outfalls is greater than that specified in Table 21 above, the size or gradient of the drain should be increased. Although increases in gradient rapidly increase the carrying capacity, care should be taken not to exceed 2% if possible since the increase in velocity of flow will probably necessitate lining. (See ***Drain Lining***).

(iii) Location of Side Drains

It is normal practice to establish the side drain as close to the toe of the embankment or side slope of the formation as possible, in order to obtain maximum value possible from depression of the water table as shown in ***(ii)*** above. However, a berm or ledge of not more than 60cm (shown as "W1" in Figure 41 below) may be left to facilitate mechanized drain cleaning. In cutting an outer berm or ledge of not less than 60cm (shown as "W2" in Figure 41 below) should be left between the drain edge and the foot of the cutting. Where cutting faces are unstable or contain considerable ground water this berm should be the maximum available within the width of the cutting.

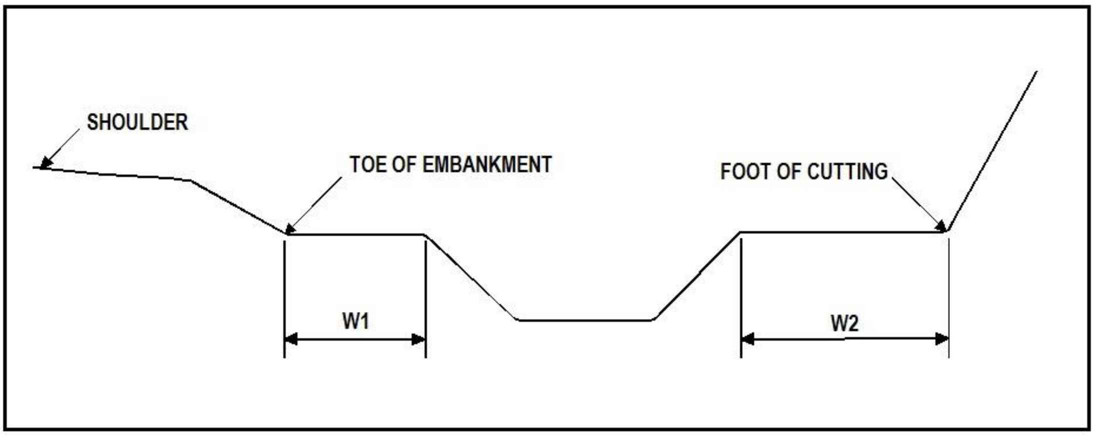


Figure 41: Side Drain Construction

(iv) Shape of Side Drains

All the illustrations shown in the Figures above are trapezoidal with 1:1 side slopes.

Side drains may, however, be cut as a continuation of the side slope of the embankment and even as “V” notches as shown below. These shapes have the advantages of easier cleaning by graders and reduce damage to vehicles leaving the embankment in the event of accidents. The main disadvantage of the shallow “V” shaped drains lies in the grader cleaning method which tends to strip grass growth from the drain sides. Generally, it is desirable to encourage grass growth on drain sides as a deterrent to erosion.

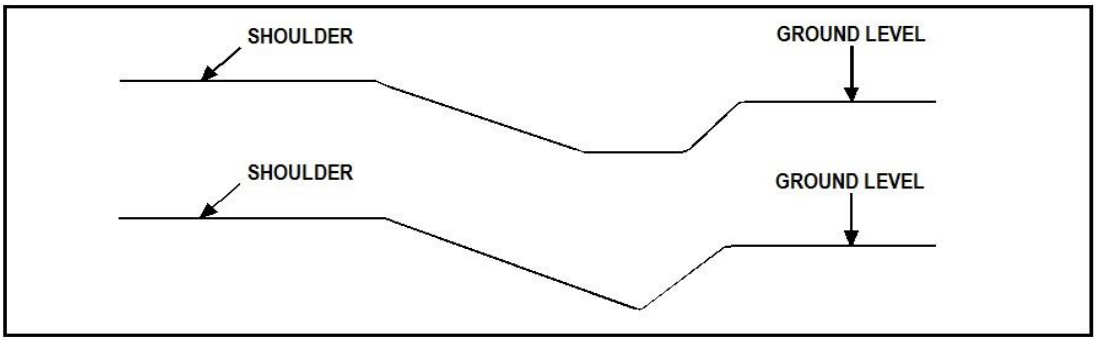


Figure 42: Shape of Side Drains

b. *Cut-Off Drains*

(i) Responsibility

Cut-off drains are responsible for intercepting surface water, which would otherwise enter the side drains and overload them. The intercepted run-off is conducted by cut-off drains to lower levels where it is discharged direct into outfall drains and water courses. An example of such a function is shown in the right hand side of Figure 43.

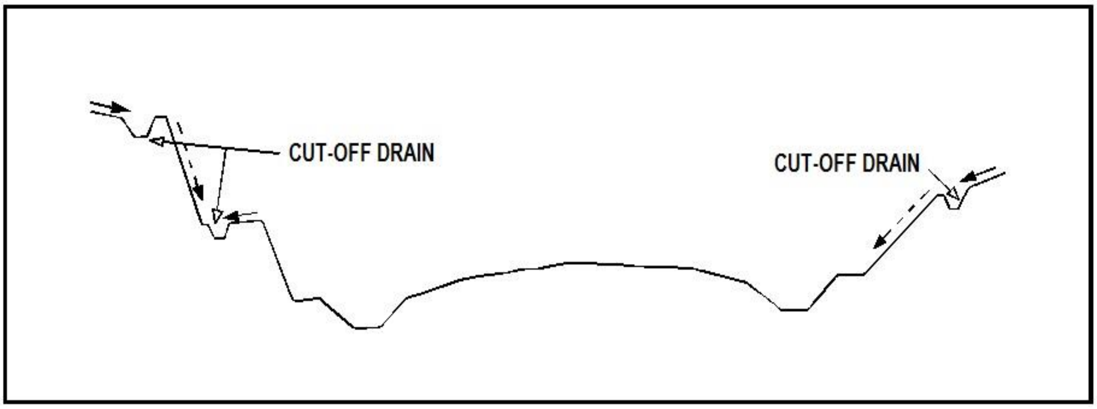


Figure 43: Cut-Off Drains

The cut-off drains illustrated on the left hand side of Figure 43, while fulfilling the same objective, also protect steep cutting slopes from overspill and terrace ponding, which could lead to erosion and subsidence.

(ii) Dimensions of Cut-off Drains

The dimensions of cut-off drains will depend upon the area of catchment that they serve. Generally 30cm half round precast concrete channels will prove to be adequate, except for long runs, which will need to be tabulated for enlargement at their outlets ends.

(iii) Location of Cut-off Drains

Cut-off drains should be located as close to the head of cutting slopes as is practical depending on the stability of the soil. In general, a distance of one metre back from the head should prove to be adequate. The area between the drain and the cutting head should be grassed or close turfed to aid stability.

Cut-off drains on cutting terraces should be placed as close to the back wall as possible with a 15cm wide strip of close turfing on either side of the drain.

(iv) Materials for Cut-off Drains

In order to fulfil their responsibilities, cut-off drains must be water-tight and free from erosion. They should therefore, by preference, be constructed of precast concrete channels or invert sections. To construct the open earth drains with prime and surface dressing is a cheaper form of construction and is frequently used where good quality gravel soils exist. The latter type of construction, however, requires more frequent inspection and maintenance of grass surround. The relative in-accessibility of cut-off drains makes it well worth while using the more permanent type of construction.

c. Outfall Drains

The responsibility of the Highway Maintenance Engineer, in respect to drainage, does not end with the construction of a “turn-out” or short spur outlet to a soak away hole.

Any outlet of side drains that does not work efficiently, or may be tampered with by adjacent land owners, destroys the drainage system. Outfall drains must be designed, built to design and maintained in working order. Nature looks after 90% of the problem but the remaining ten percent (10%) requires engineering ingenuity.

The majority of highways are traversed by natural water courses enabling side drains to be discharged directly into the streams and rivers. The length of side drain between such water courses may however be too great to enable standard sections to cope with the total accumulated run-off. Under these conditions the maintenance engineer must seek low ground on either side of the highway into which he can construct an outfall drain within the distance limits shown in the Table 22 above. Where such low ground is rare then the side drain must be enlarged to deal with the accumulated run-off over greater distance.

(i) Responsibility and Function

Outfalls drains are responsible for the collection of surface water from side drains and cut-off drains and direct water safely to natural water courses. In doing so the outfall drains may extend beyond the Right of Way and cross private lands. If this situation becomes a necessity then agreement must be reached with private lands owners and users to permit personnel the right of entry to the lands for the purpose of cleaning and repair.

(ii) Dimensions

The cross sectional area of outfall drains will be that of the side drain or cut-off drain at entry and progressively enlarged to accommodate surface water run-off of the catchment through which it passes. On the relatively rare occasions when outfalls are required to exclude additional intake, e.g. when passing through rice fields, the dimensions may be maintained continuously in equal size and the banks raised as bunds to exclude additional water entry.

(iii) Type of Outfall Drain

Generally outfall drains are constructed as earth drains of trapezoidal shape and grass or other vegetation, encouraging to grow on their sides and banks.

Where outfall drains received surface water from cut-off drains they may be subjected to high velocity flow and sections of the drain may have to be lined with concrete or rip-rap. (See ***Drain Lining***).

(iv) Outfalls

The discharge end of the outfall will usually have either an increase in gradient or a sudden fall to enable water to reach the lower levels in rivers and streams. Invariably, either condition will result in scouring, which will undermine the drain. The defect in its earliest stages is illustrated in Figure 44 below.

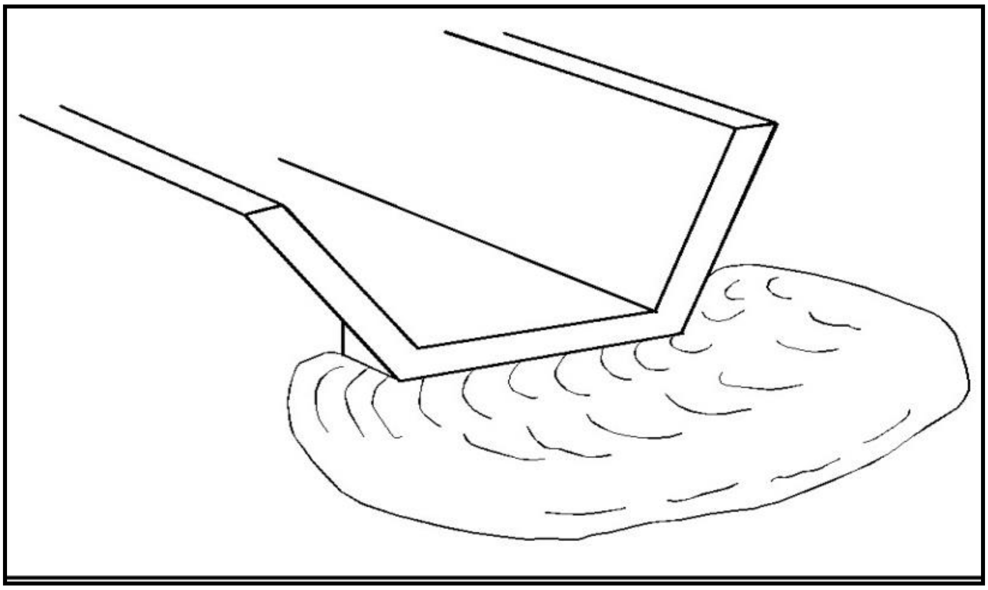


Figure 44: Scouring at Outfall

The river bed, its bank and the drain must be protected from erosion by construction of an apron by placing boulders into the scour area or by construction of rip-rap on the spillway as illustrated in the Figure 45 below.

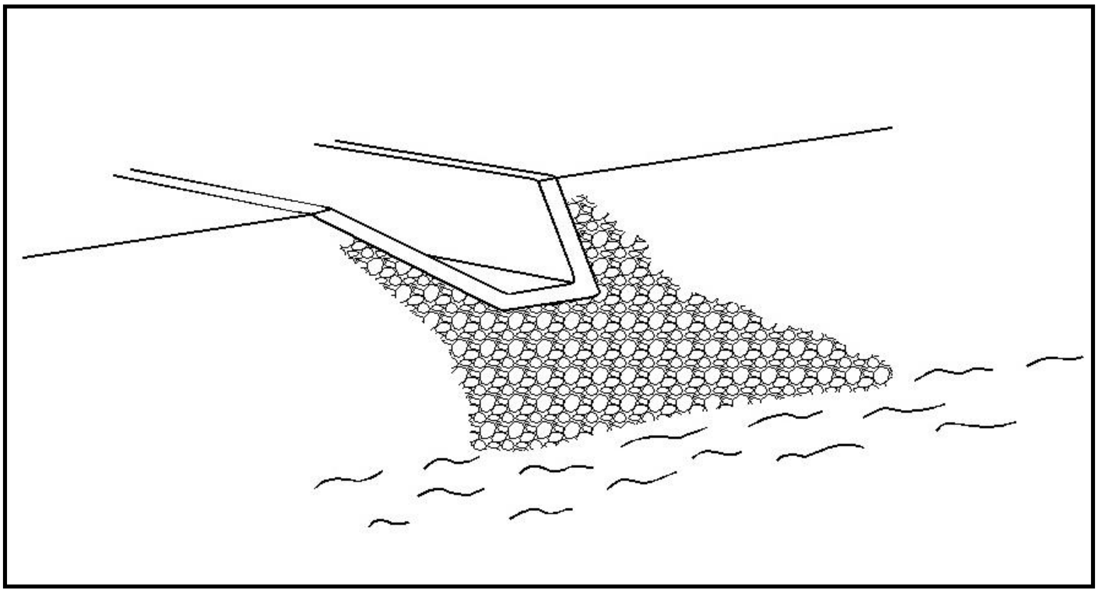


Figure 45: Protection of Outfall

d. Cascade Drains

In the sections above, dealing with the three basic elements of surface water drainage, it has been stressed that velocities should be kept low. In many instances side drains, obliged to follow highway gradients cannot avoid high velocity sections. While these sections can be lined to prevent localized erosion, the terminal velocity when the drain finally arrives at lower levels will necessitate unnecessary lengthening of the lined section and considerable enlarging of the cross-sectional area to accommodate the increased depth resulting from change of velocity. The same conditions will occur more frequently in both cut-off drains and outfall drains.

It is therefore economically desirable to reduce flow velocities as early as possible. This will reduce the expensive outfall erosion control elements to manageable proportions. The primary tool for this purpose is the cascade drain.

Figure 46 illustrates the principles of cascade drainage with precast half round channels. The drain can similarly be constructed with half elliptical invert sections or precast slabs. The individual drain sections are laid close to the horizontal (0.5 to 1.0% slope) with concrete pointed back wall joints. The height of the back walls are being determined by the drain gradient.

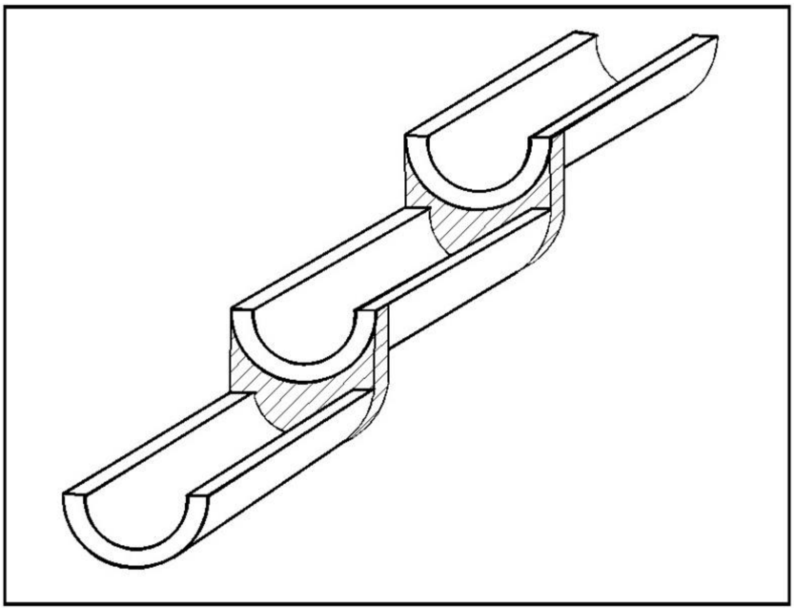


Figure 46: Cascade Drainage

It is recommended that all drains with gradients in excess of 5.0% be closely monitored during rain seasons for cascade sections in zones of high-velocity and above stilling zones of extreme depth.

8.2.3 Ground Water Drainage

In ***Surface Water Drainage (8.2.2)*** a secondary task of side drains was described as depressing the water table within the formation and this was illustrated in Figure 39.

Sometimes within cuttings, particularly those constructed in broken or decomposed rock, ground water tables may be so high or seepage from cutting faces so severe, that it fills the side drains.

There may not be sufficient width available within the cutting to enable deeper drains to be installed and under these conditions; the only satisfactory solution is the construction of sub soil drains.

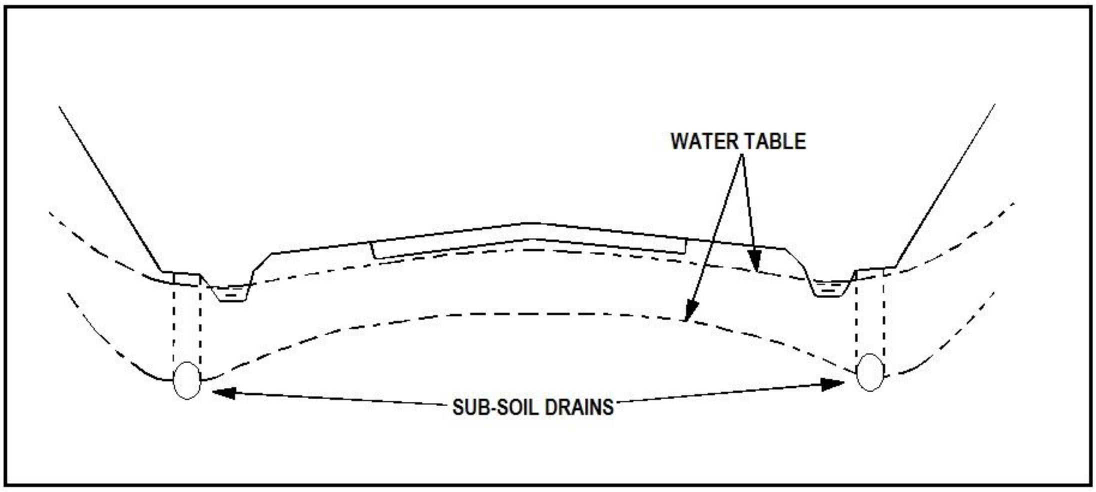


Figure 47: Lowering of Water Table with Construction of Sub-Soil Drains

a. Sub Soil Drains

(i) Functions of Sub Soil Drains

Subsoil drains perform two main functions, namely:

- Depressing high water tables
- Intercepting seepage water
- Depressing high water tables

The method of performing this function in cuttings is clearly shown in Figure 47, where the drain may be installed in the berm between side drain and the foot of the cutting or directly underneath the drain which may then be lined.

Sub soil drains are also recommended by some authorities for use in low-lying areas with high water tables. This, however, is not a very practical solution since successful sub soil drains depend upon clear free flowing outlets, which are rarely obtainable under these conditions.

- *Intercepting Seepage Water*

Figure 48 below, illustrates an example of a highway constructed on a side-cut where high water table conditions overlying an impervious strata may cause failures.

The construction of an intercepting sub soil drain will effectively seal off the formation.

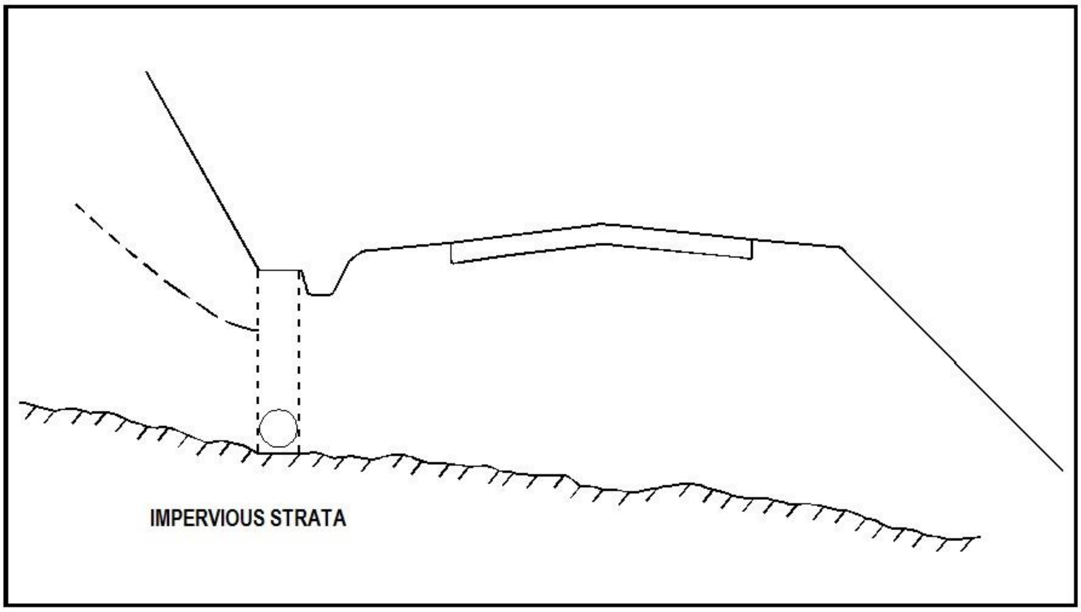


Figure 48: Sub-Soil Drain Overlying Impervious Strata

(ii) Dimensions of Sub Soil Drains

The basic principles of sub-soil drains are illustrated in Figure 49. The depth to which they are constructed will depend upon its purpose and site conditions. Where it is acting as an interceptor of ground water seepage it will have to be carried down to the impervious base layer. Elsewhere acting as a depressor of high water tables a depth of 0.65 to 1.0metres will normally suffice for two lane highway formations in cuttings.

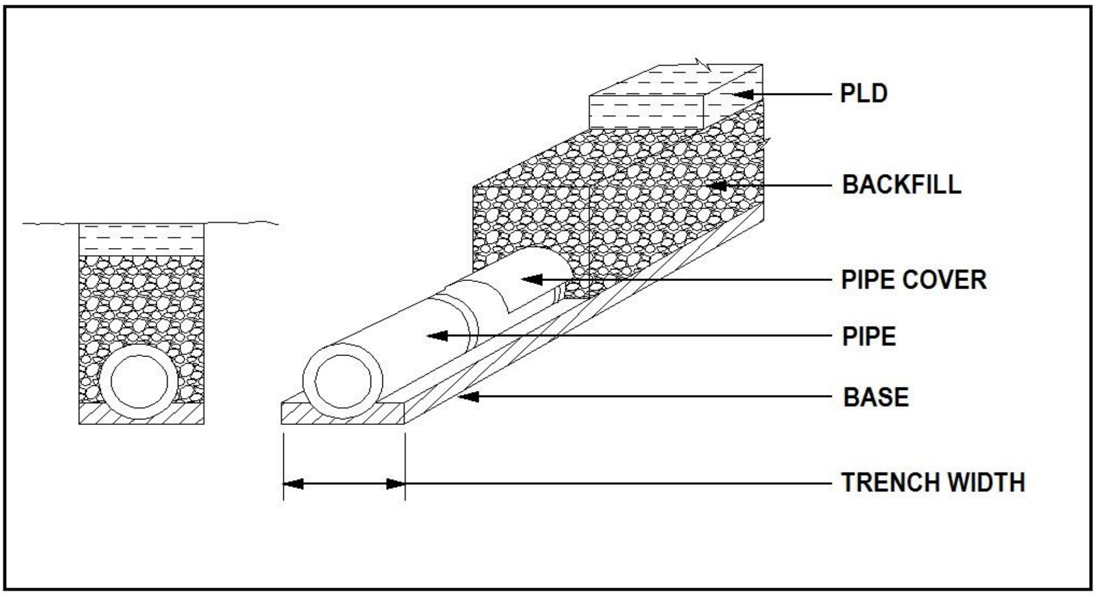


Figure 49: Basic Principles of a Sub-Soil Drain

- *Trench Width*

The sub soil drain is established in a vertical sided trench. The width will not be less than twice the diameter of the sub soil pipe. For economy of construction and stability of the drain, the width should be kept to the minimum practical for installation.

- *Base*

Where the trench is carried down to impervious strata, the base of the trench may be cleaned and compacted with hand tampers to a uniform slope and the pipe may be laid directly upon it. Elsewhere in permeable soils a 5cm thick of lean mix concrete should be laid and grooved to enable the pipe to be firmly seated to at least its wall thickness.

- *Sub Soil Pipe*

The ideal pipe for installation in sub soil drains is an unglazed earthenware pipe with either 10cm or 15cm internal diameter. Perforated concrete or asbestos/cement pipes may be used as an alternative.

- *Pipe Cover*

The top 210° of the pipe should be covered with a continuous strip of impervious material. Tar paper is normally used for this purpose. It is possible to obtain a good permanent cover with strips cut from bitumen drums and lapped with a 10cm overlay.

- *Backfill*

The trench is backfilled with a suitable filter media. Well graded crusher-run aggregate with less than 5% passing a No.200 (075 micron) sieve or 13mm single size aggregate is ideal for this purpose. Clean washed coarse concrete sand would also be suitable. The main essential of this material is that it shall drain efficiently and at the same time excludes fine silts from the neighbouring soil from entering the pipe.

- *Top Plug*

The top 15cm of the trench will be backfilled with an impervious plug, such as clay to exclude all surface water from the subsoil drain. Where available space is restricted, as in narrow cuttings, plugs may consist of a lean mix concrete carrying the lined surface water side drain.

(iii) Construction Methods

- *Excavation*

The trench may be excavated by hand or with a backhoe. The sides should be precisely vertical. The width should be restricted to the limits set out in (ii) above subject to practical working space. The floor of the trench must be cleaned to an even slope and compacted with hand rammers.

- *Installation*

Where necessary a lean mix concrete base should be installed to receive the pipe. Where the slope of the trench exceeds a gradient of 1.0% it is desirable to insert such a base even in impermeable soils.

The sub soil pipe must be well bedded into the base with open joints. A gap of up to 1 or 2mm may be left between pipe sections. The top of the pipe must be covered by a continuous strip of impervious material, which should be cut to a width of 1.85 times the outside diameter of the pipe. Where short strips only are available a 10cm overlap from the high side should be allowed on each strip.

- *Backfilling*

The backfill material should be placed to the level of the pipe top and lightly tampered on either side of the pipe. Successive layers of 15cm thickness should then be placed and firmly tampered with a hand rammer up to 15cm from the top of the excavation.

The final 15cm should be finally installed over the surface of the reinstated excavation and extend 30cm to either side.

(iv) Life of Sub Soil Drains

A well constructed sub soil drain should have an almost infinite life. It is not subjected to wear due to exposure to either traffic or weather. In practice, it will fail only by virtue of silting or chocking by entry of clays and silts. If this happens it is the fault of the filter media, which should be so graded as to exclude movement of fines through the media and into the pipes.

Newly constructed sub soil pipes will usually discharge water containing a little silt and occasionally a little sand during the first few days of their life. This should not cause alarm as it is merely the filter media and adjacent soil adjusting the balance to meet the requirements of stable flow.

If the discharge continuous to be unclean, in all likelihood the drain will start to silt-up and the flow will dwindle. The survival life under these conditions will probably be limited to one or two wet seasons.

It is therefore necessary that the outfalls of all sub soil drains be regularly inspected particularly in wet seasons when water tables are high to ensure that flow is reasonably strong and that the discharge is clean water. If these conditions do not exist the drain will have to be excavated, cleaned and reinstated with well compacted and well graded filter media.

b. Sand Blankets

(i) Functions of Sand Blankets

Sand blankets fulfil two main functions, namely:

- Rapid drainage from previous pavements and shoulders
- Prevention of capillary rise of ground water into the base

(ii) Use of Sand Blankets

Sand Blankets are most commonly and usefully employed on low embankments in swampy areas, in areas with high water tables and in flat country sides with difficult drainage outlet problems.

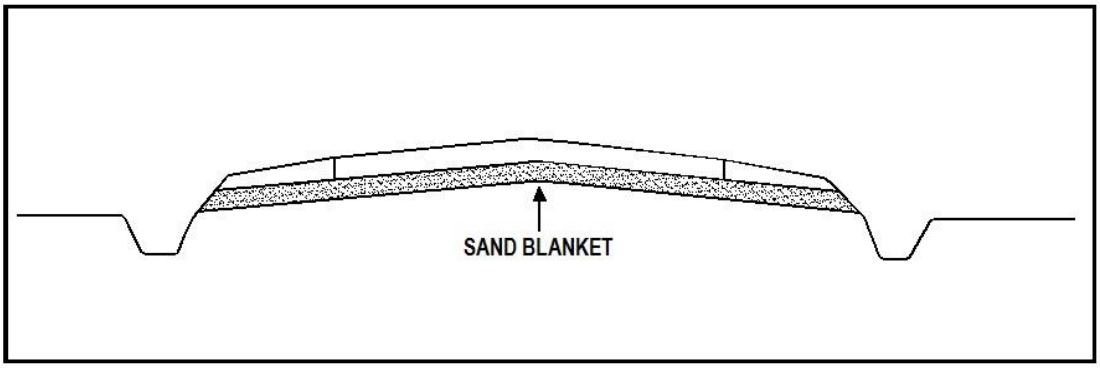


Figure 50: Typical New Construction Sand Blanket

Figure 50 illustrates a typical sand blanket installation. It is normal in new construction for the sand blanket to extend to the full width of the formation, providing a clear drainage path to side slope of the embankment. Where it is necessary to install a sand blanket on existing highways to provide drainage to localized defective areas, such as valley curves with ponded drainage outlets, it may not be practical to extend the blanket through the existing shoulders. Under these conditions the sand blanket should be constructed to the width of the pavement base and provided with light sub-soil drain outlet every 20 metres on either side as shown in Figure 51.

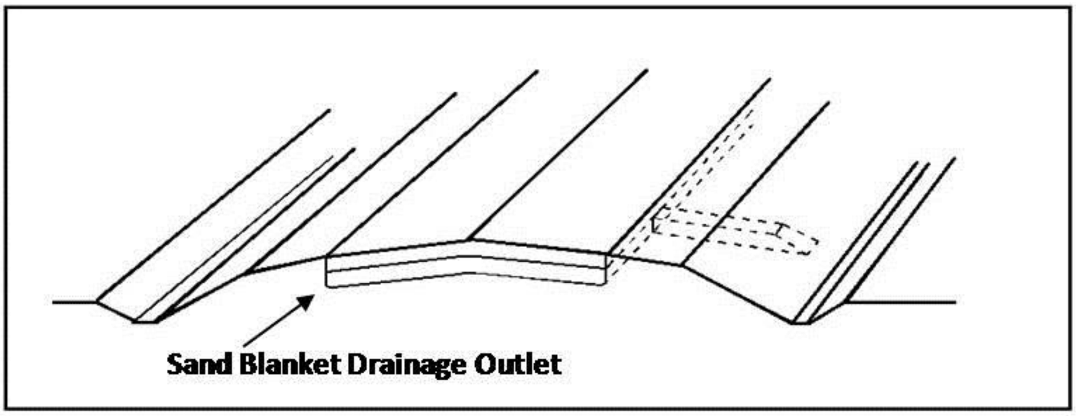


Figure 51: Sand Blanket in Existing Pavement

(iii) Installation of Sand Blankets

- *Excavation*

Strip and load out to stockpile the old surfacing and base material to half the width of pavement and to such a length as may be satisfactorily managed with maintenance of traffic flow.

The longer practical length should be worked to enable the operation to be mechanically assisted by a front-end loader and grader. The material of the old base will probably be saturated and unsuitable for use.. It may however be suitable for fill and shoulders will be required to be raised at least to the height equivalent to the sand blanket thickness. Hand trim or grade the base of the excavation (sub grade) to a camber of not less than 2.5%and compact with a 6-8 ton tandem steel wheel roller or hand operated roller in restricted size works.

- *Outlet Drains*

Cut by hand 25cm wide channels through thin shoulders every 20 metres on both sides to the depth of the excavation and to a fall of 2.5%. Compact the base with a hand rammer. Some authorities recommend installation of sub soil pipes in these outlet drains. If this is done as described above the entry to the first section must be closed with fine mesh wire gauge to prevent loss of sand from the blanket. Pipes are not strictly necessary since the volume of flow is very small except during construction of dry stone bases by the wet process.

- *Installation of Blanket*

Clean river sand should be uniformly spread to a minimum depth of 15cm in any one course simultaneously into the excavated area and the outlet drains. The sand should be thoroughly watered, graded or trimmed to the final highway design camber and compacted with a hand operated vibrating roller or vibrating plate compactor. Outlet drains will be compacted by hand rammers and the remainder of the excavated trench backfilled with shoulder material.

- *Reinstatement*

Shoulders should first be reinstated, raised and if necessary widened to their final height and slope.

The base is then reconstructed to the half width pavement and provided with a temporary wearing course or surfacing.

Traffic may now be diverted to the newly completed half pavement and the operation repeated on the second half width.

- *Completion*

When reinstatement of both sides of the pavement is complete, the final permanent wearing course may be installed, including feathering out any temporary ramps at beginning and end of the section being worked.

Finally, shoulders may be spot turfed, dibbled or seeded with close turf strips being laid not less than 70cm wide over each drain outlet to avoid early damaged by chocking or traffic.

(iv) Strength of Sand Blankets

A sand blanket is essentially a sub base, which in its compacted and contained condition, will develop a CBR value of between 15% and 30%. The installation of a sand blanket will therefore assist in the solution of drainage problems and also provide added strength and life to a previously weak section of the highway. Location, depth and CBR value of the blanket should therefore be recorded on Highway Register Sheets.

(v) Maintenance Inspection

An efficient sand blanket will show little if any visible flow at its outlets. There is therefore no necessity for the regular and careful inspection of discharge from sand blanket outlet drains as described for sub soil drains. Where unglazed earthen ware pipes have been installed in outlet drains, it is however, necessary to maintain a careful watch on pavement edges, since loss of sand due to defective entrance sealing will result in pavement edge cracking or even subsidence.

8.2.4 Transverse Drainage

Transverse drainage is the control of water passing across the highway front areas of precipitation to area of reception, lakes and seas. Generally, these crossings are in water courses accommodated by bridges and culverts. Maintenance operations associated with these are dealt with under ***"Culverts"*** and ***"Bridges"*** below.

However, there may be need to install, replace, or repair transverse drainage in locations other than established water courses for the purpose of:

- Side drain outlets
- Balancing water tables

a. Side Drain Outlets

(i) Side Drain Outlet Culverts

In ***Section 8.2.2*** above, side drain outlets were defined as being required not less frequently than every 300 metres unless the standard dimensions were increased.

Thus, in cross fall terrain, discharge from an uphill side drain must be provided with an outlet culvert to carry away surface water to the downhill side of the highway. Where no natural water courses exist, additional transverse drainage culverts must be provided.

Enlarging the size and capacity of the uphill side drain will reduce the frequency with which these transverse drainage outlets are needed. However, this will also result in a loss of available head and an increase in the size of the culverts. There is therefore no advantage and no economic benefit to be derived from reducing the number of culverts to be installed under these conditions. Figure 52 illustrates a transverse drainage culvert in cross fall terrain.

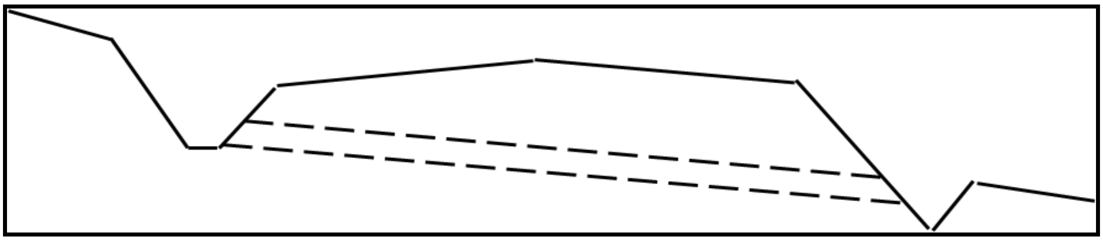


Figure 52: Transverse Drainage Culvert

(ii) Soak Away Pits

A frequently encountered outlet design utilizes a blind outlet and occasionally a soak-away pit to accommodate the discharge from side drains or the uphill side of a highway. The size of such soak-away pits would have to be extremely large to accommodate the discharge from a ten minute peak storm. In practice, with relatively high water tables during rain seasons these soak-away pits never work. Highways with this type of drainage design will almost certainly show drain silting on the upstream side of the side drain and probable erosion of side drains on the downstream side.

The presence of blind outlets and soak-away pits should immediately be noted as maintenance points. Corrective action will almost certainly be required in the near future and may entail:

- Enlarging sections of drain
- Drain lining
- Installing

b. Balancing Water Tables

Highway formations or embankments present attractive, readymade dams and dykes to local authority irrigation projects.

An example of such of a highway embankment is shown in Figure 53 with the installation of a control gate to regulate levels during irrigation and drainage seasons. This will create a hydraulic gradient through the embankment with differential settlement during successive wet and dry seasons. Any proposals for such use of highway embankments should be discouraged and adequate culverts without controls should be installed to balance water levels on either side through the year.

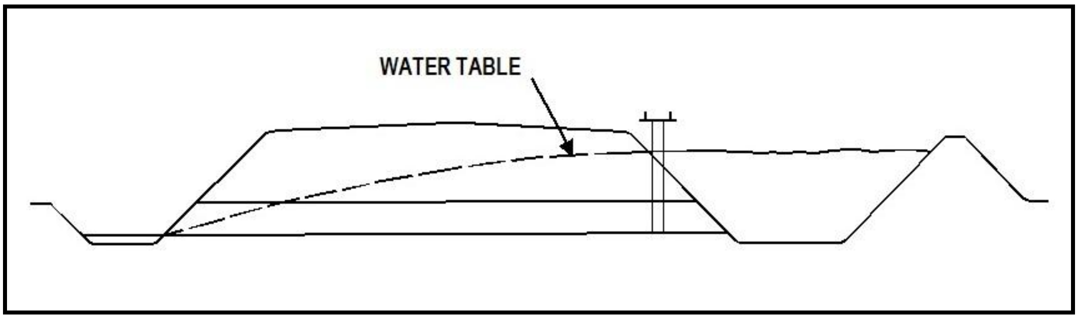


Figure 53: Side Drain in Irrigation Zone; Incorrect Application

Where existing canals have caused the subsidence of the pavement edge and shoulder, the situation can be rectified by movement of control gates onto a parallel minor embankment for the affected length of highway. This results in minimum loss of cultivated land and enables the highway culverts to remain permanently open as balancing culverts. The construction is illustrated in Figure 53.

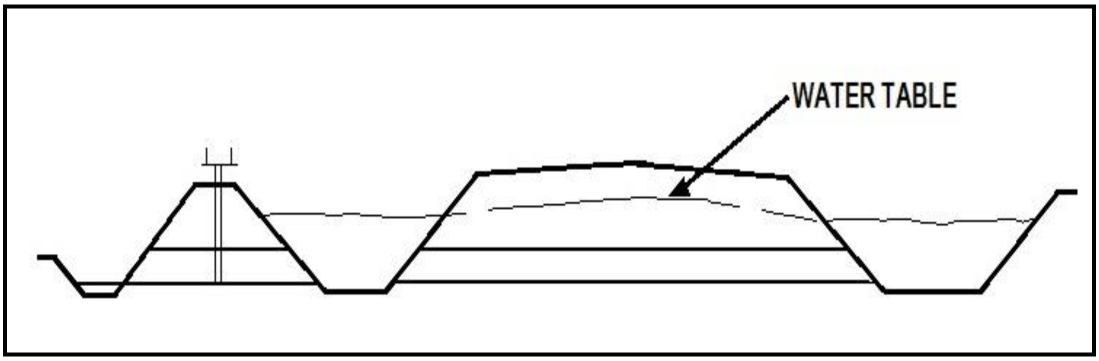


Figure 54: Side Drain in Irrigation Zone: Correct Application

8.2.5 Mountain Road Maintenance

Mountain roads are essentially side cuttings on steep gradients in areas of usually high intensity rainfall. As such, they are subject to damage by washouts caused by overspill of surface water over the outer (embankment) slope and by erosion due to high velocity surface water run-off. The build-up of defects to a condition of total failure is very fast under these conditions and there is little warning to maintenance personnel. It is therefore essential that mountain road drainage system be well designed and continuously inspected for the immediate repair of each and every minor defect.

a. Collection of Surface Water

The fundamental principle for the collection of rain precipitated on the pavement area is to direct it as quickly as possible into the inner (cutting) side drain of the roadway. This principle had led to the practice of super elevating the entire mountain section towards the inner face of the side cutting. Although this is very safe from a drainage point of view, it leads to great discomfort to the user who is faced with adverse camber on re-entrant (gully) curves and probable loss of control of the vehicle during rain storms. Mountain sections should wherever possible be designed to the same principles as any other highways. Figure 55 illustrates a section of mountain road containing the three basic drainage situations:

- Spur curve
- Re-entrant curve
- Transition or short tangent

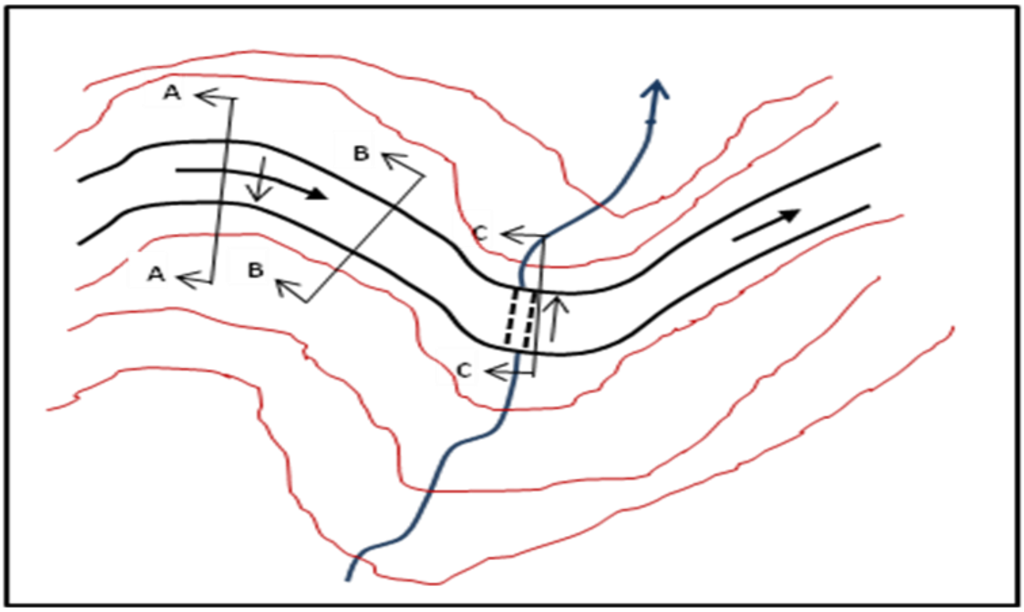


Figure 55: Diagram of a Mountain Pass Showing Basic Drainage

The arrows indicate the downwards slopes of super elevation and gradients. Since the gradient is likely to be in the order of 10% super elevation, it is designed to the maximum comfort of vehicles, which is usually about 5%.

(i) Spur Curves

Spur curves, as illustrated in Figure 56, present the least problem for drainage. Super elevation carries surface water to the inside drains and provides a feeling of security to the motorist. The side drain should be fully lined and placed hard up against the cutting face to avoid the risk of seepage water getting behind the drain and undermining the formation.

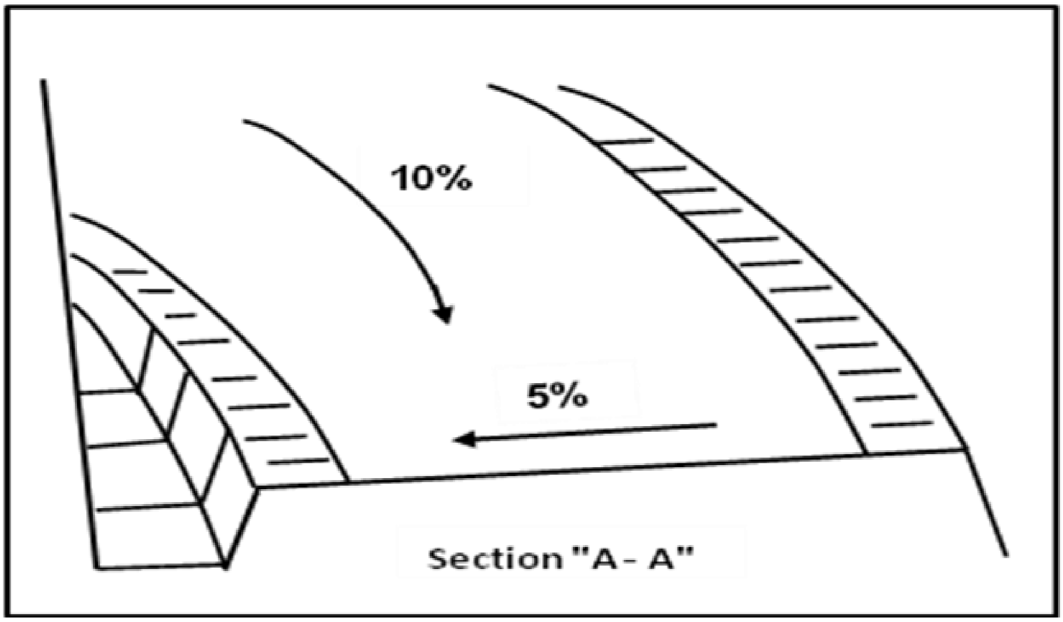


Figure 56: Spur Curves in Mountain Pass

(ii) Re-entrant Curves

On re-entrant curves, as illustrated in Figure 57, the super elevation carries surface water towards the outer (embankment) side of the formation. To prevent overspill it is necessary to install a lined gutter and bund or back wall. The size of this gutter will depend upon the length of the curve but usually a square gutter of 45cm width and depth will be adequate on the relatively short sharp curves encountered on mountain road sections.

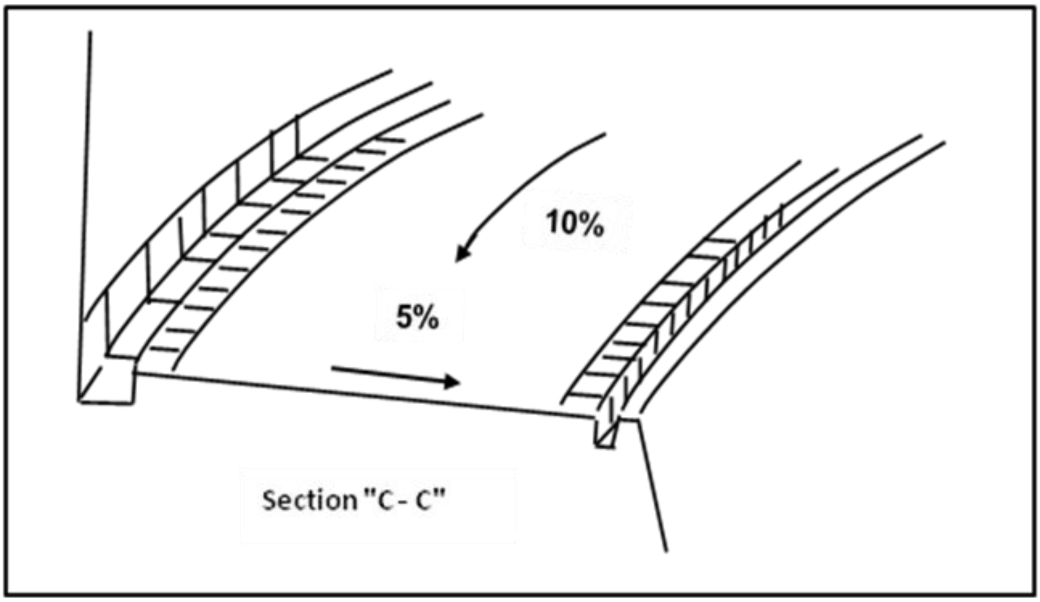


Figure 57: Re-Entrant Curves in Mountain Pass

(iii) Transition and Tangent Sections

At transitions from spur curves to re-entrant curves super elevation is zero as shown in cross section “B-B” in Figure 55and illustrated in Figure 58.

Even on longer tangent sections where a 2.5% camber could be installed the 10% longitudinal gradient takes over and surface water will stream down the line of the roadway. It is necessary to intercept this flow and simultaneously collect gutter discharge from the lower half of re-entrant curves and return the lot to the inner side drain.

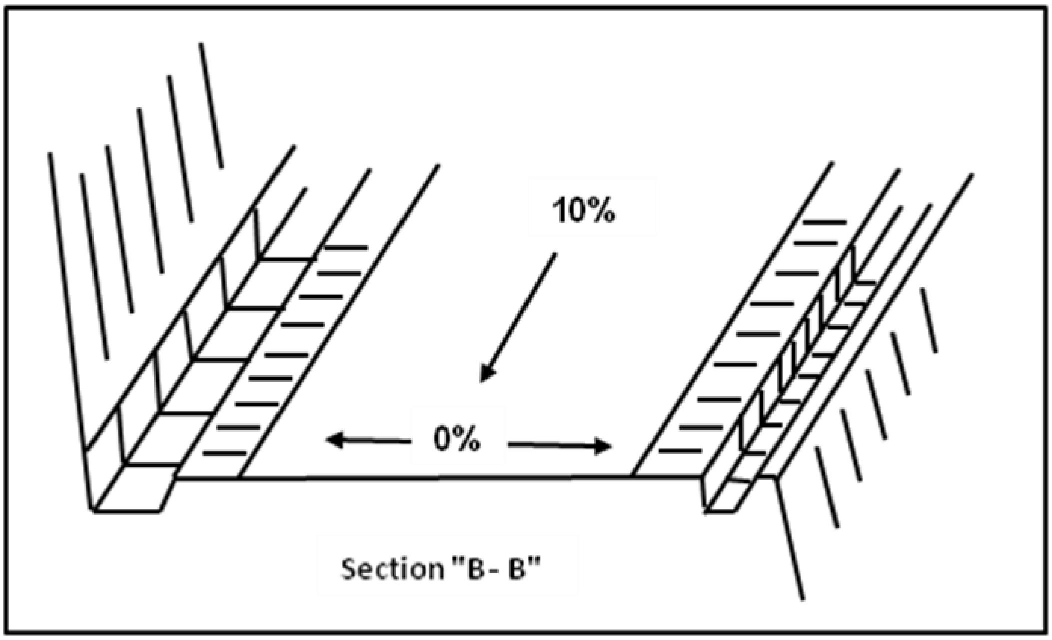


Figure 58: Transition Section in Mountain Pass

(iv) Lateral Interception Drains

Lateral interception drains consist basically of shallow listed open channels topped by cattle grid type of covers as illustrated in Figure 59. Depth and gradient need only be sufficient to receive discharge from the outside gutters and discharge it and intercept the run-off into the inner side drains. Lateral interception drains must be placed at every transition of super elevation and additionally on tangents where required.

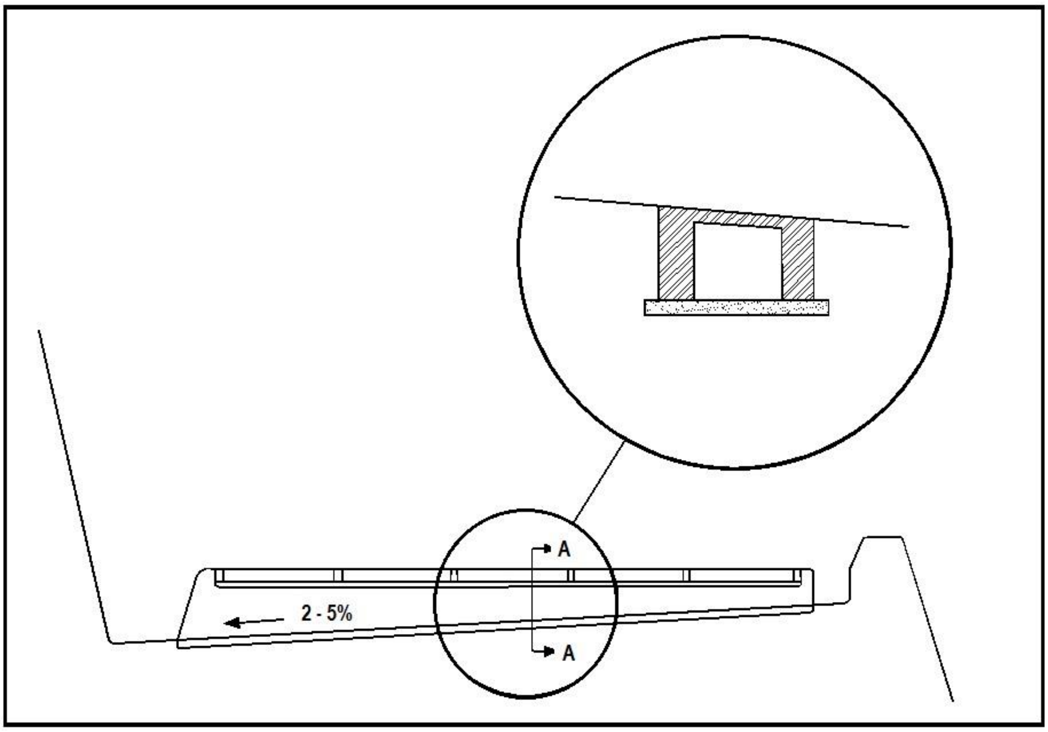


Figure 59: Lateral Interception Drain

b. Control of Velocity

Having achieved the primary objective of preventing surface water overspill, it is now necessary to control erosion by controlling the velocity of discharge flow in side drains, culvert entries, culvert outlets and outfall drains.

(i) Side Drain Velocity

The average gradient of side drains will be that of the mountain road, probably up to 10% in sections. Such gradients must obviously demand fully lined drains and velocity checks.

This can be achieved with cascade drains, check weirs and rough rubble lining. Very steep gradient sections can be supplied with vertical drops into concrete lined catch-pits.

(ii) Culvert Entry

Generally, culverts will be situated in gullies on re-entrant curves and will have to accommodate discharge from drains as well as the streams flowing in the gullies.

Both discharges are likely to be of fairly high velocity. Stream flow should first be slowed down by a vertical drop into semicircular stilling basin leading into catch pit which will receive side drain discharge. Dimensions will depend upon the volume flow but should not be less than 1 metre square for the catch pit and 1 metre radius for the stilling basin. The flow should be approximately 45cm below the culvert entry level.

Figure 60 illustrates this.

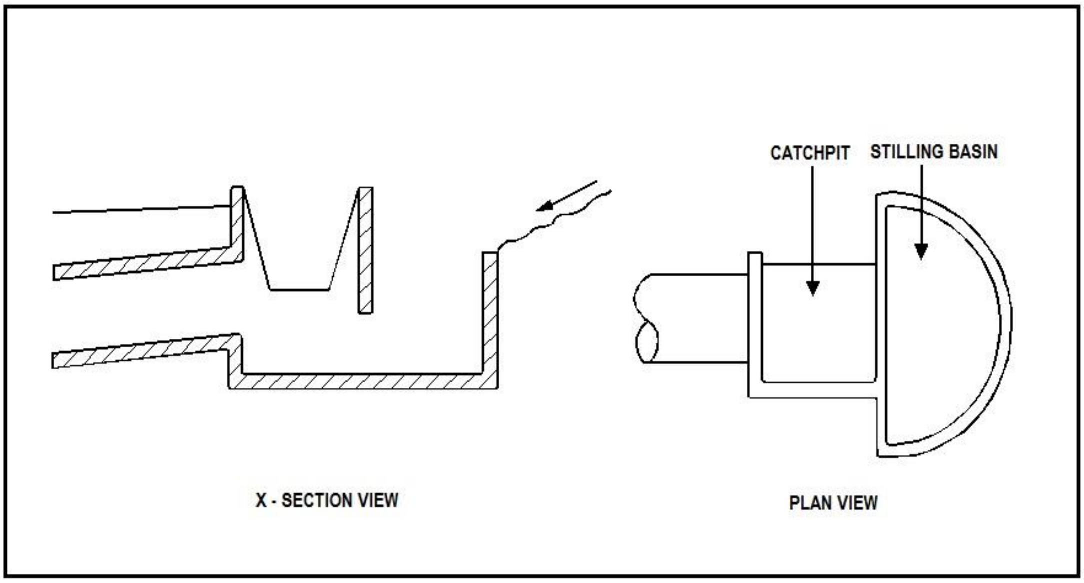


Figure 60: Velocity Control

(iii) Culverts Outlets

Culverts will normally discharge into stream beds but from a higher level than natural. In order to ensure that no erosion occurs at the culvert outlet, an outlet apron and cascade discharge drain or a rip-rap trough should be provided. It may also be useful to cast small rocks or boulders into the surface of the apron to break up the discharge stream.

(iv) Outfall Drains

Where no rocky river exist to carry away the discharge from culverts, genuine outfall drains in rip-rap or cascade invert sections will have to be constructed down to natural ground level with gentle slopes.

Final discharge onto open land may be permitted if flow velocities are kept to a minimum and water is spread over as large an area as possible. The outfall drain should terminate in a standard catch pit overflowing onto a semi-circular apron with 10cm concrete cubes set into its perimeter. Loose rubble should be rolled into the ground for a further 60-70cm surrounding the apron, as shown in Figure 61.

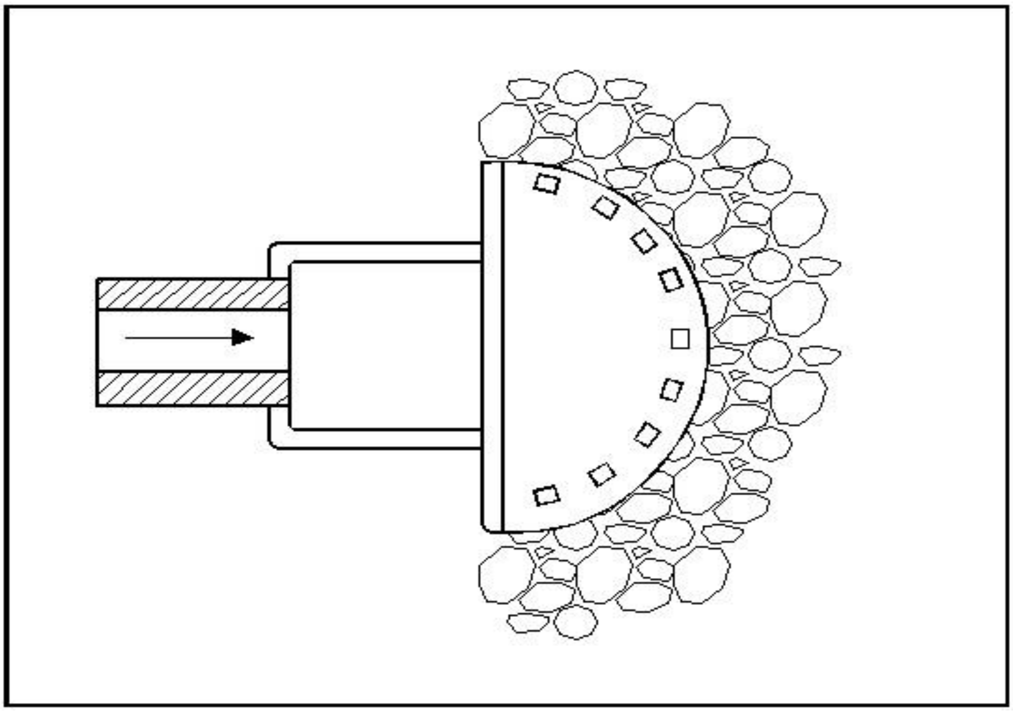


Figure 61: Outfall Drain

8.2.6 Side Drain Lining

a. *Need for Drain Lining*

(i) Visible Drainage

In general, the identification of the need to line drains in maintenance operations will result from routine field inspections.

Erosion or scour of drain sections deepening of drains and collapse of side walls will be evidence of excessive velocity. These sections clearly require lining. The exact definition of the extent and size of the lining is not always clearly defined. The very act of lining a drain will result in less resistance to flow, an increase in velocity and an extension of the length requiring protection from erosion.

(ii) Inferred Damage

A length of drain requiring repeated de-silting suggests that erosion is occurring upstream. This may be due to washout of surface soil from cutting shoulders or even gravel surfaced pavements. However, it is equally likely, that it is due to the slow and steady erosion of drain walls and bases by flow close to the permissible velocity. Recovered silting should always be examined to determine the source of material and defect in the drainage system that permits the erosion to occur.

b. *Design Principles*

From the foregoing it is obviously desirable that the maintenance engineer should have an understanding of the basic principles of drainage channels design in order to solve the relatively simple problems occurring in the day to day maintenance, repair and improvement of side drains. The following presentation has been simplified for the use of the maintenance engineers for side drain design and is therefore not applicable to major drainage problems or the study of large catchment areas.

(iii) Surface Water Run-off

The side drain accommodates the surface water run-off from a very small catchment area. It is therefore reasonable to use the rational formula of:

$Q = C.I.A.$

Where:

Q = Run-off

C = A coefficient depending on terrain

I = Intensity of rainfall

A = Area of catchment

The limit of the area for which the side drain is responsible was shown in Figure 38.

Since the majority of highways under maintenance are two lane highways of reasonably constant formation width, it is possible to establish a representative area per unit length of highway. Although values of the coefficient (C) and intensity (I) will vary from one part of Nigeria to another, the areas being dealt with are sufficiently small and materials of surface and cover reasonably uniform to enable a fair average to be assumed. Under these conditions, which must assume all necessary cut-off drains have been established and are being maintained, the rate of collection of accumulated flow of peak runoff in each side drain will be:

- *Tangent Section (cambered both sides)*

Accumulated flow (in each side drain) = 0.08m^3/sec/100 metres

- *Curve Sections (super elevated to one side)*

Accumulated flow (low side) = 0.11m^3/sec/100metres

Accumulated flow (high side) = 0.05 m^3/sec/100 metres

(iv) Flow in Side Drain

It is in the interest of the maintenance engineer to confine flow in side drains to low velocity and it will under these conditions be a uniform or calm flow. The principles of the manning equation will therefore apply:

$Q = M.A.R^{2/3}.S^{1/2}$

Where:

Q : Quantity in m^3/sec.

M : Manning coefficient

A : Area of cross section of flow in m^2

R : Hydraulic radius = A/WP

WP : Wetted perimeter of flow in "m"

S : Slope or gradient of the drain

And

V : Velocity = Q/A

D : Depth of flow

Provided that a standard cross-section may be established as recommended above and provided that standard maintenance practice preserves those drains in permanently good conditions then the manning equation can be greatly simplified.

The manning coefficient (M) has been established by experiment and shows a wide range of values of different qualities and conditions of channels. Taking an average existing sided drain with grassed banks and the same drain with rough concrete or mortared the rip-rap lining average values of the manning coefficient are:

- Unlined drain M = 25
- Lined drain M = 55

Under these limiting conditions, it is now possible to present the manning equation by a simple graph with variable of "Q", "V", "S" and "d" as shown in Figure 109.

The chart relates to a flow in the standard trapezoidal drain of base width 0.6 metres with side slopes between 1:1 and 2:1 having a depth of not less than 0.60 metres below shoulder level and designed to carry water to a depth of up to 30cm under normal conditions.

c. *Permissible Velocities*

The table below lists the maximum permissible velocities of flow in unlined side drains where the velocity exceeds that specified erosion will occur by picking up the material from the drain base and sides and then carried in suspension to be deposited as silting at a lower level when the velocity drops.

Table 22: Maximum Permissible Velocities

Material	Maximum Permissible Velocity (m/sec.)
Fine sand (non-colloidal)	0.44
Sandy loam (non-colloidal)	0.5
Silt loam (non-colloidal)	0.6
Ordinary firm loam	0.7
Volcanic ashes	0.7
Fine gravel	0.7
Stiff clay (very colloidal)	1.1
Graded loam to cobbles (non-colloidal)	1.1

Generally, existing side drains under maintenance will have grassed banks and exposed soil bases. Under these conditions velocities should be restricted to that of the appropriate base soil where drains are generally dry and in good maintained condition. Their bases may also be well grassed. If this condition exists the flow velocity may be permitted to rise to the higher levels shown for fully grassed drains.

d. Use of the Design Chart

(i) Measurement of Drain

Measure the length of drain between outfalls and subdivide these lengths into lengths of the constant gradient. Record the pavement type as being either cambered or super elevated.

(ii) Calculation of Run-off

Calculate the total run-off for each individual length of drain of constant gradient from the data provided in section ***"b(i)"*** above.

Sum up the totals to obtain the total accumulated run-off for the entire drain length

(iii) Determination of Velocity and Depth

Insert the total accumulated run-off in m^3/sec onto the horizontal axis of the upper chart in Figure 109. Construct a vertical line to intersect with the appropriate slope curve corresponding to the drain gradient at the point being studied. Read off the velocity on the vertical axis. Determine the depth by interpolation between the straight depth lines.

(iv) Excessive Velocity

Where the velocity determined above exceeds that permissible for the drain material listed in the velocity table, lining will be required. Construct a horizontal line on the upper chart of Figure 109 at the permissible velocity to intersect with the appropriate slope curve. Read off the quantity flow on the horizontal axis. Determine the chainage at which this accumulated flow occurs. This is the chainage at which lining must be introduced.Height of Lining

Using the lower chart, insert the final total accumulated flow quantity and drain gradient and read off the depth of flow in the lines drawn by interpolation between the depth curves. Choose a standard height section to accommodate this by allowing for not less than 5cm freeboard.

(v) Example Calculation

Consider the need for lining. A 350 metre drain section, which is causing silting in the outfall drains.

- *Measurement*

Field measurement shows the highway to be a tangent equally cambered to both sides. The two side drains consist of 150 metres at a gradient of 2% followed by 200 metres at a gradient of 3%. All drain sections are cut into stiff clay with clean soil bases and well grassed banks.

- *Calculation*

- Run-off

Since the highway is cambered, run-off to each side drain will be as from sub-section ***"b)(i)",*** above. 0.8m^3/sec for each 100 metres of the highway. The quantities are calculated separately for each section and entered into tabular form as shown in Table 23 below.

- Velocity Depth Calculation

Table 23: Velocity Calculations

Chainage	Length	Gradient	Cross Fall	Quantity Section Total	Velocity	Depth
0 -150	150	2%	Camber	0.8x150/100 = 0.12	0.86	16
150 - 350	200	3%	Camber	0.8x200/100 = 0.16 0.28	1.22	22

Inserting quantity 0.12m^3/sec into the upper chart of Figure 109 (point A) and drawing a vertical line to cross with slope curve 2% gives a velocity on the vertical axis of 0.86 metres/sec, (point A1) at chainage 0+150. The depth at this point is by interpolation between the 15cm depth line and 23cm depth line and 16cm depth.

The accumulated quantity at chainage 0+350 is 0.28 (point B) which similarly inserted into the upper chart to the 3% slope curve gives a velocity of 1.22 metres/sec (point B1) and a depth of 22cm.

- Permissible Velocity

In the velocity table the maximum permissible velocity for staff clay is 1.1 metre/sec, whilst that for good quality grass it is 1.8 metre/sec

Thus, the velocity at chainage 0+150 is satisfactory whilst that at chainage of 0+350 will cause scour of the drain base with no damage to the grasses side slopes.

The depth of flow at both locations is well within the drain capacity.

- Location of Lining

Insert the maximum permissible velocity of 1.1 metres/sec (point C) onto the vertical axis of the upper chart to intersect with the 3% slope curve as shown in Figure 109. Intersection occurs at a quantity of 0.195m3/sec (point C1). This quantity of flow is accumulated in the drain at:

(0.195 - 0.12) x 100 = 93.75 metres

0.08

From the start of the 3% gradient section or at chainage 150+93.75 = 243.75 metres.

Lining must therefore commence at chainage 0+243.75 and continue through to chainage 0+350 at the outfall on both sides.

- Height of Lining

Using the lower chart for lined drains inserting the total flow of 0.28m³/sec at a slope of 3% results by interpolation in a depth of 17.3cm (point D).

Thus, a standard 25cm deep lined section will be adequate to carry the estimated maximum peak flow.

It should be noted, that the terminal velocity of flow at the outfall will not be much greater than 1.2m/sec (as indicated by the reduced depth of flow). It will therefore be necessary to protect both outfall drains by lining cascade sections aprons with random rubble, etc., depending on the type and condition of the outfall.

e. *Type of Lining*

Commonly employed drain linings are:

- Cast-in-situ concrete
- Rip-rap
- Precast invert sections
- Precast concrete slabs.

For simplicity and economy only, rip-rap and precast concrete slabs are recommended for use in maintenance operations were relatively short will be required.

(i) Rip-Rap

Where quarried stone boulders and cobbles are readily available, rip-rap offers an easily constructed material that can be laid as a drain lining by semi-skilled labour available to maintenance crews. Stone size should be flat or flaky with minimum size of 10cm. The base and side slopes to be lined should be trimmed and well compacted with hand rammers. Stone should be laid first on the base, binding each stone to the proceeding ones with a full depth of 1.2 cement sand mortar. Work should progress uniformly up the 1:1 side slope joints and should be trowelled roughly level to the surface.

(ii) Precast Concrete Slabs

Ideally, such drain linings are constructed with cast-in-situ concrete bases on a lightly sanded and compacted soil bed and rebated to receive precast slabs for the side slopes. Precast slabs of 35cm x 25cm laid at 1.1 side slopes will provide a lined drain with depth of 25cm requiring 8 slabs per metre run. Joints may be left open to receive seepage water, provided that the slabs are bedded firmly on well dressed and lightly sanded slopes. The joint with the base must be mortared. Slabs of these dimensions will weigh approximately 21kg and will be sufficiently easy to handle to reduce risk of breakage or need for reinforcement.

Should it be necessary to lay precast bases to the drains due to high water tables or urgency in wet seasons, , the length of base slab should be reduced to 15-20cm to keep the weight of the units within practical limits of handling. Figure 62 illustrates a drain lined with concrete slabs.

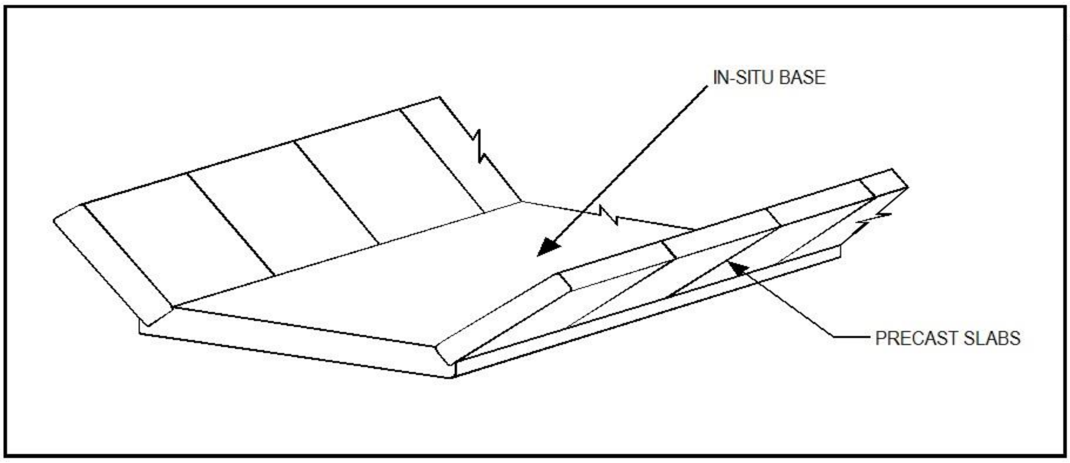


Figure 62: Concrete Lined Side Drain

8.3 Shoulders

The shoulder is the part of the highway structure lying between the pavement edge and the side drain or side slope of the formation or embankment.

Shoulders fulfil the following primary functions:

- Provision of lateral support against the horizontal components of load and weight from the pavement structure.
- Provision of space for vehicle escape in dangerous traffic situations

- Provision of emergency parking space for broken down vehicles
- Provision of space for highway furniture such as road signs

Supplementary uses of shoulders, for which they are not normally designed, are the provision of parking space and space for the installation of utility services. Wherever possible, utility services should be placed outside of the line of the side drain. Shoulders may be constructed either as hard shoulders or soft shoulders.

Both types are subject to erosion both by weather and traffic and will therefore require replacement or renewal of the eroded fraction by periodic maintenance.

8.3.1 Paved Hard Shoulders

Hard shoulders are usually provided either in areas where climate conditions or soil makes it difficult to cultivates cover-crop, heavily trafficked highways or where break-down and parking incidence is most likely higher. Under these circumstances, the hard shoulder will usually be paved with surface dressing bitumen macadam or asphaltic concrete. These surfaces will be subject to wear and will require periodic renewal. The operations are described generally below.

8.3.2 Unpaved Hard Shoulders

Where parking loads are less likely and in the dry northern areas where soils and climate make grass a difficult cover-crop to grow, hard shoulders are frequently constructed of soil aggregate such as lateritic gravel. Such soil aggregates are very susceptible to wear, both from weathering and traffic and particularly where pavement widths are inadequate to traffic demand. The periodic maintenance operation is described generally below.

8.3.3 Soft Shoulders

a. General

Soft shoulders are normally dressed with topsoil and planted or turfed with grass as a cover-crop to protect them from weather erosion. They are however very susceptible to traffic damage which takes the form of rutting and potholing and particularly traffic wear, resulting in an eroded channel between shoulder and pavement edge. Although much of this damage should be continuously made good by routine maintenance, it will be necessary to undertake periodic major repair once or twice a year, preferably at the beginning and end of the rain season when shoulder material will be sufficiently malleable (available).

b. Operation

The shoulder should be given one pass with a light roller of 4½ ton capacity under moist conditions. This will even out minor depressions and irregularities. The remaining holes and ruts should now be clearly visible and will be raked out to square edged shape with loosened soil in the base.

The holes and ruts are then filled with turf and given a further two passes with the roller.

c. Turf Stockpiles

Turf will normally be cut from suitable level turfed areas of the right of way outside of the line of the side drains. Turf should be cut in 20-30 cm squares and 5 cm thick, taking spot turfs from not more than 20% of the area available. Turf will be loaded into a pick-up or flat bed truck, lightly watered and transported to the working site. At the end of each working day the holes left in the stockpile area will be backfilled with top soil and lightly tamped level with the surrounding ground. The newly backfilled areas should be lightly seeded to encourage re-growth of grass, unless the existing cover consists of a rapid spreading grass such as dub.

8.3.4 Cycle Tracks and Footpaths

In urban areas, the shoulder may be used to accommodate cycle tracks or footpaths. These are usually constructed of surface dressing or bitumen macadam wearing course on light soil aggregate bases. Periodic resurfacing of cycle tracks is best undertaken with fine textured mixes of bitumen macadam, since cyclist invariable reject coarser textured surface dressings and use the smoother main carriageway. The operations required for such periodic maintenance are described generally below.

8.4 Right Of Way (ROW)

8.4.1 Periodic Clean-Up

At least once a year in the north and twice a year in the south (or three times in two years) there should be a general clean-up of the full width of the right-of-way. This includes cutting vegetation that was missed in routine operations (probably because it is near the fence lines or is bearing a crop), removing rubbish and scarp such as vehicles that had been in accidents, repairs of fences where they exist and generally improving the aesthetic appearance of the ROW. In areas where crops are growing within the ROW the owner of the crops should be requested to do his own clean up after the crop is harvested and, that he should be asked not to replant within this area.

8.4.2 Illegal Structures and Buildings

During the periodic clean-up of the ROW, it is essential that all structures and buildings erected by the population within the ROW should be listed and appropriate action be determined by the maintenance engineer.

In some cases, such as illegal buildings, legal action may have to be initiated by a senior engineer in corporation with local authorities and perhaps even the police. In other cases, such as new accesses, the engineer will have to decide on the spot whether the access can be allowed to remain and whether the actual location of the access does not present a traffic hazard. Owners of kiosks and market stalls should be discouraged from infringing on the shoulders and side drains and preferably should be encouraged to locate their business completely outside of the ROW.

Advertisement boardings should be dismantled as they are not permitted within the ROW, but it is obviously more effective to control the erection of hoardings at the time they are being erected. Signs, indicating directions to adjacent properties, establishments or signs which are defunct, should be removed.

Any other objects which the engineer considers could present possible danger to traffic including the emergency use of any part of the ROW, shall be removed. Included in this category are concrete flower beds adjacent to the shoulder and in general any solid object which, if hit by a moving vehicle would be likely to cause injury to the vehicle‘s occupants.

Finally, local authorities should be discouraged from erecting archways over the highway, A common practice in Nigeria is to stretch cloth or paper signs over the highway between two poles. If the use of either of these is considered essential they should be removed as soon as their practical use has become outdated.

Other appurtenances within the ROW are dealt with in ***Sections 8.10 and 8.11***

8.5 Bituminous Pavements

8.5.1 Prime Coat

a. *General Theory*

(i) Definition

Priming consists of a thin membrane of cut-back bitumen, which penetrates into the material voids and pores of a surface in order to prepare the surface to receive a bituminous pavement course. Its performance and purpose are that of a primer paint applied to raw timber.

(ii) Functions

The main functions fulfilled by priming are:

- Provision of a bond between a non-bituminous lower course and a bituminous upper course of the pavement structure.
- Provision of a weak waterproofing membrane to a limited extent
- Stabilizing the surface of a lower course to a dust free condition that will not damage the next course of construction.

It should be noted that a prime is not in itself a wearing course of surfacing. It has little strength and will strip from the surface if exposed to traffic for any appreciable length of time.

b. *Application*

A prime can be applied satisfactorily to any of the following pavement courses:

- A soil aggregate surface to receive a surface dressing
- An unpaved hard shoulder to receive surface dressing or bitumen macadam cycle track or footpath.

- A dry stone surface to receive a surface dressing, bitumen macadam or asphaltic concrete

- A soil cement base to receive a surface dressing, bitumen macadam or asphaltic concrete.

- A soil or soil aggregate drain to receive a light surface dressing as a protection against erosion.

c. Strength

A prime does not possess any structural strength to contribute towards the load carrying capacity of the pavement.

d. Design Principles

There are no mathematical or empirical formulae to aid the engineer in the grade selection of bituminous materials, or conditions and rates of application for priming. Although, in general, a nominal rate if application for prime is taken at 0.7litres per metre squared (l/m^2), successful priming is dependent largely upon experience and the knowledge of the pavement layer materials. Wherever a major application of priming is to be carried out a test strip or trial should first be tried and examined in detail to determine the appropriate rate of application. The factors governing the successful application of priming are:

- Porosity of the existing surface to be primed

- Rate of application of cat-back bitumen

(i) Porosity

The strongest and most efficient prime will be that which penetrates most deeply into the surface pores of the material to be treated. The surface should therefore be carefully examined to determine the size and depth of pores to ascertain application rate of the prime.

- *Soil Aggregate Surfaces*

Soil aggregates will have a fine textured surface with small pores /voids and will probably have a very dusty surface. Excessive dust should be removed by light brooming or blowing. The pores can be enlarged and deepened by light watering up to an hour prior to the application of the prime.

- *Dry Stone Base*

Crushed, graded stone aggregates will be relatively coarse textured and probably, if recently constructed, have a surplus of fines lying on the surface. The surface should be firmly brushed / broomed to remove all loose fines and blown free of dust.

- *Soil Cement Bases*

Newly constructed soil cement bases will be very close textured with very small pores and very little voids. They may be dusty and should be very lightly brushed before priming. Sometimes the specifications for construction require the soil cement to be bituminous sealed to aid curing. If so, no priming should be undertaken and a normal tack-coat will suffice. For the next stage of construction a bitumen macadam or asphaltic concrete is to be applied.

- *Rate of Application*

The cut-back bitumen primer will fulfil two tasks:

- To lightly coat the surface and expose particle faces in the surface voids
- Penetrate down into the material voids

The coating effect is relatively large with coarse textured materials such as dry stone bases and very small with the finer textured materials such as soil cement and higher clay content soil aggregates. The penetration effect will depend upon the density of the material and will vary from 5-8mm with soil aggregates to 5-12mm with-dry stones bases. Approximate application ranges are given in Table 24 below:

Table 24: Approximate Application Rates

Surface Material	Application kg/m^2
Soil Aggregate	0.8 – 1.2
Dry Stone Base	1.0 – 1.4
Soil Cement	0.7 – 1.0
Soil Drains	0.6 – 1.0

- *Test Section*

For small scale operations, mark out a section of the carriageway adjacent to the edge or on the shoulder if construction is of the same material (half a metre wide by two metres long). Erect barriers, warning signs and lights. Clean and prepare the surface and lightly water it to achieve a drying moist condition.

Select a rate of application near the middle of the appropriate range in Table 24 above. Apply the primer and allow 48 hours for full penetration and curing.

For major operations, the same procedure can be applied using a bitumen distributor over a length of plus / minus 50m and a width equal to the spray-bar of the bitumen distributor.

Examine the surface condition carefully:

- A bare light brown appearance will suggest insufficient primer which can be verified by cutting.
- A uniform dark surface with the original texture still recognizable will suggest close to correct rate of application.
- Pools of bitumen visible on the surface overlaying and obscuring the texture will suggest either too much primer or no penetration.

Cut a number of small holes or trenches in the primed surface carefully with a penknife. Measure the depth of penetration. A minimum of not less than 5mm should be achieved. It should average within the ranges quoted above. Where less than 5mm penetration is achieved on soil aggregate in association with pools of freestanding bitumen on the surface, it will suggest excessive fines in the surface and a poor grading that would warrant scarifying, mixing and re-establishment of the surface prior to priming.

e. *Equipment*

(i) Bitumen Distributor

As described under ***Surface Dressing***

(ii) Mechanical Broom

As described under ***Surface Dressing***

(iii) Chipping Spreader

Where traffic is permitted to use the primed section of the highway between priming and subsequent application of the next course of construction it will be necessary to utilize a chipping spreader to loosely bind the prime with sand during the intervening time interval. This machine required is described under ***Surface Dressing.***

f. *Construction Methods*

(i) Inspection

The first essential work to be undertaken is a detailed inspection to determine the factors governing design repair works and possible changes to geometry.

- *Factors Governing Design*

Pavement widths must be measured throughout the section to be treated and the surface condition must be checked for:

- Porosity
- Type
- Dust

It is necessary for existing (i.e. in use) soil aggregate surfaced roads to check for looseness or less of fines from the surface and depth of gravel surface remaining.

Due to rapid wear of this material under traffic and weather there may not be sufficient or sufficiently well graded material remaining to support the next course of construction with stability.

- *Repair Works*

The highway must be inspected for:

- Drainage defects
- Shoulder defect and irregularity
- Culvert damage or inadequacy
- Bridge approach subsidence's and damage
- Pavement defects such as potholing, cracks, depressions, corrugation and ravelling

All these defects must be made good well in advance of commencements of priming.

In the case of existing (in use) soil aggregate surfaces being primed for upgrading, extensive damage to the pavement would justify total scarifying, regarding and compaction.

- *Changes in Geometry*

Where existing soil aggregate pavements are to be overlaid with bituminous material courses, consideration must be given to the need to change the camber prior to priming. Soil aggregate pavements are usually laid to a camber of 4.5%. This should be reduced to 2.0 to 2.5% depending on the material of the final course to be constructed. Excessive camber in bituminous wearing courses will result in a too rapid run-off velocity of surface water and subsequent erosion of shoulders, particularly if they are uncovered hard shoulders.

(ii) Planning

As soon as design and remedial work is complete, all materials may be ordered and reservations made on equipment. A date may be assigned to the operation. Priming is most satisfactorily carried out in dry seasons when water used for opening pores can evaporate quickly.

Consideration should be given to carrying out priming works to full width whenever possible since it is basically a simple and fast operation. Where by-pass roads are available due notice should be given to the public of the hours of closure. Where this is not possible, planning should allow for the maximum practical single lane operation or short section of full width in either case immediately blinded with loose sand for minor interruptions to traffic flow.

(iii) Safety

Warning signs, barriers, stop-go boards or lights and flagmen will be required. If short duration total road closures are planned, the presence of a policeman at each end of the work is desirable. Where traffic is to be allowed on the prime it must be regulated to slow traffic speeds. Adequate warning boards for possible windscreen damage must be displayed.

(iv) Operation

The operation of priming is basically identical to that described under ***Surface Dressing*** with the following exceptions only:

- *No Cover Aggregate*

No chippings will be placed on the prime. Only if traffic is permitted to use the primed surface will coarse dry river sand be applied over the prime and left in a loose un-compacted condition.

- *No Rolling*

The prime does not require rolling. The loose cover of sand, if applied, must not be rolled since it has no permanent place in this operation or as part of the structural bond between courses.

- *No Hurry*

Since there is no aggregate to be placed onto the cut-back bitumen and no compaction requirement the cooling of the primer is of no consequence.

- *Long Application Lengths*

Due to no concern and time restrictions on the construction of the next layer, long lengths of highway can therefore be treated, restricted only by inconvenience to traffic and construction programmes.

(v) Longitudinal Joints

If it is necessary to undertake the operation in lane widths, extreme care should be taken for the overlapping joint on the centre-line of the carriageway. Single lap spraying is preferable since a light application of primer will tend to seal the surface and prevent penetration of the balance requirement applied at a later time. This results in a weak and fatty centre-line to the carriageway.

(vi) Preparation for Next Course

Prior to application of the next course of construction the primed surface must be prepared. The works required are:

- *Cleaning*

All remaining loose cover sand, where this was used and all dirt and dust should be lightly brushed from the surface.

- *Traffic Damage*

The primed surface should be checked for ruts, potholes and corrugation caused by traffic provided the loose cover sand was not excessive in quantity and the time interval under traffic minimal. These damages will not be extensive.

- *Reinstatement of Defects*

Any defects in the priming which will not become apparent until the 48 hour curing time has elapsed and loose sand cover removed should be made good as described under ***Defects In Priming*** below.

g. *Defects in Priming*

(i) Under-priming

Under-priming will become apparent by the appearance of dry light coloured patches or lines on the surface. If these are small isolated patches they are probably due to areas of low fines content that absorbed the available prime too quickly. Extensive areas or lines may be due to faulty nozzles on the bitumen distributor or miscalculation of the rate of application.

Correction of under-priming is relatively easy provided the areas concerned are first lightly brushed to break the surface seal and then re-primed with a hand lance. The work is most efficiently carried out if the defect can be identified early before the initial prime is complete.

(ii) Shallow Penetration

Shallow penetration will become visible through the appearance of pools of cut-back on the surface and is usually caused by excessive fines in localized patches or by careless preparatory cleaning of the surface. Depth of penetration should be checked with a penknife and the defect corrected by removal of the area concerned. Reinstatement is carried out with correctly and well graded material as for pothole patching and re-primed with a hand lance.

(iii) Over-priming

Over-priming will become visible by the presence of a free film or pool bitumen on the surface completely obscuring the pattern of the original surface texture. It may be due to incorrect application rates, a surge in the bitumen pump of the distributor or, if localized, due to a depression in the surface receiving excess primer from surrounding higher and dry looking areas.

This is the most serious of all defects and one which, if not corrected will result in reflected bleeding through the subsequent course of either surface dressing or asphaltic concrete.

Correction of over-priming can be partially achieved by spreading a layer of course dry sand over the area at the hottest part of the day, rolling and subsequent removal with square ended spades. The treatment must be repeated as often as is necessary to achieve the best possible texture. Localized over-priming is most satisfactorily corrected by removal and reinstatement as a pothole.

8.5.2 Single Surface Dressing

a. General Theory

(i) Definition

Single Surface Dressing is a wearing course consisting of a thin layer of bitumen followed by a layer of aggregate placed shoulder to shoulder and pressed into bitumen. Also known as a "Single Seal"

(ii) Functions

The main functions fulfilled by single surface dressing are:

- Provision of a dust-free wearing surface
- Provision of a water-proof seal to prevent ingress of surface water to the pavement courses.
- Reduction of disintegration of old bituminous surface showing signs of wear
- Restoration of non-skid qualities to surfaces that have become smooth

To a lesser extent single surface dressing may also fulfil the following additional functions:

- Closure of voids and hardening of existing surfaces
- Provision of a temporary wearing course to surfaces where further strengthening is subsequently required (deferred improvement)

b. Application

Single Surface Dressing may be satisfactorily applied to any of the following pavement types:

- A good quality gravel road surface that has been primed satisfactorily.
- An existing surface dressed road surface, which has become porous or smooth
- An existing penetration macadam road surface, which is not excessively open textured
- A new dry stone base that has been primed satisfactorily
- A new cement stabilized base that has been primed satisfactorily
- An existing asphaltic concrete road surface where individual stone shapes are readily visible over 80% or more of the surface area.
- An existing bitumen macadam road surface.
- An existing or new concrete road surface, which has been suitably roughened to receive the treatment

c. Strength

Single Surface Dressing is essentially a wearing course and possesses no structural strength to contribute towards the load carrying capacity of the pavement courses. It should be noted however, that properly designed and applied multiple surface dressing and therefore successive Single Surface Dressings can provide additional strength to the pavement if there is a stone-to-stone interlock between successive courses of aggregate.

d. Design Principles

The three primary factors to be considered in design of Single Surface Dressing are:

- Rate of application
- Aggregate size

- Rate of application of aggregate

Since both, the rate of application of aggregate and binder are largely dependent upon the size of aggregate selected, this item must be considered first.

Secondary factors in design, such as aggregate types, are discussed below. The first analysis of design principles is however restricted to consideration of crushed stone chipping, which constitutes the most common and effective aggregate in use.

(i) Selection of Chipping Sizes

Factors governing the behaviour of chipping in Single Surface Dressing are primarily:

- *Surface Texture*

Open textured pavements such as old penetration macadam or primed water bound macadam will require larger sized chippings to fit surface voids. Old asphaltic concrete and bitumen macadam will require smaller sized chippings.

- *Surface Strength*

Very hard surface such as good penetration macadam and old concrete will resist the bedding of aggregate and thereby necessitating the use of small sized chippings. Conversely the relatively soft primed lateritic gravels permit chippings to bed well down into the surface where small chippings would be too deeply immersed in the binder layer and result in a fatty surface condition. This will necessitate either a reduction in binder or a larger stone aggregate.

- *Traffic*

Heavily trafficked highways should be surfaced with small sized chippings since these lie closer to the road surface and are more strongly bedded into the binder layers. Therefore, there will be less risk of whip off of chippings under fast moving vehicles. Careful attention should also be given to binder application rates and a balance be made between chippings size and binder application rate. Table 25 gives an approximate estimation of stone size. However, it should be used in isolation binder application rates and must be taken into account when determining the size of chippings.

Table 25: Relationship between Traffic and Size of Chippings

Surface Texture	Traffic	Surface Strength		
		Hard	Medium	Soft
Dense	Heavy	6	6	6
	Medium	9	9	9
	Light	9	9	9
Average	Heavy	9	9	12
	Medium	9	9	12
	Light	9	12	12
Open	Heavy	9	12	12
	Medium	12	12	12
	Light	12	12	16

(Sizes are in mm square mesh screen)

Traffic densities are defined as:

- Light Traffic Less than 100 vehicles per day

- Medium Traffic 100 – 100 vehicles per day
- Heavy Traffic More than 100 vehicles per day

Where excessive contractions to selection of chipping sizes occur alternative solutions will have to be used. For example, an excessively open textured penetration macadam requires the use of large chippings of 16mm or larger size. However, if such a highway were also subjected to very heavy traffic, the surface would be too coarse a texture and would almost certainly experience excessive whip off resulting in broken windscreens and failure of the surfacing treatment. The alternative solution will be found below under Multiple Surface Dressing.

(i) Rate of Application of Chippings

The rate of application of chippings is dependent upon the size and shape of the chippings selected and is summarized for these in Table 26 below:

Table 26: Rate of Application of Chippings

Size of Chippings	Cover (kg/m²)
6mm	6 – 8
9mm	9 – 12
12mm	11 – 16
16mm	13 – 20

Higher rates are used for round or cubical chippings, lower rates for flaky chippings.

The above rates of application are slightly in excess of those theoretically required to allow for early losses of some chippings brushed off by traffic before chipping are fully bedded.

(ii) Rate of Application of Binder

A number of formulae and charts have been developed to assist engineers in estimating the correct rate of application of binder. The most popular of these is shown in Figure 63.

The zero diagonal line represents the rate of application of binder under average and ideal conditions. The positive and negative factor diagonal lines on either side represent the cumulative effect on the rate of application of binder caused by variations in traffic density, type of old surface, aggregate quality and climatic conditions. The factors recommended are shown in Table 27 to Table 30 below:

Table 27: Traffic Factors

Traffic	Commercial Vehicles/day	Factor
Very light	0 – 15	+ 2
Light	15 – 45	+1
Medium	45 – 150	0
Medium-Heavy	150 – 450	- 2
Heavy	450 – 1,500	- 4
Very Heavy ***	1,500 – 4,500	- 6

***This factor is dangerously low and Single Surface Dressing would not normally be used for such a high traffic density, except as a short term stage construction expedient.

Table 28: Surface Factors

Type of Old Surface	Factors
Untreated/Primed Base***	+ 6
Very Lean Bituminous	+ 4
Lean Bituminous	+ 2
Average Bituminous	0
Rich Bituminous	- 1
Very rich Bituminous	- 3

*** This factor is dangerously high and would require careful inspection of the quality of prime surface dressing and should not be applied on un-primed bases.

Table 29: Aggregate Quality Factors

Quality of Aggregate	Factors
Pre-coated	- 2
Flaky	- 2
Cubical	0
Round or Dusty	+2

These factors do not differentiate between types of stone, which vary in their absorption and affinity properties.

Table 30: Climatic Factors

Climatic Conditions	Factors
Wet and Cold	+2
Wet and Hot	+1
Temperate	0
Dry	-1
Dry and Hot	-2

Single surface dressing will be planned for dry season work and the wet and temperate conditions will apply therefore only to emergency works.

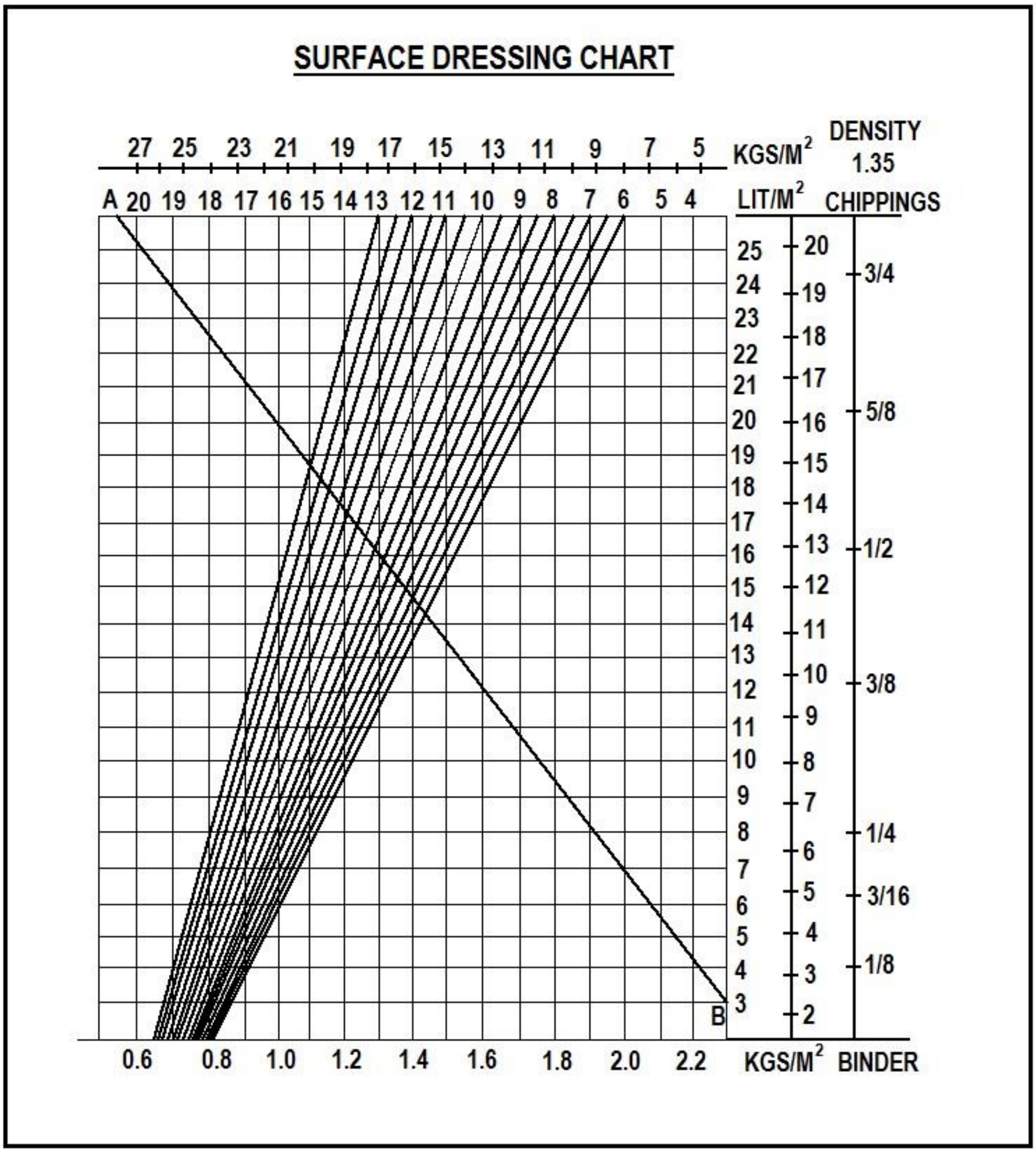


Figure 63: Surface Dressing Chart

All of the above four factors, Traffic, Surface Condition, Aggregate and Climate are now added geometrically to obtain an overall factor to be used in selection of binder application rate. See Figure 63.

In practice, the maintenance engineer will be using chipping from only one source and in constant pre-selected climatic conditions. He will therefore build up experience, which will guide him into making his own adjustments to the factors shown above to suit his own requirements.

The most dangerous of all the errors that can arise from above empirical approach is miscalculation of the chipping sizes. Badly designed screens can admit a surprisingly large proportion of undersize material into a nominal size bin. Badly worn screens (particularly round hole punched plate) can admit consistently oversize material. If the results of work show that the finished surface is becoming fatty or lean then a check analysis of aggregate is the first investigation to be carried out.

A sample of aggregate is sieved and measured for average least dimension (laboratory test). The results are plotted as given in Table 31 below:

Table 31: Example of Average Particle Size Calculation

Sieve Size	Percent Passing	Average Least Dimension Size (mm)	Percent	Calculation
12mm	100	10.6	10	10.6 x 0.10 =1.06
9mm	90	7.4	70	7.4 x 0.70 = 5.16
6mm	20	4.7	17	4.7 x 0.17 = 0.80
No. 8	3	-	-	
Average Particle Size			= 7.02	

Nominal Particle Size = 12mm

Average Particle Size = 7.02mm

The result above, probably due to elongated chippings is a typical defect in limestone and would result in 0.12 kg/m^2 excess bitumen – probably just sufficient under medium to heavy traffic to concrete a fatty appearance.

(iii) Acceptable Materials

- *Aggregates*

- Crushed Stone

Ideally only crushed stone chippings should be used for single surface dressing. These should, as closely as possible from the quarry plant available, be single size chippings. Their shape should be as nearly cubical as possible. All faces should be crushed or cut faces to enable the individual particles to interlock.

Granite particularly and practically all igneous rocks are suitable as surface dressing aggregates

Of the sedimentary rocks only some lime stones are suitable. Whilst most limestone's have sufficient strength and good affinity to asphalt many of them polish under traffic wear and provided a low sideways force coefficient.

Quartzite's generally are very strong and may be excellent surface dressing aggregates provided the silica content is not so high as to make them hydrophilic

- River Gravel

River gravels are not normally acceptable as aggregates due to their polished and rounded faces. Crushed and screened gravels can be accepted as material for medium to low trafficked roads, provided at least two faces have been broken.

- Sands

Washed and screened coarse river sands are acceptable only on very lightly trafficked roads and when placed on hard dense old surfaces. Coarse sands have been used with success on concrete pavements and as temporary seals to good bitumen macadam surfaces.

- Pit Gravel

Quartz and quartzite gravel washed and screened from soil aggregate deposits are usually of an excellent shape and hardness. Normally they are highly hydrophilic although successful use has been made of them by pre-coating.

Pea gravel washed and screened from lateritic gravel deposits and crushed lateritic conglomerate may be used as aggregate on very lightly trafficked roads which are being upgraded from gravel pavements. Pea gravel can be quite hard and provided it is clean has good affinity for asphalt and its irregular shape beds well into lateritic gravel bases.

- *Binders*

The most common binders in use for single surface dressing are:

- Straight run bitumen 85 – 100 penetration; 120 – 150 penetration and 200 – 300 penetration
- Heavy-cut-backs such as S.125
- Medium to heavy cut-backs such as MC 250, MC 800 and MC 3000.

Generally straight run bitumen and heavy cut-backs are preferred with the larger sizes of chipping sand the lighter cut-backs are preferred with smaller sizes of chipping owing to their lower working temperature and greater fluidity. The prejudice against the use of straight run bitumen‘s can largely be overcome by mechanization of chipping application and good planning to eliminate needless time delay and cooling after the binder has been laid.

(iv) Application Temperatures

The choice of binder to suit the works, materials and availability will govern the temperature at which application is made. The recommended viscosity for spraying is 20 to 120 centistokes kinematic viscosity and the temperatures required to produce this range are shown in Table 32 below:

Table 32: Bitumen Spraying Temperatures

Bitumen Grade	Spraying Temperature ºC
Penetration Grade	
85 – 100	145 – 200
120 – 150	140 – 200
200 - 300	135 - 195
Cutback Grade	
S.125	130 – 160
MC.250	75 – 130
MC. 800	95 – 150
MC.3000	115 - 170

e. *Equipment*

(i) Bitumen Distributor

- *Basic Distributor Machine*

The bitumen distributor consists of a truck mounted, insulated tank containing an oil burning heating system. An armored thermometer records the bitumen temperature.

The distributor is equipped with a power driven pump capable of handling a wide range of products from light emulsions to heavy straight run bitumen heated to spraying viscosity. At the rear of the machine is a spray bar and nozzle through which bitumen is forced under pressure onto the road.

- *Circulation System*

The pump and value controls provide a circulation system which:

- Fills the distributor tank
- Circulates bitumen in the spray bar and tank

- Sprays bitumen through the spray bar or hand lance
- Draws bitumen back to the tank from the spray bar
- Pumps bitumen from the tank to outside storage

- *Spray Bar*

The spray bar is the most important part of the machine and that part is most susceptible to damage or misuse. It is vital that spray pressure shall be uniform across the full width of the bar and that each and every nozzle shall be clear and fully operational. This can only be achieved if the bar and nozzle are cleaned out with a solvent (Kerosene) at the end of each day‘s work and that the bar be checked in the depot prior to each day‘s work. Nozzles may be individually or collectively closed to vary the width of spray. The bar may be adjusted in height to provide single or multiple lap.

- *Bitu-metre*

The rate of application of bitumen to the surface is varied by the speed of travel of the distributor to enable the driver to control this accurately. The machine is fitted with a measuring wheel on a retractable frame connected by cable to an odometer in the driver‘s cab showing the speed in metres or feet per minute. Care must be taken to ensure that the wheel is clean as a build up of bitumen on its tyre will result in measuring errors.

- *Calibration*

The distributor should be calibrated from time to time by driving it over 30cm square absorbent pads or shallow metal trays and weighing the resultant cover of bitumen. These are plotted on a graph to ensure correct speed; pump pressure and lap are selected and controlled for each job.

(ii) Chipping Spreader

The chipping spreader consists of a hopper mounted on wheels, which is clipped to the rear of a tipping truck and driven by drums and chain drive attached to the truck‘s rear wheels. Paddles within the hopper ensure an even lateral distribution of chippings. Adjustment to the hopper feed gates and operating speed of the reversing truck control the rate of application. Calibration checks are carried out in a similar manner to that described for bitumen distributors using shallow metal trays.

(iii) Mechanical Broom

All pavement surfaces must be cleaned prior to application of the binder. New road surfaces must be cleaned of loose binding material and dust. Old surface must be cleaned of dirt and dust.

This cleansing will be done immediately prior to laying of the binder. It is therefore essential to use a mechanical broom, which is usually towed or driven by an industrial tractor.

(iv) Rollers

Just as it is of primary importance to place the aggregate onto binder whilst it is still hot, so it is necessary to bed it firmly down as quickly as possible. The best rollers for this purpose are pneumatic tyred rollers and steel wheeled tandem rollers. One steel wheeled roller should be used for initial compaction as closely as possible behind the chipping spreader. It should be assisted by one or two pneumatic tyred rollers to complete compaction.

f. *Construction Methods*

(i) Inspection

The first essential work requirement is a thorough inspection of the highway section to determine both the factors governing design and the repair works necessary prior to surface dressing.

- *Factors Governing Design*

Pavement width must be measured at every change of width. Surface condition must be checked for:

- Hardness
- Texture

Surface condition must be examined for richness or leanness of existing bitumen content.

- *Repair Works*

- Drainage

Defects in side drains must be noted for immediate reinstatement

- Shoulders

Low or high shoulders must be measured for reinstatement before surface dressing is commenced.

- Culverts

These should be examined to ensure no cracked or collapsed sections exist. Any replacement must be completed well before surface dressing is undertaken to allow for settlement of backfill.

- Bridges

Approaches should be checked for settlement behind abutments, which must be repaired and made good well before surface dressing operation commences.

- Pavement

This must be examined in detail to locate potholes, cracks, depressions, localized bleeding, abnormally open dry areas, etc. All pavement defects must be made good and the repairs brought to the average level, texture and richness of the surface in general.

It is particularly necessary to note that the above repairs must be undertaken in sufficient time to allow them to settle down under traffic and if necessary carry out further remedial action.

It is also vital to remember that single surface dressing constitutes a thin skin of wearing course, which will faithfully reflect each and every blemish in the old pavement over which it is laid.

(ii) Planning

As soon as the design has been completed and all material quantities calculated, orders for materials must be placed and reservations on equipment made. A date may now be consigned to the operation, making due allowance for weather conditions where the site is distant from the quarry and/or depot. Stockpile sites will have to be located for aggregates and if necessary for bitumen heaters and bitumen storage.

(iii) Safety

The safety of workmen operating on site, the safety of highway users and the safekeeping of the surface dressing work during execution repairs, the provision of warning signs, barriers, cones, stop-go boards or lights and/or flagmen must be ensured. It may also be necessary to provide for watchmen and lamps for the early hours of darkness should the operational work only be completed late in the day. The availability of bye-pass roads, density of traffic and number of lanes available to traffic will be of the factors in determining the length of lane to be surface dressed at any time and therefore determine the type and quantity of safety equipment required.

(iv) Operation

- Single Lane Work

The most important factor to keep in mind throughout the entire operation is that bitumen applied to a road surface will cool to the temperature of that surface in about one minute no matter what its temperature was initially. For high quality work only one minute of time exist between laying the bitumen and covering it with drippings and achieving the first rolling pass. Speed, efficiency and practice to eliminate errors are the keys to success. The length of lane to be surface dressed in any one pass must be limited to the number of trucks available with chippings on site, rolling capacity of lead roller-steel wheeled, efficiency of drivers and labour force in hitching trucks to chipping spreader, density of traffic using second lane and relative speeds of the distributor and chipping spreader at the predetermined application rates.

- Preparation

- First, the lane length to be surface dressed is given its final cleaning with a mechanical broom.
- Barriers, warning signs and controls are erected and manned.
- A string line is placed parallel to the pavement edge one to two feet outside as a guide for the bitumen distributor driver.
- Paper strips one metre wide are placed laterally across the lane at start and stop positions to make a clean cut joint.
- All equipment is checked.
- Bitumen distributor is lined up with its spray bar over the starting paper strip.
- Chipping spreader with first tipper hitched is lined up immediately behind the distributor.
- Rollers are lined up immediately behind the chipping spreader.
- Second, third, etc. tippers with chippings are parked facing against the direction of work in the free lane.
- All traffic in the free lane is halted or diverted.

- Execution

With all machines in correct position, engines running and in full operational order, the distributor switches on the spray bar and moves forward off the paper strip at its predetermined speed and continues smoothly to the end of the lane and switches off the spray bar over the stop paper strip.

The chipping spreader and tippers follow at their predetermined speed and the rollers complete compaction. Although there is no room for time delay in these sequences of operation, there must be no panic and no rushing. This in particular applies to the operation of rollers, where excessive speed will result in corrugation, a defect that can only be cured by total removal of the surface dressing.

As soon as the chipping cover has been laid, paper strips are removed, the string line is coiled up in readiness for the next section, surplus chipping scattered in the free lane are swept and traffic will be permitted to flow.

- Multi-lane Work

The above description is very simple and the entire operation is very quickly completed. It can be kept this way and can produce consistently high quality results if it is well planned, well organized and well supervised. Practice and a pride in the quality of work are the key factors. The description has been confined to single lane operation ideally suited to a distributor without use of extension spray bar and a single chipping spreader.

This necessitates a longitudinal joint on the centre line which is a point of weakness in many construction techniques. Should traffic conditions permit, the entire road must be closed fully, that surface dressing can be undertaken with the addition of one or two extra chippings spreaders and comparable increase in rolling equipment.

(v) Longitudinal Joints

Errors in longitudinal joints arise from overlap of bitumen, build up of aggregate and lean patches in lines. This can be overcome by use of the double lap height of bitumen. Bitumen applied to the outside strip of width equal to nozzle spacing will only be half the normal application rate. The second lane when laid will have an overlap equal to this nozzle spacing, providing the remaining half bitumen application and full chipping cover as before. Surplus chippings, not required by the bitumen, will brush off easily after compaction is completed.

Edges of pavements in urban areas with kerbs or gutters are established by protecting them with paper strips.

(vi) Transverse Joints

No difficulty will be experienced in constructing clean accurate transverse joints of any shape by use of paper strips as described above. For successive lengths of lane the starting paper strip is laid within 1.5cm of the cut-off line created by the stop paper strip of the previously laid treatment.

(vii) Traffic Control

As described above, no traffic is permitted to operate in the adjacent lanes whilst bitumen or chippings are being applied.

As soon as the chipping spreader has completed its lane length of operation traffic may operate in adjacent lanes but must not be permitted onto the new surface dressing until the chippings have become firmly attached to the binder. The time taken for this to occur will vary from 15 minutes to 2 hours depending on the type of binder used and the prevailing air humidity. Naturally, the longer that traffic can be held off the new surface the better. Practically, this decision must be made at the planning stage dependent upon the traffic density and the lane length to be treated in each stage of the operation.

When traffic is finally permitted to drive over the new surface dressing its absolute maximum speed should be restricted to 25km per hour until the surfacing is at least 4 hours old. This can only be achieved in practice by informing motorists of the limit with temporary speed restriction signs, the reason for it with warning signs ***"hazard-loose chippings"*** and enforcing it with flagmen. Fast traffic will not only damage the surface by loosening or displacing chippings but will also break headlamps and windscreens of following vehicles. Where highly undisciplined drivers exist it may be necessary to guide each convoy of vehicles through the newly opened section with a pilot vehicle controlling the speed from the front.

g. Defects in Surface Dressing

In spite of the utmost care being taken in planning and supervising work, defects may from time to time occur in surface dressing because of its very precise design parameters and its relative fragility as a surfacing course. Examples of the primary defects and their curses are given below:

(i) Loss of Cover Aggregate (Stripping)

Stripping is a condition that occurs when the aggregate cover is whipped off the surface under traffic, exposing the bare binder.

The main causes of such loss of aggregate cover are:

- Aggregates spread after binder has cooled too much
- Aggregate not rolled immediately after spreading
- Excess aggregate
- Aggregate dusty

- Aggregate wet
- Traffic allowed on new surface too early
- Steel wheeled roller bridging over depression in surface
- Insufficient or wrong grade of binder

The only effective cure and if not entirely satisfactory, is the addition of hot coarse sand to the patches at the hottest time of the day. This sand cover must immediately be rolled with a pneumatic tyred roller.

If stripping continuous after all the ***"physical***" causes have been examined and overcome, the adhesion between the aggregate and the binder may be suspect. In this case, reference should be made to the Central Laboratory of the Civil Engineering Services Division at FMW Headquarters, who can advise whether an adhesion additive is necessary and what quantities should be used.

(ii) Longitudinal Streaking

Longitudinal streaking appears as alternately lean and rich lines of binder running parallel. The main causes of longitudinal streaking are:

- Spray bar not set at correct height
- Spray bar nozzles not at correct angle
- Individual nozzles not properly cleaned and functioning
- Bitumen pump operating at wrong pressure or speed
- Bitumen applied at wrong temperature or viscosity

There is no method of cure possible for streaking and it will remain evident for the rest of the life of the surface dressing. The only repair possible is the total removal of the affected portions of the surfacing and replacement by a new surface dressing. Streaking left in the surface will have to be planed off prior to eventual resurfacing since it will reflect through a new surface dressing treatment.

(iii) Transverse Streaking

Transverse streaking appears as alternately lean and rich lines of binder at right angles to the road centre line. The main causes of this defect are:

- Corrugations in the old pavement surface
- Pulsation in the bitumen pump caused by worn parts
- Incorrect bitumen pump speed

There is no cure possible and repair for longitudinal streaking is defined above.

(iv) Bleeding

Bleeding is a defect that can either become immediately visible as patches or areas of shiny bitumen fully coating or overlaying the aggregate or more slowly developed under action of traffic. The main causes of bleeding in surface dressing works are:

- Too much bitumen in the application. Incorrect calculation of application rate
- Wrong grade or type of bitumen for the aggregated
- Dusty drippings
- Fatty old surface of the road

Isolated patches of bleeding can be reduced by application of coarse sand and rolling during the hottest time of the clay. The sand should be gently removed with a square bladed shovel the following day and the treatment repeated as often as it is necessary. Extensive bleeding is virtually incurable without extensive heating and planning of the affected areas.

(v) Corrugation

Corrugation becomes visible as a series of lateral waves or ridges on the surface of the road. The main courses of corrugation are:

- Reflection of corrugation from the old surface

- Dusty chippings
- Fast rolling

Where corrugation has been caused by dust it can sometimes be partially repaired by hand removal of the ridges with a square bladed shovel. The exposed binder is then covered with coarse sand rolled during the hottest time of the day. Corrugation, where caused by other factors and where extensive can be eliminated by scarifying and relaying the entire affected area.

8.5.3 Double Surface Dressing

a. General Theory

(i) Definition

Double surface dressing is a wearing course consisting of two complete successive applications of surface dressing placed one on top of the other. The aggregate being applied in the second layer is approximately half the size of the aggregates used in the first layer.

(ii) Functions

The functions of double surface dressing are exactly the same as the main functions of single surface dressing described under ***Single Surface Dressing***. In addition, double surface dressing fulfils the following important supplementary functions:

- Provision of a stronger and longer life wearing course
- Provision of a material, which can bridge across the conflicting requirements of an open textured surface (demanding small stone sizes).

b. Application

Double surface dressing may be satisfactorily applied to the following pavement types:

- An existing penetration macadam surface, which has become open textured due to the loss of keystone

- A new primed dry stone base of open texture
- A high quality primed gravel surface carrying a low volume of heavy vehicles

c. Strength

Double surface dressing, consisting of two courses of mechanically interlocking layers of stones of not less than 20mm thickness, may be considered to add very little structural strength to the pavement courses. Its effective thickness may therefore be added to that of the lower courses in thickness design considerations.

d. Design Principles

The primary design factors are the same as those of single surface dressing, namely:

- Rates of application of binder (two operation)
- Aggregate sizes (two sizes)
- Rates of application of aggregates (two operations)
- Selection of chipping sizes

The following are recommended aggregate size combinations of double surface dressings:

- 25mm / 12mm
- 19mm / 9mm
- 16mm / 9 or 6mm
- 12mm / 6mm

(iii) First Course of Chippings

Selection of chipping size is normally dependent upon the three primary factors of surface texture, surface strength and traffic. In the case of double surface dressing however, only the factor of surface texture is relevant to the first layer of chipping. The size selected will be that necessary to fill the surface voids in the existing penetration macadam or dry stone base.

Where surface voids are smaller than 12mm size single surface dressing only should be applied. Where surface voids are larger than 25mm size, a three coat application should be used. T he specification for which would be equivalent to penetration macadam for high quality gravel surfaces, No chipping size for the first course chipping should be applied due to the risk of larger sized chipping particles puncturing the prime and thereby destroying the bond between the base and the wearing course.

(iv) Second Course of Chippings

Having made a selection of chipping size for the first course, the second course is now similarly determined on the residual surface voids sizes of the first course construction. These will normally be approximately half the first course particle size, namely 12mm, 9mm and 6mm respectively.

(v) Rate of Application of Chipping

The rates of application of chippings are dependent upon the size, shape and type of aggregate of chippings selected. Table 33 below gives an indication of chippings spread rates. It is essential, that the application rate chosen for a specific project be determined by tests carried out on the existing surface and aggregates characteristics of chippings to be used.

Table 33: Rate of Application of Double Dressing Chippings

FIRST COURSE		
Size (mm)	Application Rates	
	kg/m² ***	m²/m³
25	18-30	60
19	15-25	75
16	13-20	90
12	11-16	110
SECOND COURSE		
12	11 -16	110
9	9 – 12	165
6	6 - 8	200

*** Higher rates are used for round or cubical chippings, lower rates for flaky chippings.

(vi) Rate of Application of Binder

The rates of application of binders is dependent upon the six primary factors discussed under ***Single Surface Dressing.*** These are:

- Chipping size
- Chipping quality
- Surface richness
- Traffic
- Climate
- Binder type.

- *Chipping Size*

For the first application of binder for chippings sizes must be considered. They are presented below in a separate table for each size.

- *Chipping Quality*

Chipping quality is expressed in terms of its shape as being flaky, cubical or round. Should the chippings supplied be pre-coated then the rates of binder application shown below can be reduced by 0.05 kg/m^2

- *Surface Richness*

Surface richness is expressed in terms of the visible condition of the old surface as being either rich, average or dry in bitumen content.

- *Traffic*

Traffic is expressed as being heavy, medium or light. These terms are represented by:

- Heavy traffic : More than 1000 vehicles/day
- Medium traffic : 100 – 1000 vehicles/day
- Light traffic : Less than 100 vehicles/day

- *Climate*

No bituminous work should be done during foggy or rainy weather and, when a cold wind is blowing. It is recommended that double surface dressing operations be planned for dry weather seasons only and the tables have been presented on that basis. No surface dressing must be done in wet or rainy weather.

Where in the rare event of emergency it is necessary to undertake such work in wet conditions, then the rates of application of bitumen should be increased by 0.05 kg/m^2. However, this emergency work is to be kept to the absolute minimum.

- *Binder Type*

As with single surface dressing only straight-run bitumen's and medium to heavy cut-backs are recommended for use in double surface dressing. The tables presented below express the rates of application of binder in terms of straight-run bitumen's. Should it be found necessary to use cut-back bitumen, then the rates quoted should be increased by 0.1 kg/m².

(vii) Binder Application Rate for First Course of Chippings

The design of the rate application of binder for the first course can now be made by inserting the inspected and known factors of chipping quality, surface richness and traffic into the relevant chipping size as per Table 34 below:

Table 34: Binder Application Rates – First Course

25mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round
Heavy	Rich	1.20	1.30	1.40
	Average	1.25	1.35	1.45
	Dry	1.35	1.45	1.60
Medium	Rich	1.30	1.40	1.50
	Average	1.35	1.45	1.60
	Dry	1.45	1.60	1.70
Light	Rich	1.45	1.60	1.70
	Average	1.50	1.65	1.75
	Dry	1.65	1.75	1.85
19mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round

Heavy	Rich	1.05	1.15	1.20
	Average	1.10	1.20	1.25
	Dry	1.20	1.25	1.35
Medium	Rich	1.15	1.20	1.30
	Average	1.20	1.25	1.35
	Dry	1.25	1.35	1.45
Light	Rich	1.25	1.35	1.45
	Average	1.30	1.40	1.50
	Dry	1.40	1.50	1.60
16mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round
Heavy	Rich	0.95	1.05	1.10
	Average	1.00	1.10	1.15
	Dry	1.10	1.15	1.25
Medium	Rich	1.05	1.10	1.20
	Average	1.10	1.15	1.25
	Dry	1.15	1.25	1.30
Light	Rich	1.15	1.25	1.30
	Average	1.20	1.30	1.35
	Dry	1.25	1.35	1.45
12mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round
Heavy	Rich	0.85	0.90	1.00

	Average	0.90	0.95	1.05
	Dry	0.95	1.00	1.10
Medium	Rich	0.90	1.00	1.05
	Average	0.95	1.05	1.10
	Dry	1.05	1.10	1.15
Light	Rich	1.00	1.05	1.15
	Average	1.05	1.10	1.20
	Dry	1.10	1.15	1.25

(viii) Rate of Second Application

The compiled first course construction should be inspected carefully to ensure that no miscalculation has been made in binder application rates. If the resultant surface condition shows a rich or dry appearance, allowance can be made in design of the second application.

At this stage of the operation, errors if any should lie on the dry side of optimum rates since the second course of chippings will be down much more firmly onto new hot binder than it will on the cold surplus material of the first course.

The design of the binder application rate is done in the same way as previously using the Table 34 above and Table 35 below, for the appropriate chipping size.

Table 35: Binder Application Rates – Second Course

9mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round
Heavy	Rich	0.75	0.80	0.85
	Average	0.80	0.85	0.90
	Dry	0.85	0.90	0.95
Medium	Rich	0.80	0.85	0.95
	Average	0.85	0.90	1.00
	Dry	0.90	0.95	1.05
Light	Rich	0.90	0.95	1.00
	Average	0.95	1.00	1.05
	Dry	1.00	1.05	1.10
6mm CHIPPINGS		Binder Application Rate (km/m²)		
TRAFFIC	Existing Surface	Flaky	Cubical	Round
Heavy	Rich	0.70	0.70	0.75
	Average	0.70	0.75	0.80
	Dry	0.75	0.80	0.80
Medium	Rich	0.75	0.75	0.80
	Average	0.75	0.80	0.80
	Dry	0.80	0.85	0.85
Light	Rich	0.80	0.80	0.85
	Average	0.80	0.85	0.90
	Dry	0.85	0.90	0.90

(ix) Acceptable Materials

The materials listed and recommendations made under ***Single Surface Dressing*** are applicable to double surface dressing. Double surface dressing is however intended to be a stronger wearing course, providing a longer life expectancy. To achieve these targets, chippings of a high quality crushed stone should be used.

e. Equipment

Equipment requirements are fully described under ***Single Surface Dressing.***

f. Construction Methods

The construction methods described under ***Single Surface Dressing*** are applicable to each course of construction of double surface dressing.

g. Defects in Double Surface Dressing

Double surface dressing may show the same defects as those described under ***Single Surface Dressing*****.** It should be noted, that errors in construction of longitudinal joints will be far more pronounced in double surface dressing. It is recommended therefore that the longitudinal joints of the first and second course be overlapped by 15-20cm to avoid intensification of bleeding or loss of aggregates.

8.5.4 Penetration Macadam

a. General Theory

(i) Definition

Penetration macadam is a compacted pavement course used either as a base or as a heavy duty wearing course. It is composed of three separate courses of single sized stones successively bonded together by two application of hot binder.

The term “penetration” derives from the process of applying the hot binder to the open textured surface of the compacted course aggregate. The binder then penetrates down into the voids fulfilling three objectives:

- Tacking the coarse aggregate to the old surface

- Coating large stone particles and binding them together
- Partially filling the voids in the coarse aggregate.

The second application of hot binder is identical in design and construction to single surface dressing. Where penetration macadam is used as a base course, to be subsequently overlaid by a hot mix carpet, the final surface dressing element is frequently omitted and replaced by a tack coat.

(ii) Functions

The four primary functions fulfilled by penetration macadam are:

- Increase of load carrying capacity of the pavement structure
- Provision of a dust free wearing course
- Provision of a non-skid surface texture
- Rehabilitation of badly potholed and broken surfaces

b. Application

Penetration macadam can be placed on virtually any old pavement surface. It's very high strength and durability, which is achieved through the mechanical interlock of large stone particles and relatively high bitumen content, makes it an attractive material for rehabilitation of badly deteriorated bituminous pavements.

The high residual voids in the lower courses of the material render it proof against reflection of bleeding. Thus, it is an ideal material for use on heavily patched and overstressed surface dressed pavements.

Penetration macadam can be laid on old surfaces, provided that they are relatively true to profile, without resorting to scarifying and re-compaction. Nor is it necessary to provide a tack coat since sufficient binder is provided in the penetration (first) application to fulfil this objective.

Where penetration macadam is placed on soils and soil aggregates containing a high percentage of plastic files, it is customary to eliminate the risk of base infiltration by first blanketing the soil with not less than 10cm of sand or crusher fines.

Penetration macadam may be laid by either mechanically assisted teams or by labour intensive methods. It is therefore an acceptance alternative to bitumen macadam in pavement strengthening operations where production from a batch-mix plant is not available

c. Strength

Penetration macadam is one of the strongest materials available for pavement courses and for design purposes its effective thickness is always included in calculations of pavement course thickness.

d. Design Principles

The primary design factors for penetration macadam are:

- Aggregate size (three courses)
- Rates of application of aggregates (three operations)
- Rates of application of binder (two operations)

(i) Selection of Aggregate Sizes

- *Coarse Aggregate*

The selection of size of coarse aggregate is dependent only upon the desired thickness of the total course to be applied and the practical availability of crushed stone from quarries. Normally only 50mm and 40mm nominal sized aggregates will be considered. Specifications of these aggregates and their course thickness are shown in the

Table 36, below.

Table 36: Aggregate Size and Course Thickness

Square Sieve Size (mm)	Percentage Passing Sieve	
	50mm	40mm
60	100	100
50	95 – 100	95 – 100
40	35 – 70	
25	0 – 15	
19	0 - 5	0 – 5
9	0	0
Total Course Thickness	50 – 60mm	40- 50mm

The thickness of total course obtained will vary within the tolerance shown depending upon the rock and crushing plant characteristics for any material.

Larger stone sizes than 50mm nominal would have to approach a crusher run aggregate specification to obtain a good mechanical interlock. If a larger thickness than 6cm is required, it is preferable to consider either two successive courses of penetration macadam or a dry stone base.

Smaller stone sizes than 40mm nominal are not successful with this type of work. Should a smaller thickness than 4cm be required, consideration should be given to double surface dressing or hot mix carpets.

- *Key Stone*

Irrespective of the choice of course aggregate, key stone to be applied to the penetrated coarse aggregate will be 19mm single sized crushed stone.

- *Chippings*

As in double surface dressing the corrected chipping size to fill the surface voids of the key stone will normally be 9mm chipping. However, at this stage of the operation, the completed work should be thoroughly examined and final selection of chipping will be made on the principles laid down under ***Single Surface Dressing.***

(ii) Rates of Application of Aggregates

- *Coarse Aggregate*

Application rates of coarse aggregates are shown in Table 37 below.

Table 37: Coarse Aggregate Application Rate

Nominal Size (mm)	Application Rate (kg/m²)
50mm	100 - 130
40mm	80 – 100

The tolerances shown in the application rates are due to the crushing characteristics of the stone and are related to the variable thickness of the course.

- *Key Stone*

Application rate of key stone will vary slightly with choice of nominal size of coarse aggregate and will be approximately 25 kg/m².

- *Chippings*

Application rate of the chippings will, dependent upon size selected, be as shown under ***Single Surface Dressing.***

(i) Rates of Application of Binder

- *Penetration Grade Binder*

The rates of application of binder recommended by various authorities vary considerably. Penetration macadam being a material with a high voids ratio after compaction in the coarse aggregate can accommodate large quantities of excess binder without suffering from the defects of bleeding or loss of stability as occurs in most other paving materials. Since the hot binder penetrates from the surface downwards there is an inherent danger of not having sufficient surface coating to bind the keystone into the surface voids. This in fact does occur when low viscosity straight-run bitumen and cut-backs are used in tropical climates.

Provided straight-run bitumen of relatively high viscosity, such as a 60-70 or 85-100 penetration grade bitumen is used, it is possible to design an application rate without wasteful excesses.

Based on the use of straight-run bitumen with a 85-100 penetration grade, the recommended application rates for adequacy and economy are shown in Table 38.

Table 38: Penetration Binder Application Rates

Nominal Size Coarse Aggregate (mm)	Binder Application Rate (kg/m²)
50mm	4.3 – 5.2
40mm	3.5 – 4.3

For precise calculation of the rate of application it is recommended to use the relationship to weight of coarse aggregate applied, rather than to depth, which can result in wastage. The application of penetration binder should be at a rate of 0.043kg/m² per kilogramme (kg) of coarse aggregate in each square metre. Thus coarse aggregate laid and compacted to a weight of 92kg/m² should be penetrated with bitumen applied at a rate of 92 x 0.043 = 3.95kg/m².

- *Seal Binder*

The second application of binder should be designed in accordance with the principles detailed under ***Single Surface Dressing.*** It should be noted however that the surface at this stage of the operation will be fairly lean and contain a proportion of deeper voids than will normally be encountered in single surface dressing work.

Application rates for this seal may have to be increased by up to 25% in order to provide an adequate film in which to base the final chipping cover.

(ii) Acceptable Materials

- *Aggregates*

The primary assets of strength and durability of penetration macadam can only be achieved by the mechanical interlock of the stone particles. Thus, only crushed stone as defined under ***Single Surface Dressing*** should be used for this work.

- *Binders*

Only straight-run bitumen of 85-100 penetration or higher viscosity should be used for hotter application of binder. Where a bitumen distributor is employed, the placement of the binder to 85-100 penetration will be found to be most satisfactory. Application temperature for spraying should be in the range of 145ºC - 200ºC.

e. *Equipment*

(i) Aggregate Spreader

Should an aggregate spreader be available it may be employed to lay the coarse aggregate. However, since this layer is placed only one stone thick, equally satisfactory results are obtained by spread tipping aggregate from a tipper and hand raking it level.

(ii) Other Equipment

Other equipment required for use in this work is fully described under ***Single Surface Dressing.***

f. *Construction Methods Inspection*

(i) Inspection

- *Factors Governing Design*

Only the geometric factors of pavement widths, junctions and tampering out depths at bridge approaches require measurement. Details of the existing pavement texture hardness and richness of asphalt content are irrelevant to penetration macadam as a material.

- *Repair Works*

- Drainage

Defects to drainage, culverts and bridges must be made good well in advance of the works.

- Regulation

Major depressions and subsidences at bridge approaches may either be regulated ahead of the works or made up with well compacted graded aggregate immediately ahead of laying the coarse aggregate.

- Shoulders

Since penetration macadam is adding a significant thickness to the pavement, shoulders will require not only repair but also building up on completion of the work. Only repairs to slips, high shoulders and clearance work should be undertaken prior to the operation.

- Pavement

Pavement potholes and cracks should be repaired well ahead of the works, although the standard of work and uniformity of finish are not as critical to the success of penetration macadam as they are to other paving techniques.

- Corrugation

Minor corrugation are rarely reflected through penetration macadam, although it is advisable to scarify and re-compact these together with major corrugations.

(ii) Planning

All of the normal sequences of planning must be undertaken as outlined under ***Single Surface Dressing.***

(iii) Safety

Requirements for consideration of safety are described under ***Single Surface Dressing.*** Penetration macadam work, however, is similar to double surface dressing in having two complete operations in each of which hot binder is applied to the pavement surface.

A time delay of 2-3 hours should be allowed between the two operations to enable the keystone to be set up prior to overlay by seal and chipping cover. Thus, the time delay before traffic is permitted to use the new surface will be nearly double that of single surface dressing. This should be borne in mind when lengths of sections to be laid and layout sequences of sections on the highway are planned.

(iv) Operation

After the coarse aggregate has been laid and compacted, the sequences of operation become identical to double surface dressing. It is therefore necessary to remember that the keystone, which follows the first (penetration) application of binder, must be placed and rolled within approximately one minute of application of binder.

Consideration of the relative speeds of the bitumen distributor and chippings spreader are therefore vital in both planning the length of section to be treated and in the actual operation efficiency.

- *Preparation*

  - First, the lane length to be treated is given its final cleaning with a mechanical broom
  - Barriers, warning signs and controls are erected and manned
  - All equipment is checked
  - First tipper with coarse aggregate is lined up at the beginning of the section and facing in the direction of work
  - Second, third, etc. tippers are similarly placed in position ahead of the work

- Rollers are lined up behind the first tipper.

- *Execution*

- Spreading and Compacting Coarse Aggregate

Rough spreading of coarse aggregate is usually achieved by spread tipping. Should the lane width to be covered be greater than one tipper width and less than two tipper widths, the additional part strip can be simultaneously laid with a second tipper fitted with a slopping cut-off plate of the appropriate length. Tailgates are restrained by chains to maintain a relatively uniform flow.

Final spreading and levelling of aggregate is achieved by hand raking to a uniform profile and hand removal of excessively large stone particles.

Compaction is carried out with 8-10 ton steel wheel rollers rolling longitudinally, beginning at the edges and progressively overlapping towards the centre. Rolling should continue until the layer is thoroughly compacted and stone particles interlocked. Care should however be taken to watch the rolling carefully and stopped as soon as any sign of cracking or rounding of aggregate due to over rolling appears. The profile should be checked with a camber board to obtain the 2.5% camber required by this type of surfacing.

- Application of Penetration Binder and Keystone

The sequence of operation and equipment used for this part of the operation follows precisely the same procedure as detailed under ***Single Surface Dressing.***

- Application of Seal Binder and Chippings

After bedding in the keystone aggregate it is desirable to allow 2-3 hours for the keystone to become firmly bonded to the coarse aggregate. If possible no traffic should be permitted onto the surface during this time. Once the keystone is securely bonded, the final seal ad chipping placement may follow precisely as previously described for ***Single Surface Dressing.***

g. *Defects in Penetration Macadam*

Penetration macadam presents a wearing course of basically surface dressing to the traffic and can therefore show any of the defects listed and described under ***Single Surface Dressing***. However, due to its high mechanical strength and greater depth, the likelihood of defects occurring is very much less.

8.5.5 Bitumen Macadam

a. General Theory

(i) Definition

Bitumen macadam is a hot-mix surface material composed of preferably crushed course and the stone aggregates uniformly mixed and coated with bitumen. Like asphaltic concrete, it is one of the families of pre-mixed surfacing material, which can best be illustrated by Table 39 below showing the three principle members of the family and their material contents:

Table 39: Comparison of Different Asphalts

Surfacing Type	Aggregates		Filler	Bitumen
	Coarse	Fine		
Bitumen Macadam	x	x		x
Asphaltic Concrete	x	x	x	x
Sheet Asphalt		x	x	x

Mineral fillers are normally not used in the mix design of bitumen macadam and its inherent design feature is therefore its relatively high voids content. Bitumen macadam therefore develops almost all of its stability and strength from the mechanical interlocking of the larger aggregate particles.

(ii) Functions

Bitumen macadam by virtue of its stone content is a versatile material which can fulfil the following functions:

- Increase the load carrying capacity of the pavement as a base course, binder course or as a temporary wearing course
- Provide a dust free wearing course
- Provide a good open textured non-skid wearing course
- Provide a platform on which a high quality wearing course can be laid either as a binder or regulating course

The major assets of bitumen macadam are:

- Relatively high voids ratio of compacted mix, permitting the material to be laid on flushed old surfaces with less risk of reflected bleeding
- cheapness of manufacture due to its lower bitumen and filler content

Both of the assets contribute to its major weakness of lesser durability and imperviousness compared to asphaltic concrete. The consequence is that it requires earlier resealing or overlaying if used as a wearing course on highly trafficked roads.

b. Application

Bitumen macadam is used in a wide variety of forms as:

(i) Wearing Course

Bitumen macadam may be utilized as a wearing course on low to medium trafficked roads:

- On any prepared (primed) base
- On any surface dressed or penetration macadam surface that has been given a tack coat
- On old bitumen macadam surfaces

(ii) Base Course

- On any prepared and primed sub-base material
- On lower base material, such as soil cement
- On temporary or low grade surface such as surface dressing.

(iii) Binder Course

On any prepared base prior to receiving asphaltic wearing course.

(iv) Regulating Course

On any old bituminous paved surface with depressions, subsidence's, ruts, etc. prior to paving with bitumen macadam or asphaltic concrete.

(v) Patching Material

On any old bituminous paved surface for pothole patching, usually as a cold.

(vi) Temporary Surfacing

On any newly constructed base courses opened to heavy construction traffic prior to final surfacing.

c. Strength

Bitumen macadam is a very high mechanical strength material and all courses. Other than wearing courses composed of less than 19mm nominal sized aggregate should be included in strength calculations.

d. Design Principles

The primary factors to be considered in the design of bitumen macadam are:

- Definition of use
- Determination of depth of course

- Aggregate bleeding
- Bitumen content

(i) Definition of Use

Variable different aggregate grading curves are available for use in design of bitumen macadam depending on its use as a base, wearing, regulating or binder course or cycle track construction. The grading curve is not interchangeable. They are presented under ***Aggregate Grading*** below.

(ii) Determination of Depth

Being a material whose strength and stability depends upon mechanical interlock of aggregate particles there are very well defined limits to the thickness that can be laid, compacted and be maintained stable under load. The larger aggregate particles will drag at the screed plate of the paver and scouring the carpet surface if excessively thin carpets are laid. Conversely, very thick carpets will fail to compact the larger aggregate particles into the required stone-to stone contact from which stability under traffic is achieved. Tolerances of permitted thickness of single course construction are shown for each grading under ***Aggregate Grading*** below.

(iii) Aggregate Grading

Bitumen macadam is simple and relatively foolproof material with good built-in tolerances that permit experienced workmen to achieve consistently acceptable material without extensive testing.

These tolerances are achieved by the open grading and it is therefore dangerous to alter the grading shown below to convert them to denser mixes. If such dense mixes are required for increased impermeability, then asphaltic concrete must be used and the full sequence of design and quality control testing must be applied.

- *Base Course*

Base course gradings are very open textured with virtually no fines and low bitumen content. They are solely for the purpose of providing strength and they are extremely porous and may not be used as even temporary wearing courses. The grading for 50mm and 40mm nominal sizes are shown in Table 40 below:

Table 40: Base Course Grading

Normal Size	50mm	40mm
Passing Sieve (mm)	Percentage by Weight	
60	100	
50	90 – 100	100
40	35 – 65	90 – 100
25	20 – 40	50 – 80
12	5 – 20	10 – 30
3	0 - 10	0 - 10
Binder content (%)	2.5 – 3.3	3.0 – 3.8
Compacted Thickness single course (cm)	6.0 – 10.0	5.0 – 7.5

- *Binder Course*

The grading shown in the Table below is suitable for use as a binder course, regulating course or temporary wearing course during construction work. If it is to be left exposed to traffic through a rainy season it should be given a light surface dressing.

Table 41: Binder Course Grading

Nominal Size	40mm
Passing Sieve	Percentage by Weight (%)
50	100
40	90 – 100
24	50 – 85
12	30 – 50
6	20 – 30
3	10 – 20
No. 52	2 – 10
Binder Content (%)	3.5 – 4.3
Compacted thickness of single course (cm)	5.0 – 7.5

- *Wearing Course*

The grading for 19mm, 12mm and 9mm nominal size wearing courses are shown in Table 42 below:

Table 42: Wearing Course Grading

Nominal Size	19mm	12mm	9mm
Passing sieve (mm)	Percentage by weight (%)		
24	100		
19	90 – 100	100	
12	50 – 80	90 – 100	100
9			85 – 100
6	15 – 35	20 – 40	30 – 60
3	5 – 20	10 – 20	10 – 20
No. 200	2 – 6	2 -6	2 – 6
Binder Content (%)	3.8 – 4.8	4.0 – 5.0	4.5 – 5.5
Compacted thickness of single course (cm)	2. 5 – 3.1	1.8 – 2.5	1.2 – 1.8

- *Dense Wearing Course*

The wearing courses showing in Table 42 above will give adequate service under light traffic conditions and remain impermeable under light to medium traffic for 2 – 4 years. For medium to heavier traffic it is advisable to use a denser grading. These gradings for 19mm, 12mm and 9mm nominal sizes are shown in Table 43 below:

Table 43: Dense Wearing Course Grading

Nominal Size	19mm	12mm	9mm
Passing sieve (mm)	Percentage by weight (%)		
25	100		
19	95 – 100	100	
12	70 – 90	95 – 100	100
9	55 – 75	65 – 80	95 – 100
6	40 – 60	45 – 65	50 – 75
3	25 – 40	25 – 40	25 – 40
No. 14	15 – 30	15 – 30	15 – 30
No. 200	3 - 6	3 - 6	4 – 8
Binder Content (%)	4.4 – 5.4	4.4 – 5.4	4.6 – 5.6
Compacted thickness of single course (cm)	2. 5 – 3.1	1.8 – 2.5	1.2 – 1.8

- *Cycle Tracks and Footpaths*

The wearing courses for cycle tracks and footpaths should be of a smoother texture than the main carriageway if they are to achieve their desired result of segregation of traffic by speed characteristics. The grading shown in Table 44 below may be laid on a primed and lightly tack-coated soil aggregate base.

Table 44: Cycle Track and Footpath Grading

Nominal Size	40mm
Passing Sieve (mm)	Percentage by Weight (%)
9	100
6	90 – 100
3	40 – 60
No. 200	2 – 6
Binder Content (%)	4.8 – 5.8
Compacted thickness of single course (cm)	1.2 – 1.8

e. Aggregate Blending

Since it may be difficult to obtain the product from any one crusher setting to comply with the grading requirements listed above, particularly for dense wearing courses, it may become necessary to blend aggregates from two or more stockpiles. The method of designing such blends is fully described under Asphaltic Concrete.

f. Binder Contents

The binder content is shown in each of the tables above and is expressed as a percentage of the total mix by weight. Where the selected blend, available from production resources, lies at the fine extreme of the range permitted then the appropriate binder content would be the maximum as shown. Conversely, the minimum binder content is appropriate to the coarse extreme of the aggregate range. The percentages of binder content are based on straight-run bitumen. These may be in the penetration range 85 – 300.

The use of medium curing heavy cut-backs can be permitted for wearing courses but is not recommended except for dense wearing courses under heavy traffic conditions.

Under these circumstances it would be more appropriate to surface highways with asphaltic concrete.

g. *Acceptable Materials*

(i) Coarse Aggregates

Coarse Aggregates for bitumen must be crushed stone. It is essential to have cut angular face coarse aggregate particles to obtain a mechanical interlock. Almost any strong rock is suitable for wearing courses except certain lime stones with high polishing characteristics. Since bitumen macadam possesses very little fines and no filter, the larger stone particles are exposed to traffic and polish far more readily than denser paving materials.

(ii) Fine Aggregates

Fine aggregates should wherever possible be crushed stone. Where crushing plant capacity cannot meet this demand clean and washed coarse sand may be used.

(iii) Binders

The recommended binders for use in bitumen macadam are:

- Straight-run bitumen 85 – 100 penetration, 120 - 150 penetration and 200 – 300 penetration

Mixing temperatures should fall within the following ranges:

- Binder 95º C – 165º C
- Preheated aggregate 65º C – 150º C

The higher levels of temperature for mixing should be employed where paving is distant from the production site. Care should however be taken not to overheat aggregate, which may cause cracking of stone particles.

h. Equipment

(i) Batch-Mix Plant

Because of the large voids ratio existing bitumen macadam grading, the materials does not require the same consistently accurate gauging of batches as is necessary in the production of asphaltic concrete. It is possible therefore to use either a batch-mix plant or a continuous feed plant in manufacture of the material. Generally, only batch-mix types of plant are readily available and this equipment is fully described under Asphaltic Concrete.

(ii) Other Equipment

The remaining equipment requirements for paving with bitumen macadam are those listed and described under ***Asphaltic Concrete.***

i. Construction Methods

Construction methods follow the same sequences and procedures as outlined under Asphaltic Concrete.

j. Testing

The need for testing bitumen macadam is less critical than for asphaltic concrete since the tolerances in design limits are wide and any reasonably trained operator in quarry production plant and paving team should be able to contain the mix consistently with these tolerances. Thus, whilst a full range of testing is required, they need to be carried out al less frequent intervals.

(i) Raw Materials Tests

- *Aggregates*

Once a week samples should be taken from each cold bin for sieve analysis. Should there be reasons to suspect the nonconformity of cleanliness of aggregates, plasticity index or sand, equivalent tests should also be performed.

- *Bitumen*

A sample of approximately one litre should be sent for laboratory tests from each major consignment of bulk delivery.

(ii) Batch-Mix Plant Tests

- *Aggregates*

Once a week or on report of defects, a sample shall be taken from each hot bin for sieve analysis.

Similarly once a week, a sample shall be taken of the combined hot aggregates for sieve analysis.

(iii) Paving Tests (Compacted Pavement)

Once a day a sample, not less than 25cm square, will be cut from the compacted carpet to the full depth of the course constructed. This sample should be tested for density and compacted thickness.

k. Defects in Bitumen Macadam

Defects common in bitumen macadam are largely due to deviation from the design grading by virtue of misunderstanding the purpose and limitations of the material or errors in production, improper compaction sequences compaction outside of temperature ranges and contamination of the material overheating during production.

Defects will materialize as described generally under ***Asphaltic Concrete***, although flushing and bleeding are both rare and unnecessary in bitumen macadam. One additional defect is however relatively common with newly trained designers and operators,

(i) Dragging

Dragging is a defect, which becomes visible by scour lines appearing in the surface of the carpet immediately behind the paver screed plate. It is caused by the larger stone particles being unable to pass under the screed plate due, either to:

- Oversize (reject) particles in coarse aggregate, which may be due to worn screen plates on the crushing plant.
- Design grading outside the coarse limits
- Carpet thickness below the minimum tolerance permitted or to a combination of two or more of the above causes.

The cure for dragging falls into three stages:

- *Immediate Reinstatement*

A shovel full of material is taken from the paver hopper and thrown with a scatter motion over the scored area. Excess coarse aggregate is lightly raked from the surface and surface gently smoothened with the back of the rake.

- *Temporary Corrugation*

Should dragging be an isolated instance occurring only once or twice per truck load, the above immediate reinstatement will suffice. The defect must however be reported to the production foremen since it most likely is due to a screen defect in the production plant.

Where two or more scored lines appear simultaneously or where the frequency is greater than two per truck load, then the paver screed must be adjusted to thicken the carpet being laid. The carpet should be stabbed to check thickness before and after adjustment.

- *Permanent Correction*

After correction to the carpet thickness the paving foremen will similarly report the defect to the production foremen and his Technical Officer, for a thorough examination of material quality, design and thickness of paving.

8.5.6 Asphaltic Concrete

For additional information on asphaltic concrete, reference should be made to the Asphalt Institute Manual MS-2.

a. General Theory

(i) Definition

Asphaltic concrete is a surface material composed of (preferably) crushed aggregates uniformly mixed and coated with bitumen. It is therefore one of the family of premixed surfacing materials which can be best illustrated by Table 45 below showing the three principal members of the family.

Table 45: Comparison of Different Asphalts

Surfacing Type	Aggregates		Filler	Bitumen
	Coarse	Fine		
Bitumen Macadam	x	x		x
Asphaltic Concrete	x	x	x	x
Sheet Asphalt		x	x	x

Asphaltic concrete therefore derives its strength both from the mechanical interlocking of the coarse aggregate particles and from the dense, low residual voids of the intimate mix characteristics.

(ii) Functions

A well designed, manufactured and laid asphalt concrete mix will fulfil the following functions and posses these qualities.

- *Stability*

Stability is the ability of the mix to resist deformation from the imposed traffic loads and is dependent upon both internal friction and cohesion. It is therefore the resultant of coarse aggregate interlock, density of mix and quantity of bitumen.

- *Durability*

Durability is the ability of the mix to resist disintegration by traffic and weathering and is dependent largely upon cohesion and low residual voids in the mix. Durability is increased by increased quantity of bitumen and increased filler to build a thicker coating around the aggregate particles.

- *Flexibility*

Flexibility is the ability of the mix to accommodate localized and differential settlements in base and sub-base without cracking. Maximum flexibility will be achieved at increased bitumen content in a relatively open graded aggregate.

- *Fatigue Resistance*

Fatigue r esistance is the ability of the mix to withstand repeated flexing under wheel loads. Resistance to fatigue is largely dependent upon the thickness of the bitumen and filler coating on the aggregate particles. Increased resistance is obtained largely by increased density of the mix.

- *Skid Resistance*

Skid resistance is the ability of the mix to provide good frictional forces between the surface and traffic wheels. Best skid resistance will be obtained from aggregates with a rough surface texture and low polishing characteristics. Very dense mixes with low residual voids may tend to flush or even bleed. The presence of free bitumen on the surface pavement will particularly in wet weather greatly reduce skid resistance..

- *Impermeability*

Impermeability is the ability of the mix to resist the passage of air and water into or through the surface course. Whilst low voids are obviously a desirable asset, they are not as important as the interconnection of the voids. Impermeability will therefore increase with increased thickness of the bitumen and filler coating on the aggregate particles.

- *Workability*

Workability is the ease with which the mix can be laid and compacted. From the previous qualities listed above it would appear desirable to aim at very high densities in design. The workability may however be so low as to make it impossible to achieve compaction to the normal 95-97% of laboratory Marshall Test Design Density.

b. Application

Asphaltic concrete is a surface material used primarily in wearing courses and binder course. It can also be used in base course and regulating (or levelling) courses. It is however a material with a relatively high bitumen and filler content and is therefore a high quality and expensive material. It will normally be more economic to use dry (crushed) stone as a base material. Should full depth bituminous base be required on a highway section, it may be more economic and practical to use bitumen macadam as a base in view of its simplicity in design and greater tolerances on grading and bitumen content.

Asphaltic concrete may be laid on:

- Untreated bases and sub-bases that have been suitably brushed clean of all loose material and dust and adequately primed
- Old bituminous prevents that have been repaired, cleaned and provided with a tack coat
- Old rigid (concrete) pavements and bridge decks that have been repaired should be cleaned and been provided with a tack coat. Joints should be raked out to a depth of 1cm and refilled with asphaltic joint filler material.

- Newly constructed asphaltic concrete or bitumen macadam bases without a tack coat, provided that no traffic or dust has been allowed on the surface prior to paving.

c. Strength

Asphaltic concrete courses are generally considered to add strength to the pavement structure. In many cases however, these course are relatively thin wearing course additions, which will be virtually eroded by traffic in 5-7 years dependent upon traffic density. Courses of less than 2.5cm cover thickness or courses containing coarse aggregate of less than 19mm nominal size are usually therefore discounted from strength depth calculations.

d. Design Principles

Bearing in mind the functions of asphaltic concrete and the qualities that are required to fulfil those functions, it must be ensured that the design provides:

- Sufficient bitumen for durability and impermeability
- Sufficient mix stability to meet traffic requirements
- Sufficient residual voids in the compacted mix for flexible and to meet additional traffic compaction; but not-so much as impair fatigue resistance
- Sufficient workability

(i) Aggregate Grading

To obtain the maximum density of aggregate after compaction, its sieve analysis should conform as closely as possible to the appropriate fuller curve for the maximum particle size being used. See Figure 64 below.

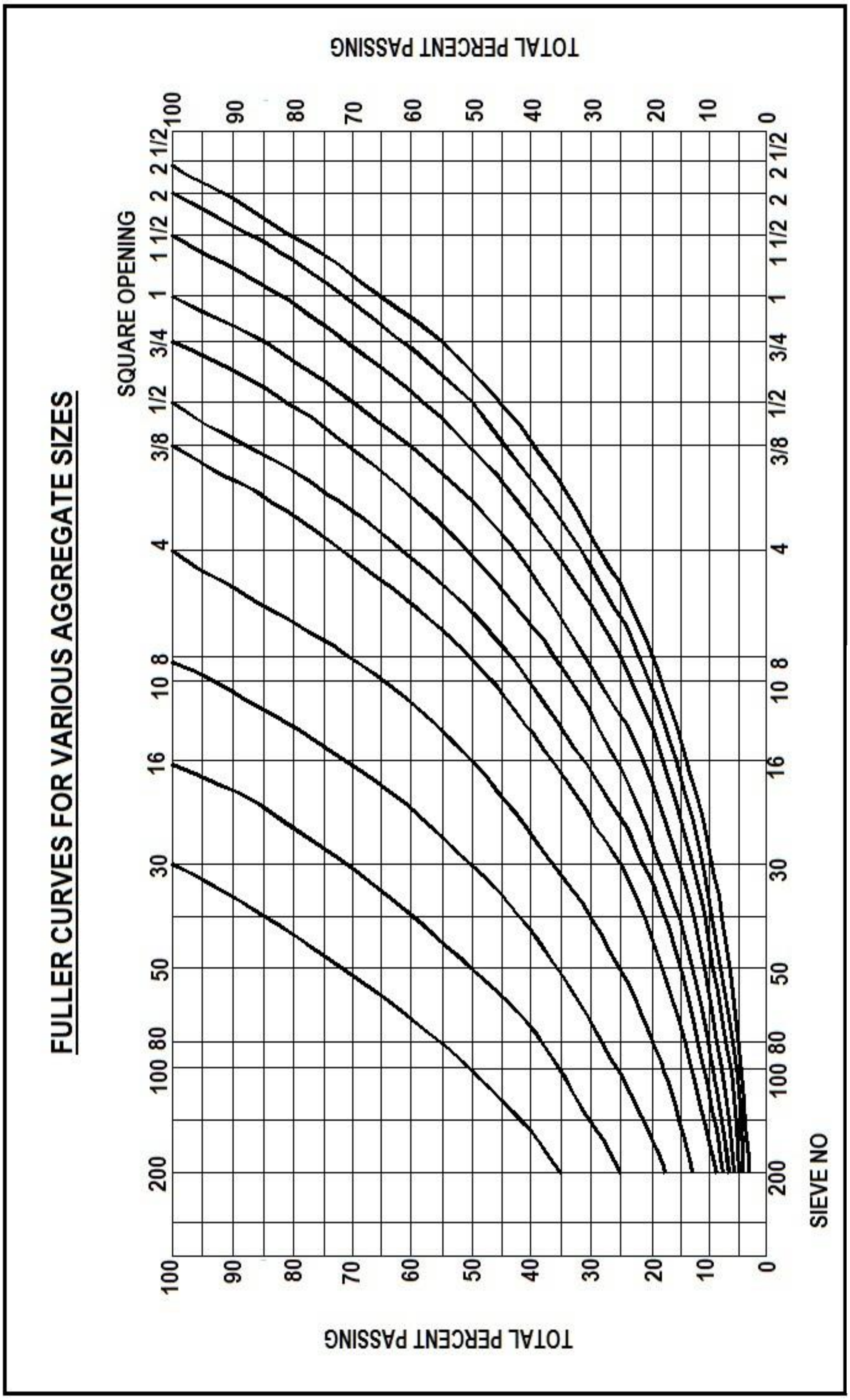


Figure 64: Fuller Curves for Various Aggregate Sizes

In practice, no aggregate will be found in nature, or manufactured by machines, conforming continuously to so precise analysis. The grading is therefore specified with tolerances, which can be shown either graphically as above, or in Table 46 below:

Table 46: Aggregate Grading

(mm)	19.1	12.7	9.52	4.76	2.38	0.59	0.297	0.119	0.074
(in)	3/4	1/2	3/8	No.4	No.8	No.30	No.50	No.100	No.200
% Passing	100	80-100	70-90	50-70	33-50	18-29	13-23	8-16	4-10
Mean	100	90	80	60	42	23	18	12	7

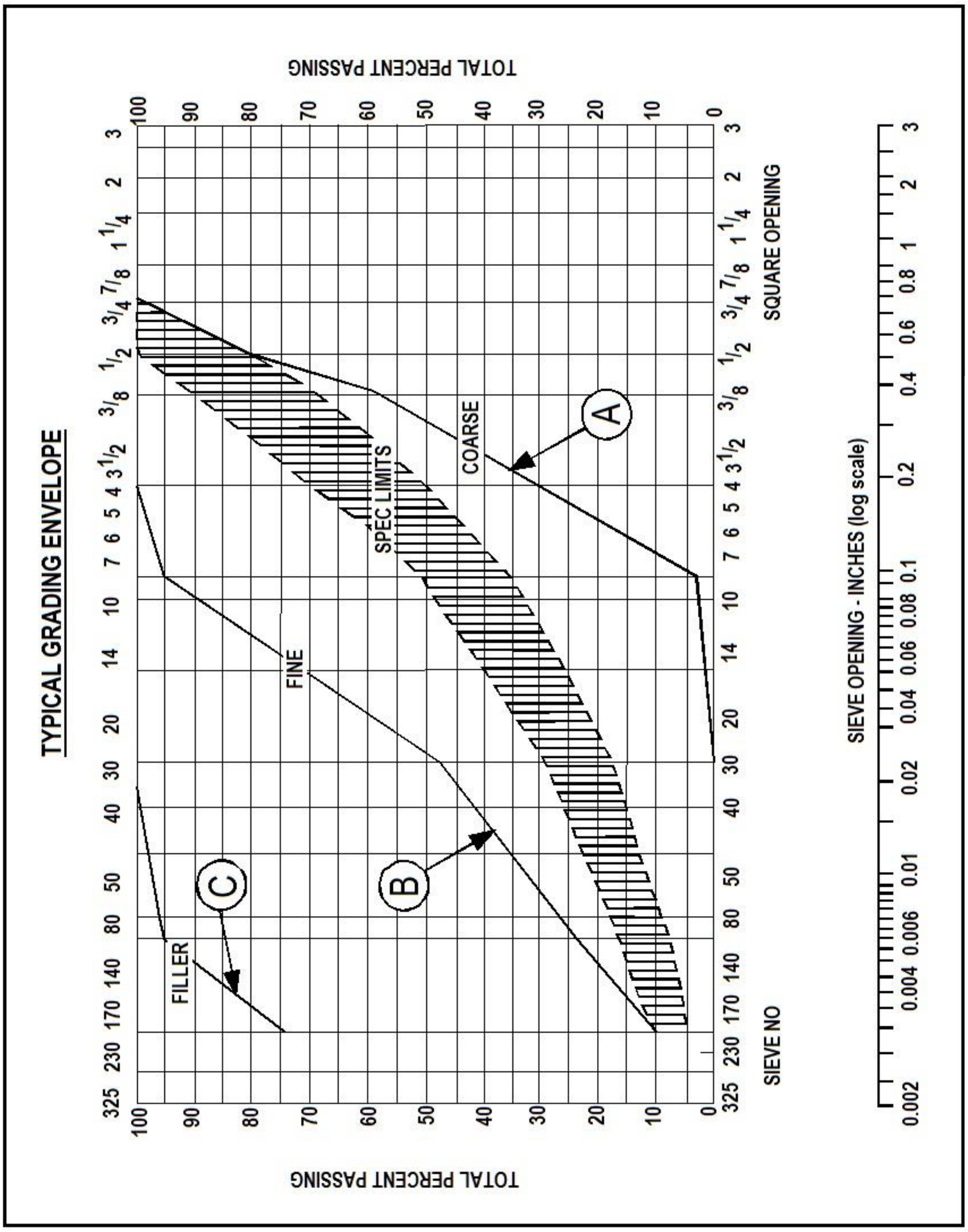


Figure 65: Typical Grading Envelope

(ii) Aggregate Blending

Although it is possible with a multi-stage crushing plant to produce such as aggregate grading, even down to fines content for filler from limestone rock, it is usually necessary to blend two, three or more aggregates to achieve the desired grading. Figure 65 shows three such-aggregates plotted for coarse, fine and filler content.

The three aggregates are represented in tabular form in Table 47 below:

Table 47: Grading of Aggregates to be blended

(mm)	19.1	12.7	9.52	4.76	2.38	0.59	0.297	0.119	0.074
(in)	3/4	1/2	3/8	No.4	No.8	No.30	No.50	No.100	No.200
Specification	100	80-100	70-90	50-70	33-50	18-29	13-23	8-16	4-10
Aggregate A	100	85	58	29	3	0	0	0	0
Aggregate B	100	100	100	100	95	47	35	23	8
Aggregate C	100	10	100	100	100	100	98	95	74

Sieves No.8 and 200 represent the border lines between coarse aggregate, fine aggregate and filler. The aggregates can be shown simplified as their percentages retained on No.8 (coarse), passing No.8 and retained on No.200 (fine) and passing no.200 (filler). This is tabulated in Table 48 below:

Table 48: Example of Simplified Grading

Sieve Size	+ No.8	- No.8 + No.200	- No.200
Specification	58	35	7
A	97	3	0
B	5	87	8
C	0	26	74

These results may now be plotted on a tri-axial chart as shown in Figure 66. The line joining AS is produced to cut the line joining BC at D. Each line is measured in length.

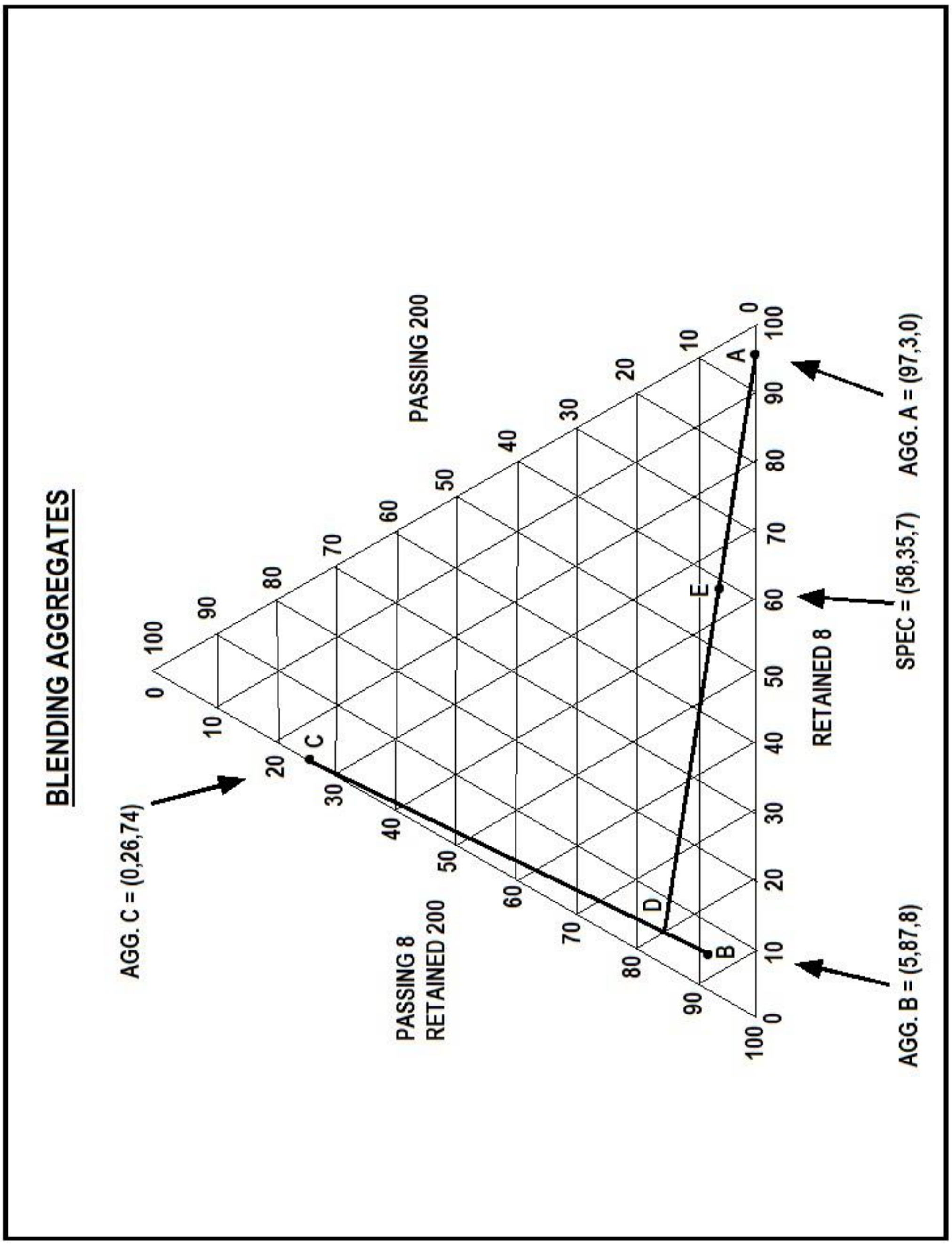


Figure 66: Blending Aggregates

From the Chart:

a = DS/DA = 49/85 = 0.58

a + b + c = 1.0

b + c = 1.0 – a = 0.42

$$b = \frac{DC}{BC}(a - c) = \frac{56}{64} \times 0.42 = 0.37$$

c = 0.42 – 0.37 = 0.05

The proportions of each aggregate (A, B, C), required to give the specification (S), are denoted by a, b & c.

Using these proportions the three aggregates may now be finally tabulated to check that they lie within the tolerances of the specification. These are shown in Table 49 below:

Table 49: Blending of Aggregates A, B & C

(mm)	19.1	12.7	9.52	4.76	2.38	0.59	0.297	0.119	0.074
(in)	3/4	1/2	3/8	No.4	No.8	No.30	No.50	No.100	No.200
Specification	100	80-100	70-90	50-70	33-50	18-29	13-23	8-16	4-10
0.58 x A	58	49.3	33.6	16.8	1.7	0	0	0	0
0.37 x B	37	37	37	37	35.2	17.4	13	8.5	3
0.05 x C	5	5	5	5	5	5	4.9	4.8	3.7
TOTAL	100	91.3	75.6	58.8	41.9	22.4	17.9	13.3	6.7

This grading of aggregate fits nicely within the tolerances permitted and these proportions of the three types of aggregate may now be used to make up specimens for testing in the design of bitumen content. When the blending of the aggregate has been determined, the bulk specific gravity of each aggregate must, if not already known, now be determined.. This will be required in the voids analysis described below and is designated as GA, GB and GC.

(iii) Behaviour of Bitumen Coatings

Many aggregates available for asphaltic concrete have a degree of porosity, which will absorb some of the bitumen.

Whilst it is relatively simple to determine the bulk and apparent specific gravities the virtual specific gravity is difficult since bitumen will never fill all of the capillary pores in aggregates. The simplest approach is to test the aggregates by rice‘s vacuum saturation method (ASTM-D2041) to determine the bitumen absorbed as a percentage of the aggregate weight. Once this relationship is known all other calculations can be made by the relatively simple bulk specific gravity.

(iv) Bitumen Content

The most common method of bitumen content design for asphaltic concrete is the Marshall Test Method. It should be noted however, that this method of design and field control is applicable only to mixes made with aggregate up to a maximum size of 25mmand penetration grades of bitumen. The test is made up of three parts:

- Bulk specific gravity measurement
- Stability and flow testes
- Density and voids analysis

The results of these investigations are plotted on five graphs or unit weight, stability, flow air voids and voids in mineral aggregate; each against varying bitumen content. The optimum bitumen content to meet the qualities required of asphaltic concrete is selected from graphs.

- *Preparation of Tests Specimens*

The tests specimens required to fit the Marshal Testing Machine are 4″ (10.16cm) diameter and 2.5″ (6.35cm) thick of compacted asphaltic concrete.

- Number of Specimens

It is necessary to have test specimens of different bitumen content varying by increments of 0.5 percent by weight across the estimated likely requirement. To allow for minor irregularities three specimens of each bitumen contents are required, making a total of fifteen specimens in all to be prepared.

- Weight-Batching of Aggregates

Aggregates are weighted separately in the following fractions to make up each of the specimens:

- Filler (passing No.200
- Fine aggregate (passing No.8 retained on No.200)
- Coarse aggregate 1. (Passing No.4 retained on No.8)
- Coarse aggregate 2. (Passing No.3/8̋ retained on No.4)

- Coarse aggregate 3. (Passing ¾” retained on 3/8”)
- Coarse aggregate 4. (Passing 1” retained on ¾”)

Bulk aggregate prior to sieving and weighing are oven dried to even weight.

- Preparation of Mix

The temperature – viscosity curve for the particular bitumen to be used must be obtained from the bitumen manufacturers or supplier. From this chart, mixing and compacting temperatures can be established as described below. Sufficient aggregate for one specimen is oven heated to approximately 30°C above the temperature required to provide a viscosity of 150-190-centistokes for the grade of bitumen to be used and dry mixed in a bowl. The weighed percentage of hot bitumen is added and thoroughly mixed to even consistency.

- Compaction of Mix

The specimen batch is placed into a mould, spaded firmly, smoothened and compacted with the standard hammer on both faces at a temperature equivalent to 250-310 centistokes viscosity. The number of blows of the hammer will be 75, 50 or 35 for heavy, medium and light traffic respectively.

- Extraction of Specimen

The specimen is permitted to cool in air prior to extraction from the mould with a jack. The extracted specimen is placed on a smoothed level surface to cool to room temperature prior to testing.

- *Bulk Specific Gravity*

This is determined by weighing the specimen in air and in water. Should the surface texture of the specimen be open textured it may be necessary to coat it with paraffin wax for a second air weighing prior to weighing in water.

- *Stability and Flow Test*

The specimen is heated to 60°C in a water bath for 30-40 minutes and then carefully dried. It is then inserted into the lower testing head of the Marshall Testing Machine. The upper testing head is fitted with the flow meter in position. The testing load is applied at a constant rate of 2 inches per minute until failure occurs, the point at which maximum load is obtained. At this point, the load dial reading is noted and the flow meter lifted off the guide rod.

Load and flow readings are recorded for each specimen.

- *Density and voids Analysis*

With the data from the penetration, test specimens and tests of bulk specific gravity it is now possible to determine the two essential factors of the mix-air voids (Va) and voids in mineral aggregate (VMA). A typical example will illustrate the methods.

From the aggregate blending and testing-section above, the bulk specific gravity of the aggregates in the wet (i.e. bituminous) mix must be determined (= G_{sb}).

PA, PB and PC represent the percentages of aggregates A, B and C in the dry mix (=58%, 37% and 5% respectively in the example given above).

The percentage of each aggregate in the wet mix, with a bitumen content Pb of 7% by weight, will thus be:

$$P_A = \frac{100 - P_B}{100} \times P_A = \frac{100 - 7}{100} \times 58\%$$

$$= 53.94\%$$

$$P_B = 34.41\%$$

$$P_C = 4.65\%$$

With aggregates A, B and C having bulk specific gravities of GA = 2.776, GB = 2.511 and GC = 2.430, the bulk specific gravity of the total aggregate in the wet mix will be

G_{sb} = $(100 – P_b) / (PA/G_A + PB/ G_B + PC/ G_C)$

= (100 – 7) / (53.94/2.776 + 34.41/2.511 + 4.65/2.430)

= 93.0/35.04

= 2.654

From the testing of the mixed and compacted samples:

- Weight of specimen (W) = 1207.2gm
- Volume of specimen (V) = 515.0cc
- Bulk specific gravity (G_{mb}) = 2.344

- Calculation of Weights

Weight of Bitumen (W_b) = Pb W/100 where P_b = Bitumen content (7.0%)

= 7/100 x 1207.2

= 84.5gm

Weight of Aggregate (W_S) = W - W_b

= 1207.2 - 84.5

= 122.7gm

Weight of absorbed Bitumen (W_{ba}) = Pba.WS / 100

= 1.10/100 x 1122.7

= 12.35gm

Note: P_{ba} = Bitumen absorbed

By Rice’s Method = 1.10gm of bitumen per 100 gm of aggregate.

- Calculation of Volume

Volume of Bitumen (V_b) %	=	(W_b/G_b) x 100/V	Gb = Specific Gravity of bitumen = 1,010
	=	84.5/1.010 x 100/515.0	
	=	16.25%	
Volume of Absorbed Bitumen (V_{ba})	=	(W_{ba}/G_b) x 100/V	
	=	(12.3/1.010) x 100/515.0)	
	=	2.37%	

Volume of Aggregate (V_{sb})% Bitumen (V_{ba})	= =	(W_s/G_{sb}) x 100/V (112.2.7/2.654) x 100/515.0)
		= 82.14% G_{sb} = Bulk Specific Gravity of Aggregates = 2.654

- Voids Analysis

Air Voids ($V_{a)}$) = 100 – V_b – V_{sb} + V_{ba}

= 100 - 16.25 - 82.14 + 2.37

= 3.98%

Voids in Mineral Aggregate = 100 - V_{sb}

(VMA) = 100 – 82.14

= 17.86%

- *Preparation of Results*

The data obtained from the above tests and analysis are shown in typical form in and are plotted against bitumen content as shown in Figure 66 at the end of this section.

The graphical plots are connected by smooth curves that obtain the best fits for all values.

- *Interpretation of Results*

The best results will be obtained from a selection of bitumen content under the following conditions:

- Unit Weight

The maximum possible unit weight should be obtained and this is defined on the curves at bitumen content 6.0%.

- Asphaltic Concrete Requirements

Table 50 is a summary of the Asphaltic Concrete mix properties and requirements:

Table 50: Asphalt Concrete Mix Requirements

Property	Mix Requirements
Marshall Stability (kN)	8 - 18
Marshall Flow (mm)	2 - 6
Voids in Mineral Aggregate (%)	> 15
Voids Filled with Binder (%)	65 - 75
Air Voids (%)	4 - 6
Binder Thickness (microns)	5.5 – 8.0
Filler Bitumen Ratio	1.0 – 1.5

- Design Bitumen Content

The design bitumen content will depend on the composition of the asphalt mix that meets the requirements set out in Table 50 above. However, for normal continuously graded asphaltic concrete the binder content should be between 5.5% and 6.5%.

As the asphaltic concrete will be produced in machines and with aggregates that will nearly always show some variations from the selected design criteria, practical upper and lower limits to the bitumen content are normally set at ± 0.2% on the optimum content. It is not difficult now to achieve a mixture with most asphalt plants within ± 0.2% of target.

e. *Equipment*

(i) Batch-Mix Plant

Mixing plants for the production of pre-mixed surface materials may be either batch-mix or continues- mix machines. In view of the very high degree of accuracy required in the design and therefore manufacture of asphaltic concrete only batch-mix plants should be used for this material. The machine consists of eight basic components namely:

- Cold bins
- Dryer
- Screens
- Hot bins
- Weighing unit
- Mineral Filler feed
- Bitumen pump
- Pug mill

○ *Cold Bins*

These are cold aggregate storage, which may range from elevated hoppers with feed control to a belt conveyor to ground stockpiles shovel loaded to a feeder. Quarry production of aggregates is delivered to the cold bins, which should have a holding of not less than 2-3 days plant capacity. If the method of cold bin storage and feed is provided, it is essential to compare the results of the various aggregate components of fine and coarse material closely to that of the design quantities.

- *Dryer*

The purpose of the dryer is to remove moisture from the aggregate and increase its temperature to that of the bitumen mixing temperature. The unit consists of an inclined rotating drum with fixed paddles permitting aggregate to tumble slowly from its upper end to the lower output end. Hot gases from a burner are fed upwards through the dryer. Since the hot air blast will usually carry away dust and fines, a cyclone or dust collector is usually fitted to the upper end of the drum to minimize atmospheric pollution. Loss of material, which if washed, may have to be replaced by an expensive alternative such as limestone filler or cement. This dust is collected and recycled direct to the filler bin.

- *Screens*

Material from the dryer is elevated directly onto a bank of vibrating square mesh screens, which separate the combined aggregates normally into four passing fractions, which are:

- Retained 25mm - rejected
- Passing 25mm Retained 12mm - bin 1
- Passing 12mm Retained 6mm - bin 2
- Passing 6mm Retained 3mm - bin 3
- Passing 3mm - bin 4

- *Hot Bins*

These are temporary storage bins mounted directly under the screens. There are usually four bins on modern equipment. They act as a single surge pile between the cold bin supply and the cycles of batch mix demand and are fitted with overflow chutes to prevent over spill into adjacent bin compartments. Feed from the cold bins must therefore he gauged with reasonable accuracy to ensure that no hot bin or bins become starved during mixing operations.

- *Weighing Unit*

Aggregates are released from the hot bins into the weigh hopper beginning first with the largest size and progressing down to the finest size. The weigh hopper is suspended from a scale beam and weights are recorded cumulatively. Most modern plants are semi- automated permitting the required proportions to be preset on the controls and thereby eliminating human error and operation fatigue.

- *Mineral Filler Feed*

The last aggregate functions to be added are the mineral fillers. These are usually fed by a worm screw via a separate hopper. Where extracted and re-cycled dust is not suitable or adequate in quantity, the filler is made up of imported limestone dust or cement, which is not passed through the dryer circuit.

- *Bitumen Pump*

Bitumen, the final addition to the mix, is either pumped to a weigh bucket or controlled directly to the pug mill by volumetric measurement. Where the latter is used, allowance will have to be made for the vibration in volume with temperature.

- *Pug mill*

This is the mixing chamber which is usually an open topped twin chamber box fitted with counter-rotary paddles and a bottom opening door. Aggregates are released into the pug mill from the weigh hopper, dry mixed bitumen added and then wet mixed for only as long as it is necessary to obtain a uniform distribution of aggregate sizes and bitumen coating on all particles.

As soon as this is achieved the bottom door is opened and the mix is being discharged into a tipper.

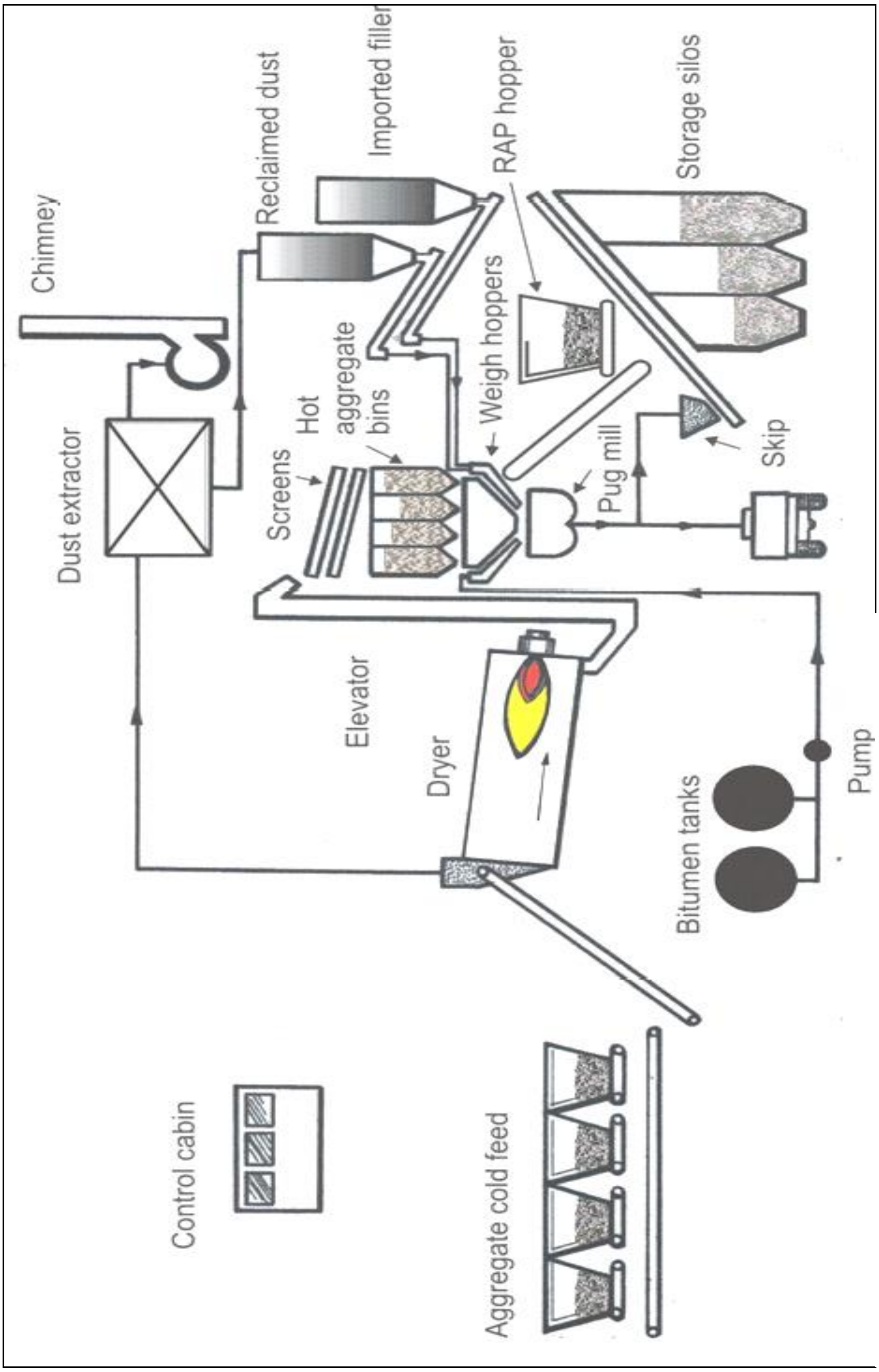


Figure 67: Batch-Mix Plant

(ii) Paver

The paver is the machine, which receives the manufactured asphaltic concrete from tippers and lays it uniformly to desired thickness and width.

The machine is basically either a crawler tractor or wheel tractor carrying a screed unit. Asphaltic concrete is deposited into the hopper by a tipper, whose rear wheels are pushed by the paver rollers. The material is carried back by slot feeds and laterally distributed by spreading screws in front of the screed. The screed unit is a delicately balanced mechanism, which is continually adjusting itself to maintain the forces acting upon its stability. When the paver is moving (Figure 69) forward the pull “P” at the pivot point always exceeds the horizontal resistance “H” on the screed plate. To increase the thickness of the mat to be laid the screed is tilted upwards to permit more material to crowd under it.

As a result, the vertical uplift "R” will exceed the weight of the unit C "W”. When balance is achieved, the screed plate will cease to rise and will move forward horizontally again. This condition of balance for the desired mat thickness is what the paver operator is aiming for. balance will be disturbed if the forward speed varies (“R” varies because “P” varies) or if the viscosity of the mix varies (“R” varies because “H” varies).

Thus the forward speed height of material in front of the screed and temperature of material must be kept constant and “fiddling with controls” kept to a minimum. The paver is adjustable to vary the width of mat laid by the addition of cut-off shoes or extensions. Operating speeds are adjustable in the range of 3-20 metres per minutes.

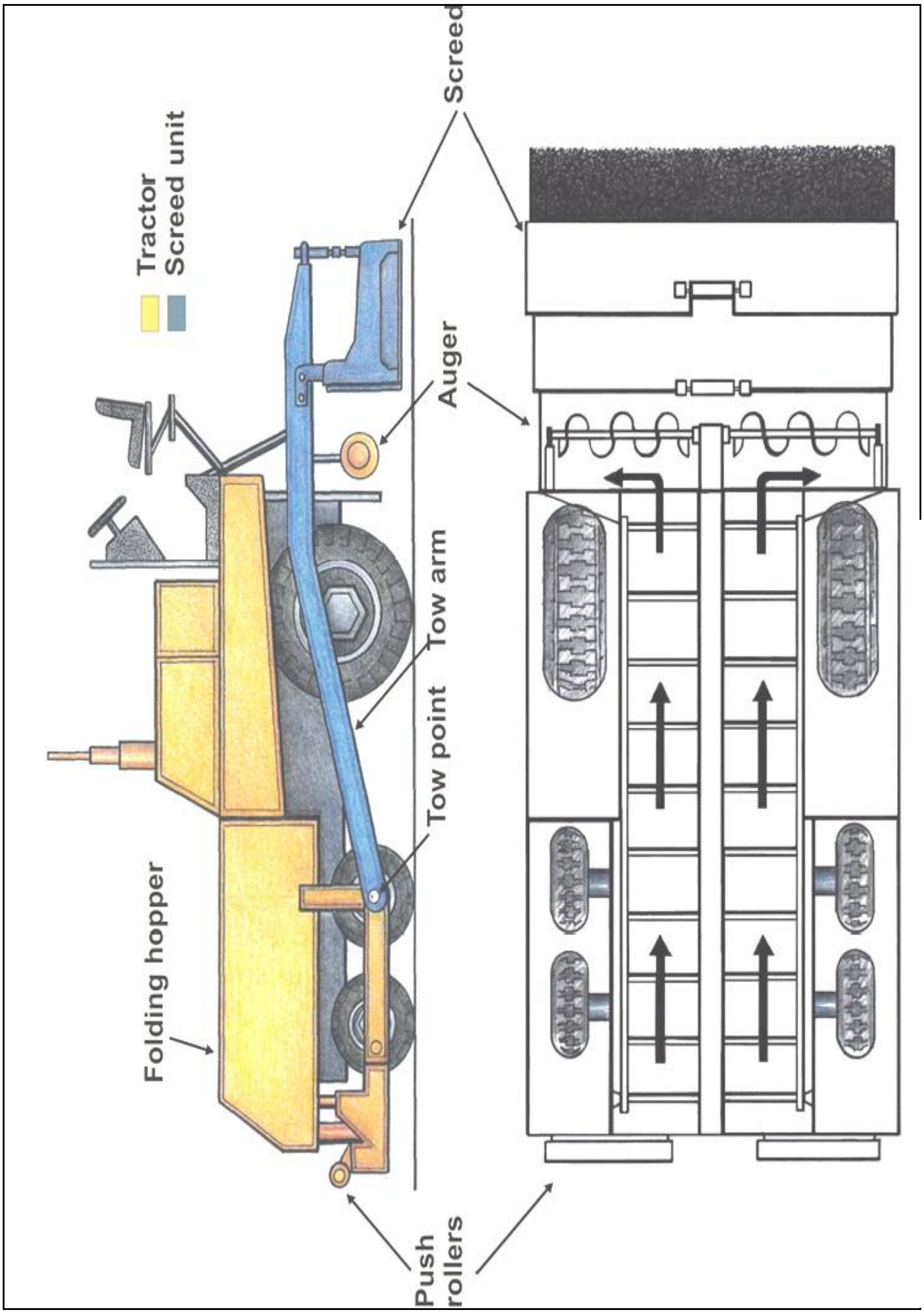


Figure 68: Asphalt Paver

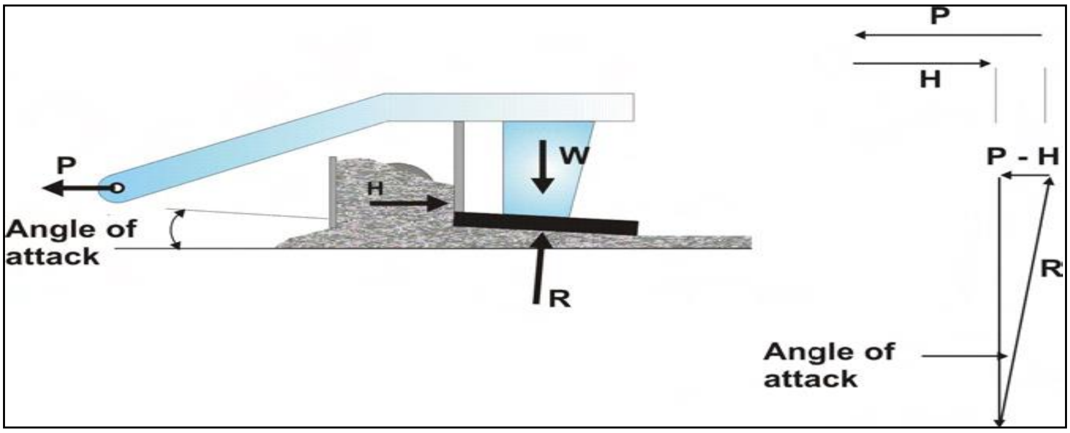


Figure 69: Asphalt Paver Floating Screed Unit

(iii) Rollers

The tamper on the paver provides some initial compaction ahead of the screed plate, but full compaction to optimum density of the material must be achieved by rolling as soon as possible after the mat has been laid. This rolling consists of three consecutive phases:

- Breakdown Rolling
- Intermediate Rolling
- Finish Rolling

o *Breakdown Rolling*

Three wheels, steel wheeled rollers are normally preferred for breakdown rolling. These should be in the weight range of 4½ - 6 tons and must be operated with the rear driven axel nearest to the paver. In the absence of three wheel rollers, 6-8 ton tandem rollers may be used.

o *Intermediate Rolling*

Pneumatic tyred rollers are the only really satisfactory machines for this phase of the work. Wobble-wheel pneumatic tyred rollers must not be used on asphaltic concrete. Vibrating tandem steel wheeled rollers are occasionally used on deeper courses of construction such as on base courses.

- *Finish Rolling*

The purpose of finish rolling is to remove blemishes and roller marks left by the earlier phases. For this purpose the only really satisfactory machine is a 6-8 ton tandem steel wheeled roller on surfacing courses.

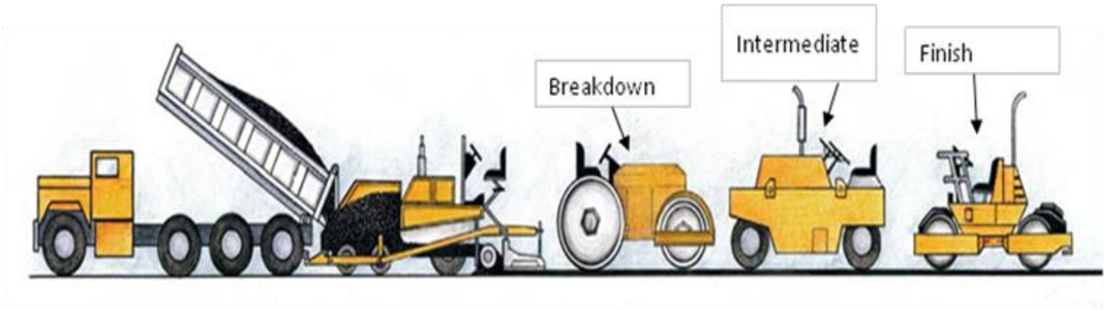


Figure 70: Rolling Configuration of Asphalt Paving

(iv) Emulsion Trolley

On most paving works using asphaltic concrete it is necessary to lay a tack coat ahead of the paver. Since this should remain active until the mat is laid onto it the extent of the tack coat ahead of the paver should be kept to a minimum for practical working. The most useful tool for this purpose is a small wheeled trolley carrying a barrel of emulsion and a hand lance. Only on large paving works where relatively high speed lying of a thin wearing course is to be employed would a bitumen distributor be justified to lay the tack coat.

(v) Hand Tools

Miscellaneous hand tools will be required consisting mainly of rakes, shovels, hand tampers, plate compactors, joint cutting and painting tools, straight edge and camber board, carpenters level, tool heating torch, cleaning equipment, blocks and boards for starting and stopping joints.

f. Construction Methods

The first essential task in lying asphaltic concrete surfacing on a highway is a careful and detailed inspection of the site. This inspection will be for the purpose of measurement repair and competent work planning.

(i) Measurement

The inspection will entail detailed measurement of the following items to ensure that data is available for planning purposes:

- Existing pavement widths
- Lengths and widths of lay-bys.
- Length and widths of turn-outs at road junctions and driveways.

It is normal to pave out junctions and entrances to driveways in the material of the main highway up to the line of the road side drain in order to protect the pavement edges and shoulders. In order to determine the extent, to which auxiliary works are required, it is necessary to additionally measure the following items:

- Extent and depth of depressions and subsidence
- Extent and depth of ruts
- Existing camber
- Existing super-elevation

If depressions, subsidence and ruts are extensive, it may be necessary prior to the main surfacing operation to place a regulating (levelling) course in by hand or machine. Similarly if the existing camber or super-elevation does not conform to the geometric design requirement or if erratic it may be necessary to pre-regulate it or lay levelling strips in the track lanes of the paver.

Requirements for widening should also be studied and accommodated in this phase of the work.

(ii) Repairs prior to Paving

All necessary repair work must be undertaken and satisfactorily completed prior to commencement of the surfacing works. The inspection will therefore allow for the following items to be studied:

- *Drains*

All drains will be checked for grade, cleanliness and adequacy. Where necessary, all repairs and new drainage work will be detailed and completed before paving commences.

- *Shoulders*

All high shoulders will be cut, low shoulders rebuilt to finished level and all shoulders will be cleaned where necessary of rubbish, broken down vehicles and unauthorized constructions.

- *Culverts*

All culverts will be inspected for damage, collapse and adequacy. Repairs, replacements and new culverts, where necessary, will be affected early and backfill and temporary surfacing well completed as far in advance of the surfacing as possible.

- *Bridges*

All bridge approaches must be checked for subsidence. Causes of subsidence must be determined, corrected and the subsidence corrected with a regulating course prior to commencement of the paving works.

- *Pavement*

The pavement surface must be checked for potholes, crack and broken edges. These must be repaired prior to paving. Pothole patches and cracks should be corrected to as close a quality of finish of the old pavement surface as possible.

Rich pot-hole patches will reflect through asphaltic concrete overlays of up to 6cm thickness as patches of flushing or even bleeding.

At this stage of the inspection the overall texture of pavement is also checked to determine the type and quantity of tack-coat required.

Care must be taken to have only just sufficient tack coat as excess will produce a slip- plane. Rates in the order of 0.18 to 0.55kg per square metre are deemed normal.

(iii) Planning

The objective in planning a paving operation is to ensure that a smooth uninterrupted sequence of events may occur culminating in an efficient high quality production. Given a good design and the capability to produce it, quantities are worked out, materials ordered and reservations for machines are made. A date is assigned to the commence work. Key staff is briefed on the operation and the following details discussed:

- Continuity and sequence of operations
- Paver capacity and speed of operation
- Batch-mix plant production capacity
- Number of tippers required
- Number and type of rollers
- Temperatures for manufacture, laying and rolling
- Distance from plant and need for tarpaulin covers
- Chains of command and communications to plant
- Traffic control

(iv) Safety

The safety of workmen on site and the road users and is an essential part of the operation. Adequate provision must be made for warning signs, cones, flags, stop-go boards and personnel to supervise their use. The problem is not as great as with surface dressing operations since compaction of asphaltic concrete is reasonably fast and completed lanes can be opened early. Exposed centre–line joints must be protected and this can either be achieved with board laid up to the joint for traffic lane changing positions or where the second lane is laid at considerable time delay by overlaying 5 to 10cm for subsequent back cutting.

(v) Operation

- *Receipting Load Tickets*

Tipper transporting asphaltic concrete material to site will carry duplicate load tickets. These will be checked by the paving foremen, receipted, one copy given to the tipper driver for return to the plant and one copy retained for the paving records. The foreman, knowing the weight to be spread (kg/m^2 or ton/m^2), will continually check his progress against loads received. This serves both as a check on the thickness of the mat laid and on the accuracy of orders placed on the batch mix plant.

- *Quality of Material Received*

The foreman should visually check each load received to ensure that it is a full undisturbed load and that it appears good. He should also check its temperature with armoured immersion thermometer. Appearance can be a valuable guide to quality and help correct errors in plant mixing. Typical defects are:

- In the Tipper
- Very flat load means there's too much bitumen
- Stiff appearance means it's too cold
- Uncoated large aggregate means it's too cold
- Lean granular appearance means there's too little bitumen
- Blue smoke rising means it's over heated
- In paver hopper
- Steamy, bubbling means there is moisture present
- Rich appearance, foamy means there is moisture present
- On road
- Un-workable, coarse, texture rich means there is too much coarse aggregate
- Smooth texture, lean appearance means there is too much fine aggregate

Only if the temperature is below specification should the foreman automatically reject the load. He should however note the observation of the load and to assists interpretation of test results log. its position on the road in his paving log.

- *Paving*

A string line should be set out parallel to the road centre line along the edge of the lane to be paved. The string line should be mounted on short stakes at 30 metre intervals on tangents and at 5-10 metres intervals on curves. The paver will be positioned at the beginning of the lane to be paved and adjusted to the width of lane required. The sacred is lowered onto wooden blocks having a depth equal to the uncompacted carpet to be laid. Where the paver is starting from the end of a previously laid carpet the screed should be lowered onto board having a depth equal to the difference between uncompacted and compacted carpet thickness. The paver on receiving its first load will draw the material back to the screed and start to move forward. For this first load the operator should check repeatedly that his un-compacted thickness is correct by stabbing his carpet.

The truck in front of the paver must have both sets of rear wheels permanently in contact with the paver rollers to ensure that there is no tendency to slew the paver off course.

It may be necessary to do occasional raking or shovel spreading over the carpet, particularly in the first load whilst the machine is being trimmed to the carpet thickness. Such work should however be kept to the absolute minimum. From time to time there will be a need for some minor raking, addition to the edge or longitudinal joining.

No tipper load should be completely paved out. The paver operator must stop before the height of material in front of the screed is depleted and await the discharge from the next truck before moving forward again.

- *Longitudinal Joints*

The longitudinal joints on a two lane carriageway will be at or near the centre-line. As the first lane is paved this will appear as a near vertical face, which should be butted with a tamping tool to elevate it slightly. This will enable rolling to be undertaken to the extreme edge off the carpet. Where the second lane is not laid on the same day or where the edge has been distorted by traffic the edge should be carefully cut or trimmed and lightly painted with bitumen.

The second lane being laid must be placed to overlap the first compacted lane by 2.5 -5cm (A- below).

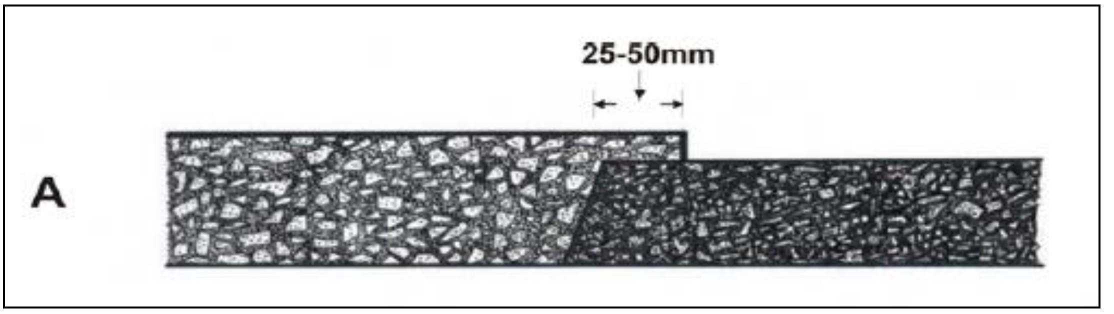


Figure 71: Overlap of Adjoining Lane

The overlapping material is then bumped back onto the hot lane using the flat edge of a rake.. Any coarse aggregate in this bumped mass is raked out to waste. The appearance is then as shown in diagram B. Below the roller the bumped material may now be crowded into the hot side of the joint.

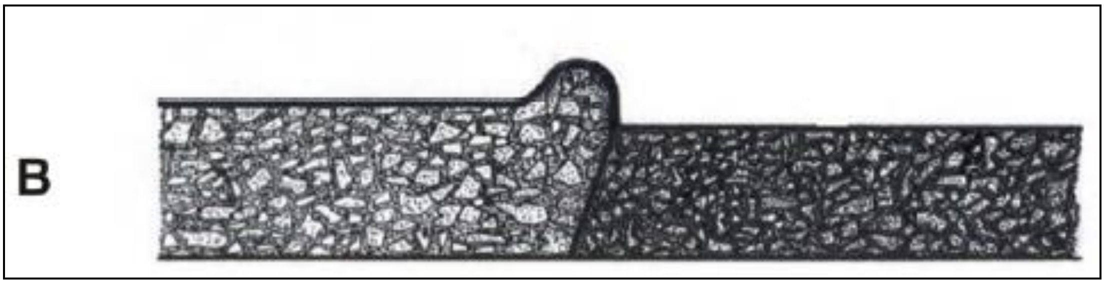


Figure 72: Overlap Crowned Back Ready for Rolling

- *Transverse Joints*

Transverse joints left at the end of a day's work must be vertical and protected from damage by overnight traffic. The most common method of construction is to insert a bulkhead of timber, equal to the compacted carpet thickness, ahead of the spread screws as the paver reaches the end of its last load. As soon as the screed has passed over the bulkhead, the paver must be stopped and removed.

The bulkhead as supporting material in front of it are removed prior to commencement of the next day's work.

- *Overlapping Joints*

Where successive courses of construction are laid in asphaltic concrete material joints should be planned for longitudinal and transverse joints in order not to appear vertically above one another. An overlap of not less than 15cm should be allowed to avoid the risk of cracks occurring. See Figure 73 below.

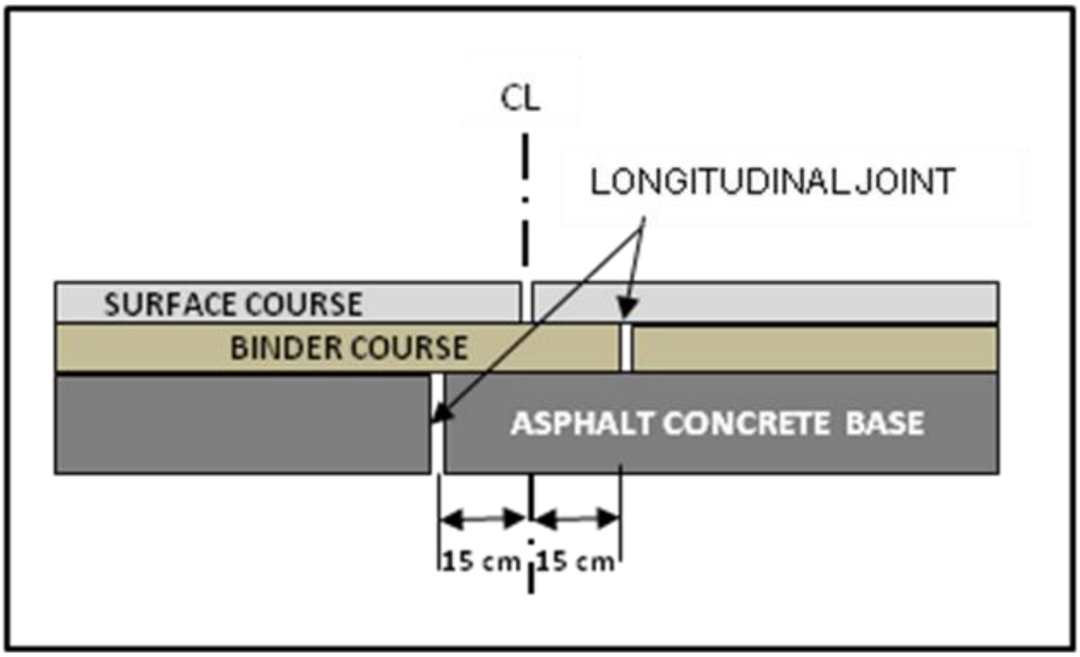


Figure 73: Joint Overlapping to Prevent Reflective Cracking

- *Compaction*

To achieve quality in asphaltic concrete construction, compaction must achieve 95% of the density obtained in laboratory design. Most of this compaction will be easily obtained when the material is freshly laid. Once its temperature has dropped to about 100°C to 105°C very little further compaction will occur.

Similarly, if rollers are introduced onto fresh material at too high a temperature there is a risk of displacing the material. The best results will therefore be obtained whilst the carpet is in the range of 105°C to 125°C. If insufficient compaction is obtained under rolling, subsequent time compaction under traffic will cause noticeable tracking in wheel lanes. The order of priority for rolling sequence is:

- Transverse Joints
- Longitudinal Joints
- Outside Edge
- Breakdown Rolling
- Intermediate Rolling
- Finish Rolling

All steel wheeled rollers used for compacting asphaltic concrete shall be fitted with water tanks and sprinklers to keep wheels moist and prevent pick-up of material. Rolling speeds shall not be more than 5 kilometres per hour for steel wheeled rollers and 8 kilometres per hour for pneumatic tyred rollers.

- Transverse Joints

When the transverse joints are in a second lane with a longitudinal joint, the first pass is made with a steel roller for 1 or 2 metres along the longitudinal joint.

The transverse joint is then rolled with the roller moving transversely starting with 15cm of its driven wheel on the fresh material and increasing the cover by 15cm per pass until the full width of the driven wheels have covered the fresh material as graphically shown below:

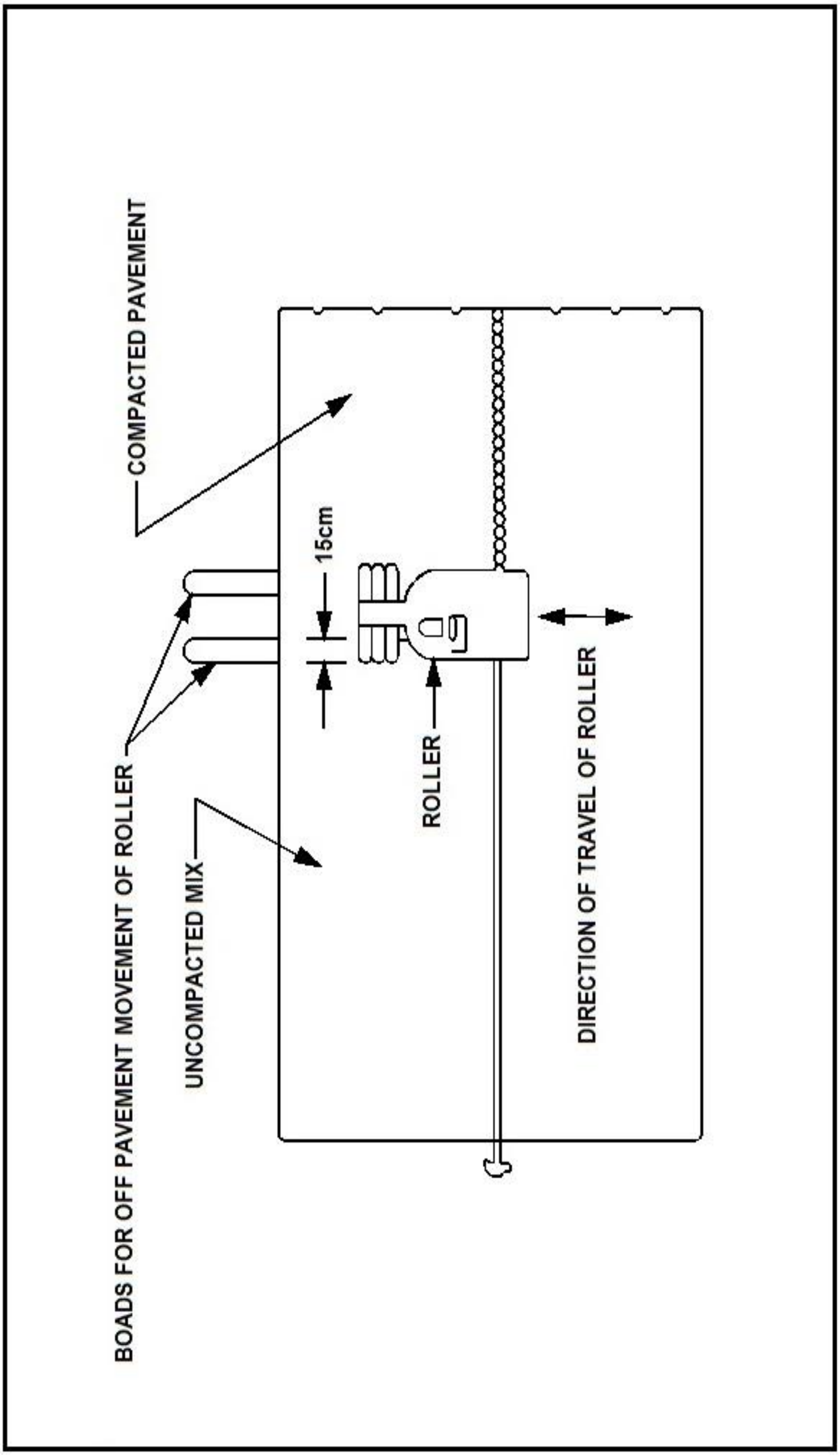


Figure 74: **Rolling of Transverse Construction Joint**

- Longitudinal Joints

A three wheel steel wheel roller should be used and should make its first pass on the compacted material with only 15cm of its rear (driven) wheel riding on the raised bumped fresh material as shown in Figure 71 & Figure 72 above. Subsequent passes gradually broaden the cover until a thoroughly compacted and neat joint is obtained.

- Outside Edges

Outside edges of the newly paved strip are rolled with a three wheel steel wheeled roller overlapping outside the laid area by 1 or 2cm on its driven wheel.

- Breakdown Rolling

Breakdown rolling follows directly from rolling of outside edges. The sequence is to start from the outside edge (low side) and progress gradually to the higher edge whereby each pair of passes overlaps the previous pair by some 20cm.

Whether using the preferred three wheel roller or a tandem roller, the rear or driven rolls shall at all times lead towards the fresh material to avoid displacement of the freshly laid material, as shown below..

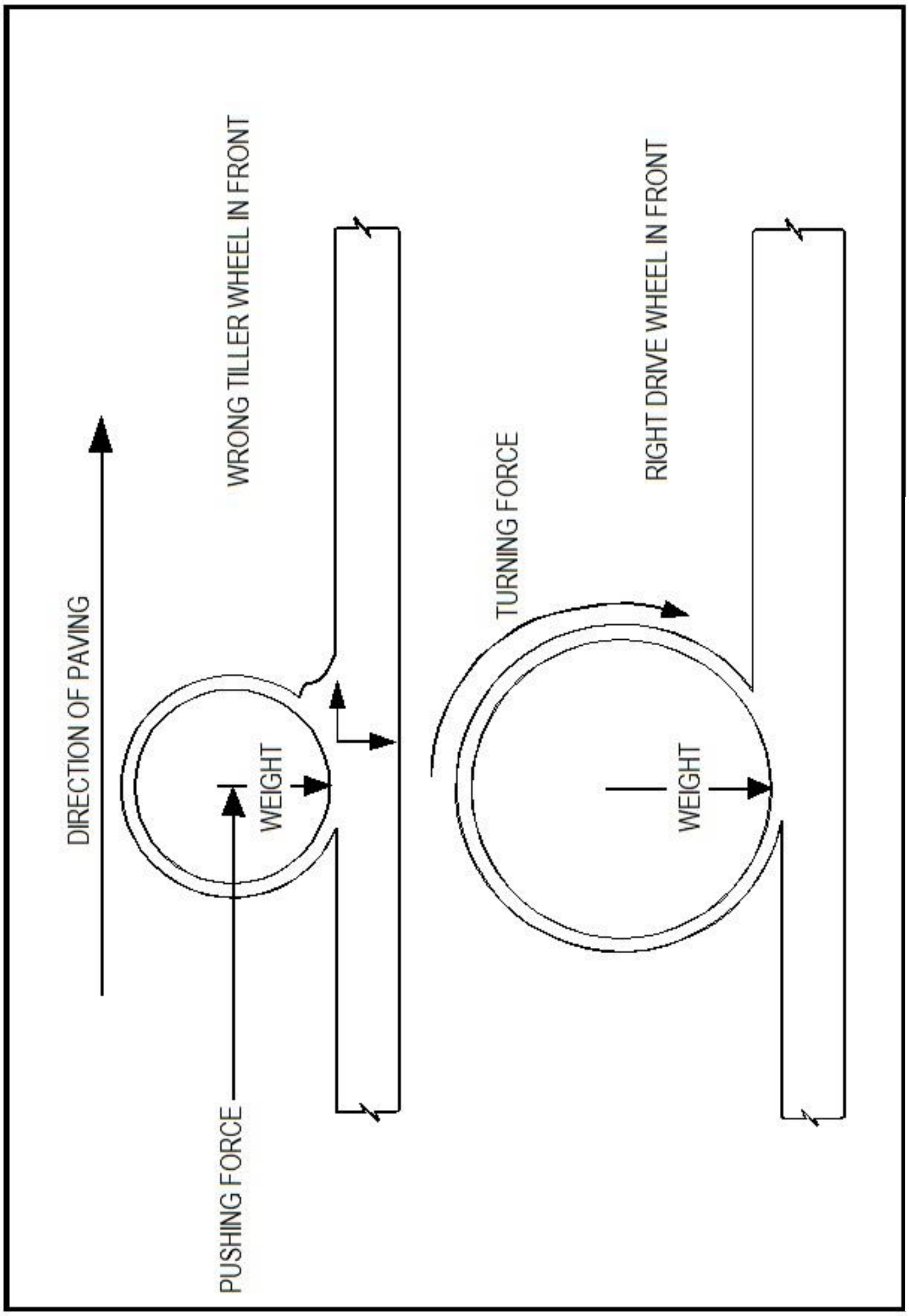


Figure 75: Forces Acting Tiller Wheel or Drive Wheel is Forward

- Intermediate Rolling

Intermediate rolling should follow immediately behind breakdown rolling and should be carried out by a pneumatic tyred roller. At least three coverages should be given to the entire carpet. The roller must not turn on the new carpet and should change lanes slowly and gradually with no sudden jerks.

- Finish Rolling

Finish rolling adds no further compacting to the surfacing material, but must be carried out whilst the paving material is still sufficiently warm to enable the tandem steel wheel roller to remove rolling marks.

- *Super-elevation*

Where super-elevation has to be built up on horizontal curves on existing highways, it may not be economic to change the mix design to base course type of material or to scarify and reconstruct the base. Care should be taken however to avoid construction of a course of so great a thickness that compaction becomes difficult or stability is impaired. As a guide, one should generally restrict thickness of course to about three times the size of the largest aggregate size in order to obtain optimum stability. Figure 76 below, illustrates a three stage method of building up super-elevation in one lane.

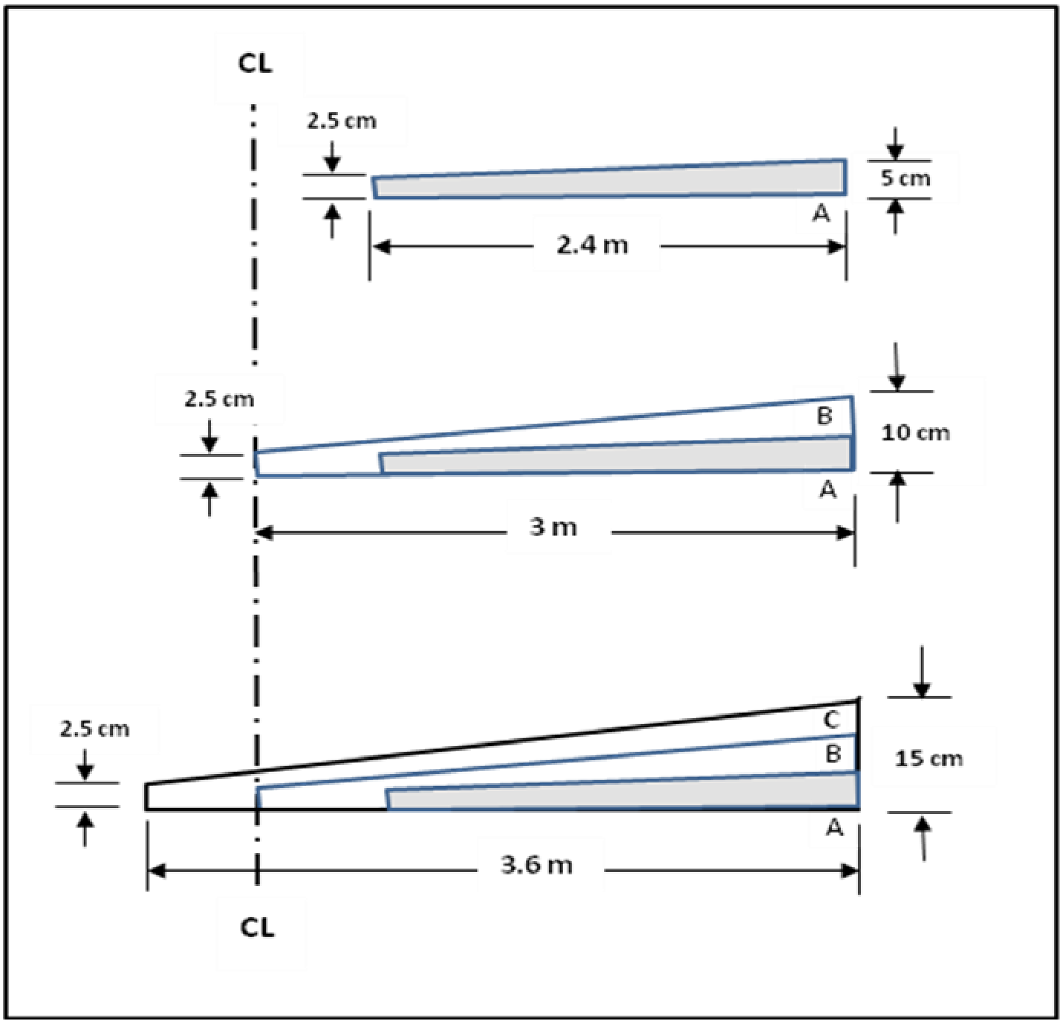


Figure 76: Building up Super- Elevated Curves with Asphalt Mix

g. Testing

Asphaltic concrete is a delicately designed mix of coarse aggregate, fine aggregate, mineral filler and bitumen. From ***Section (d),*** above it will be seen that small variations in any one of the components of the mix will cause major changes to the properties of the material. It is necessary therefore to ensure that:

- Raw materials do not vary
- Batch mix plant works accurately
- Paving can and does work efficiently

To achieve this, ongoing routine testing must be applied. .

(i) Raw Materials Tests

- *Aggregate*

Once a week samples should be taken from the cold bins for sieve analysis testing. Should there be reason to suspect compromised cleanliness of aggregate, plastic index or sand equivalent tests should be carried out.

- *Filler*

Where crushed dust is used as mineral filler similar weekly tests should be carried out on stockpiles.

- *Bitumen*

A sample of approximately one litre should be sent for laboratory test from each major consignment of bulk delivery

(ii) Batch Mix Plant Tests

- *Aggregate*

For sieve analysis once a day a sample shall be taken from each hot bin and of the combined hot aggregates.

- *Un-compacted Mix*

Twice a day, one in the morning and one in the afternoon, a 7 kilogram sample will be taken of the un-compacted mix as delivered from the pug mill. This sample should be laboratory tested for density and stability as described above.

Twice a day, one in the morning and one in the afternoon, a 9 kilogram sample will be taken of the un-compacted mix as delivered from the pug mill. These samples should be laboratory tested for analysis of the mix by extraction of bitumen and mechanical analysis.

(iii) Paving Tests

- *Compacted Pavement*

Twice a day, one in the morning and one in the afternoon, a sample of the compacted pavement not less than 25cm square or 100mm core will be cut from the surface to the full depth of the course constructed. These samples should be tested for density and compaction of the asphalt layer.

h. Defects

With the provision of regular continuous testing and inspection to support well designed and carefully manufactured material, defects should be rare and not extensive in area. The principal defects that can occur, their probable cause sand where possible their cures are listed below:

(i) Flushing

Flushing is a condition where the surface has the appearance of being dark and very rich, with the majority of surface voids filled and very smooth texture. It is undesirable because of the loss of skid resistance and the likelihood of it leading to bleeding under further traffic compaction. The causes may be due to too high bitumen content or too low residual air voids in the design. No action should be taken to cure the defect upon the laid surface at this stage but it must be carefully monitored to watch for the possible growth of bleeding or loss of stability which may be displayed as channelling (rutting) or creep under traffic. Action however must be taken at once to correct either the inaccuracy during production or an error in the design.

(ii) Bleeding

Bleeding is a condition where pools, lines or sheets of liquid bitumen are visible over the surface. This is very unsatisfactory and a permanent indication of errors in design, manufacture and/or construction. The causes of bleeding are most likely errors in the design or manufacture, in the bitumen content or residual voids where the bleeding is extensive or accompanied by a general flushed appearance. When bleeding is detected manufacture must be stopped, tests carried out and the error determined and corrected.

The most frequent occurrences of bleeding will be isolated patches. These are most likely to be due to paving over badly reinstated potholes, fatty underlying patches in old pavements and spillage from tack-coat emulsion trolleys. Such defects will pin-point careless workmanship at inspection, repair and construction stages.

Extensive bleeding cannot be cured. It can only be corrected by replacement of the affected area. Areas of bleeding cannot be overlaid with asphaltic concrete as reflection will occur within a month or two under average traffic conditions. Some of the discomfort to traffic can be alleviated by liberal sanding and rolling until plant and material are available for replacement.

Treatment of small areas of bleeding is effected by cutting out the area concerned, removal of the fatty underlying cause, reinstatement of the base and carpet patching.

(iii) Tracking (Rutting)

Tracking is the general term applied to longitudinal deformation in the wheel tracks of traffic. It is also variously described as rutting, channelling and /or grooving. The causes can vary and perhaps the most common cause is due to badly designed or compacted base material or particularly dry (crushed) stone bases. Tracking can and occasionally does occur through defects in asphaltic concrete on a sound base. It will only become apparent after considerable usage by traffic.

The causes of tracking in asphaltic concrete are:

- Low stability caused by high bitumen content and low voids, where surface conditions will probably be accompanied by flushing

- Poor compaction during the construction stage is often due to rolling too cold a carpet.

The cure of tracking is to place a regulating course of bitumen macadam or similar low bitumen content mechanically into the depressed wheel track area and to overlay the full pavement width with a thin wearing course.

(iv) Ravelling

Ravelling is the progressive loss of aggregate particles from the surface of the carpet. First appearance will be an increased coarseness of the surface as similar aggregate particles are lost and a pitted surface condition with loose particles will be visible. Ravelling can be caused by poor compaction during construction allowing weathering to occur in the excessively large residual voids.

Most frequent causes are due to poor quality or dirty aggregate. Insufficient bitumen in design, usually due to underestimating absorption characteristics of aggregate, is also a possibility as is overheating of the mix at the plant. In this case ravelling is accompanied by a brownish appearance of the mat in the vicinity of the ravelling. The cure for this condition is a slurry or light surface dressing as early as possible.

(v) Corrugation

Corrugation is the appearance of transverse undulations or ripples in the surface. It is most likely to occur at junctions and places where traffic is stopping and starting.

There are many causes based on inferior design such as too high a bitumen content and too high a fine aggregate or filler content... Defects in construction technique, such as fast rolling and rolling on a too hot carpet are also be caused in asphaltic concrete by signs of corrugation that passed unnoticed in the old surface.

The only method of elimination of corrugation is the removal of the entire affected area, scarifying the old surface or base if it is due to reflection and replacement by a new well designed and constructed carpet.

(vi) Slip

Slip is a defect occurring due to a loss of bond between the carpet and surface on which it was laid.

The causes of slip are most frequently absence of a tack coat and improperly cleaned surface prior to lying, spillage of oil in construction and even occasionally excessive quantities of tack-coat material. Cure of slippage failures is accomplished by cutting out the affected area, thoroughly cleaning the old surface, applying a tack-coat and replacing a new carpet patch.

(vii) Cracking

There are numerous causes of cracking, which are mentioned in detail under the sections on routine maintenance. All of these may occur in asphaltic concrete through no fault in the material itself or the construction technique. The risks of cracking can be minimized, by careful inspection, preparation and repair of the old surface prior to paving. Further insurance against cracking will be achieved by proper joint construction and adequate suppleness in the mix design. Areas of road that are suspect to cracking should not be overlaid with asphaltic concrete of a too mathematically perfect design. Avoid over stiff, dense aggregate grading and aim bitumen contents nearer to the higher limits.

The cures and treatments of cracking are dealt with under the sections dealing with routine maintenance

8.6 Gravel Pavements

8.6.1 Gravel Surfacing

a. General Theory

(i) Definition

A gravel surface is a wearing course consisting of soil aggregate material either as naturally occurring gravel (such as lateritic gravels or quartz gravels) or an artificially manufactured material as described under ***Soil Aggregate***. Gravel surfacing is normally laid to a thickness of not less than 10cm to achieve stability of the material and therefore act simultaneously as both a wearing course and an element of base course.

(ii) Functions

Gravel surfacing provides a wearing course that is relatively cheap and easy to construct and has the following advantages over earth roads:

- They provide a comfortable riding surface
- They have good drainage characteristics
- They provide reasonably good skid resistance
- They remain in service during wet seasons

The above characteristics are dependent on good conditions, maintenance and light traffic.

b. *Application*

Gravel surfacing may be satisfactorily applied to:

- Old gravel roads that have been eroded by traffic and weather
- Earth roads where traffic has grown above an average of 30 vehicles per day
- Old surface dressed roads that are breaking up due to inadequate height over drainage levels

c. *Strength*

Since gravel surfaces are normally applied in layers of significant depth, this thickness may be included in strength/depth calculations for pavement designs. However, gravels exposed to traffic and weathering are highly susceptible to erosion and will lose up to 125cm per year even under good maintenance. This fact must be borne in mind in assessing life cycle and planning periodic maintenance.

d. *Design Principles*

(i) Aggregate Grading

Gravel surfacing material, being soil aggregates, should conform to the basic principles discussed under SOIL AGGREGATES. However, since surfacing materials will be exposed to the wear of traffic and weather they require a higher percentage of cohesive materials than those used for soil aggregate bases. The higher percentages of material passing sieve size 40 and 20 means that a lower maximum aggregate size is required. The recommended gravel for surfacing specifications is given in Table 51 below:

Table 51: Recommended Gravel Material Specifications

Description	Specification
Maximum size:	37,5 mm
Oversize Index (I_o)[a]	5 per cent (%)
Shrinkage product (S_p)[b]	100 – 365 (Max preferable =240)
Grading coefficient (G_c)[c]	16 -34
CBR	15 @ 95% Mod AASHTO compaction and OMC[d]

Where:

a - I_o = Oversize Index (% Retained on 37.5mm sieve)

b - S_p = Linear Shrinkage x %passing 0.425mm sieve

c - G_c = (% passing 26.5mm - % passing 2.0mm) x % passing 4.75mm/100

d - Tested immediately after compaction

The relationship between the shrinkage product and grading coefficient is given in Figure 77 below.

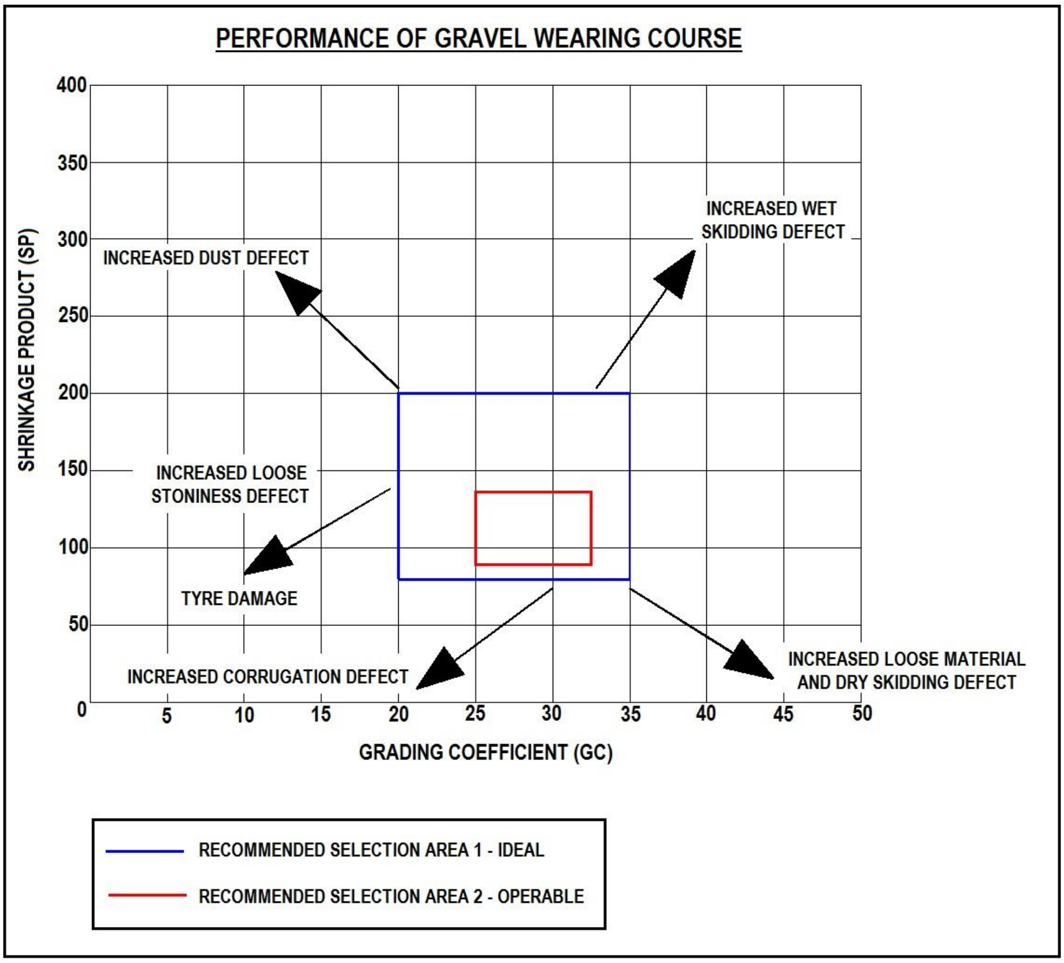


Figure 77: Performance of Gravel Wearing Course

Provided that naturally occurring gravels fit within the tolerances given in Table 51 above they should prove satisfactory for compaction and stability.

The material passing sieve No. 200 (0.075mm) represents the cohesive binder. The greater the quantity of this material present in the gravel the greater its capacity to resist loss of moisture in dry seasons. However, it will be weaker in wet seasons and more liable to the formation of rivulets from surface water runoffs since it is more impermeable. Generally, gravels with high clay content (passing No.200) should be laid at a chamber of 3.5 to 4.0% cross fall. In order to avoid gap grading of gravels it is desirable that the percentage passing sieve is No. 200 (0.075mm).

(ii) Plasticity

Gravel surfacing material requires a higher percentage of binder material to resist wear from traffic and weather, than do base materials. It is therefore normal to specify a maximum liquid limit of 35% and a plasticity index of between 15% and 9%.

(iii) Moisture Content

Soil aggregates used as gravel surfacing materials must be tested to determine the optimum moisture content for compaction. The material should be brought to a little above this moisture content after spreading to allow for small losses into underlying courses.

(iv) Ageing of Gravel Surfacing

The following elements influence the life of the gravel surface:

- Weathering by wind
- Weathering by rain
- Abrasion by traffic

Wind will tend to blow fine cohesive materials from the surface during the dry season. Rain will pick up and carry fine cohesive materials from the surface onto the shoulders and into drains during the wet season. Traffic will tend to brush coarse materials off the surface towards the shoulders once they have become exposed due to loss of fines.

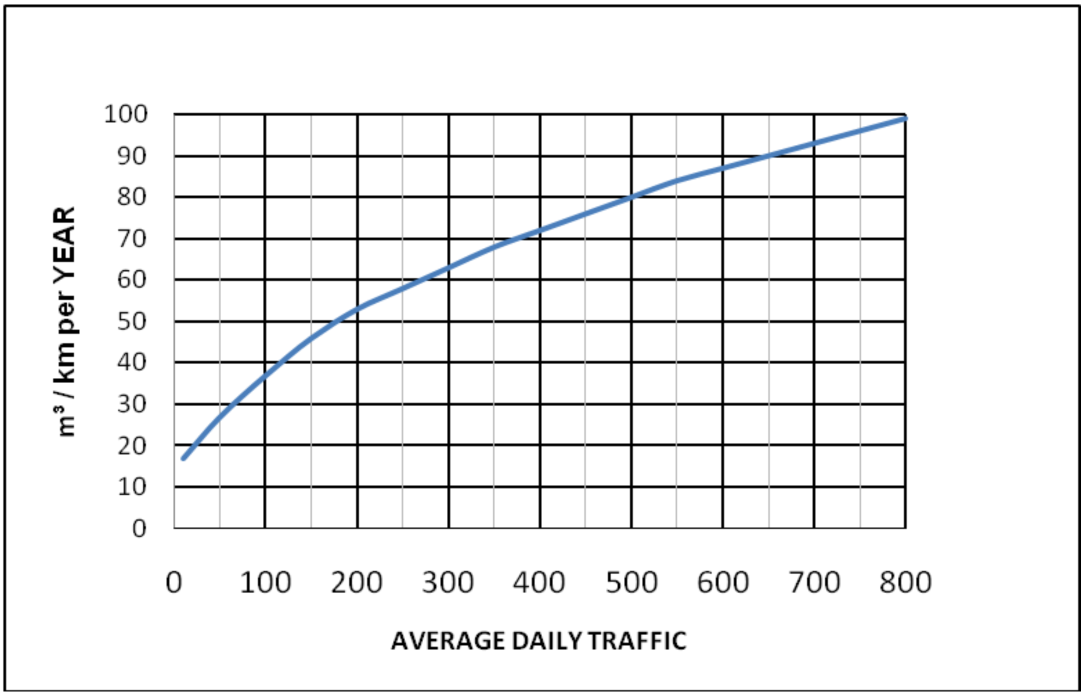


Figure 78: Expected Loss of Gravel

Thus, throughout the year, there is a steady loss of material. Figure 78 shows the loss of gravel that may be expected each year on a two lane gravel highway of approximately 7.5 metres carriageway width. An average daily traffic of 400 vehicles will result in 5.0cm loss of material in 5 years. Poor maintenance and throwing to waste the coarse particles brushed to the roadside will accelerate this loss.

(v) Practical Limits to Use

Gravel surfaced highways require continuous replacement of eroded soil aggregate. They also require continuous grading, watering and rolling to correct corrugation, rutting and loosening of the surface material. The frequency with which these corrective operations must be carried out is shown in Figure 79. The annual hours required are based on one kilometre of two lane highway.

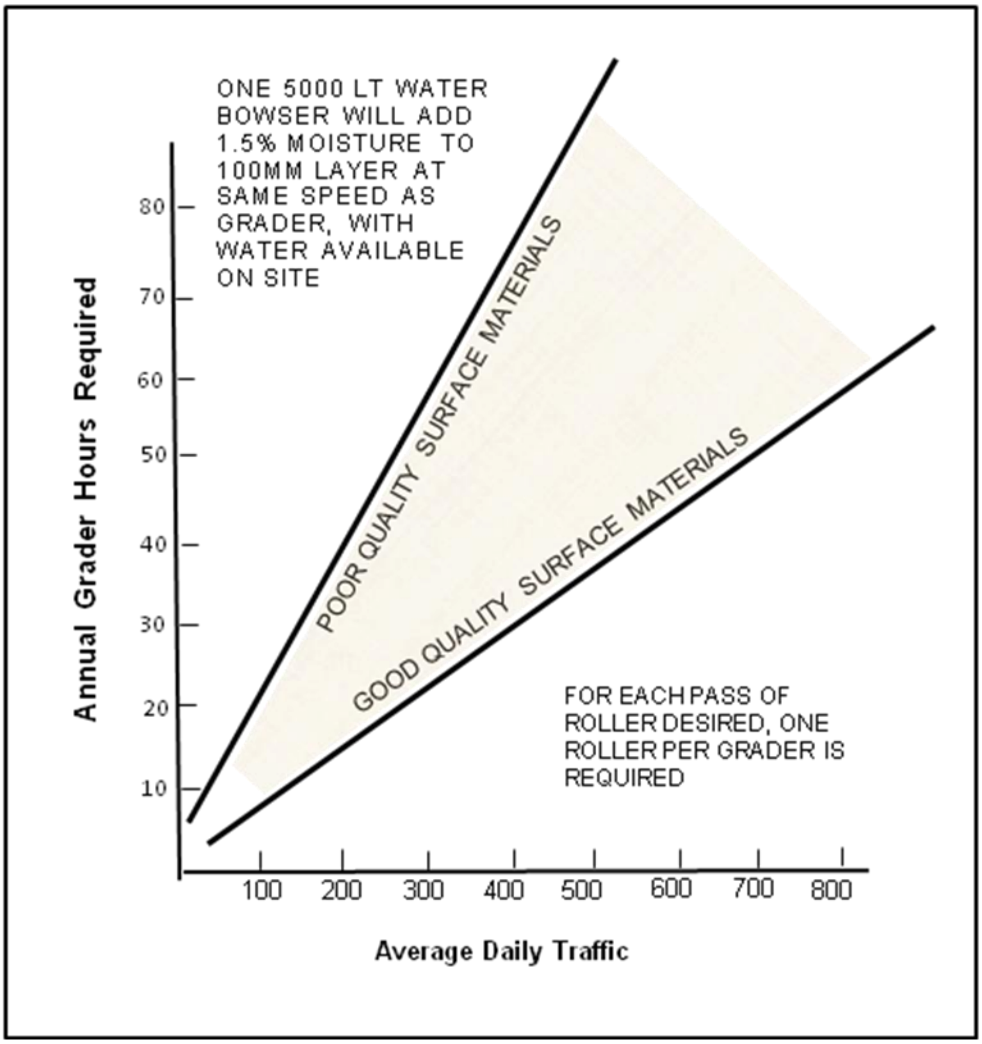


Figure 79: Gravel Surfacing – Annual Grader Hours

Continually throughout the year routine maintenance crews will undertake the repair of potholes, remove and replace as necessary defective materials as shown in Figure 79. It will be clear from the above that gravel surfaces, while being relatively cheap to lay, are among the most expensive to maintain and that this cost is in part proportional to the traffic using the highway

Table 52: Practical Limits to Gravel Surfacing

ADT	0 - 30	30 - 200	200 - 300	300 - 500	>500
	Earth Roads	Gravel	Gravel	Gravel	Surface dress all roads
		Surface Dress in Villages	Surface Dress on gradients over 4%	Surface dress if natural gravel pits more than 80km from site	

Table 52 above shows the practical limits for the use of gravel surfacing on highways. Where the ADT exceeds 500 vehicles per day, it will generally be uneconomic to maintain the highway in a gravel surfaced condition. Consideration should be given to priming and surface dressing.

This total of 500 vehicles a day may have to be reduced to 300 vehicles per day where naturally occurring gravel pits are more distant than 80 kilometres from site. Where traffic exceeds 200 vehicles per day gradients steeper than 4% will become extremely difficult to maintain in good condition during wet seasons. Under these conditions a full width prime and surface dressing should be applied.

During the dry season dust thrown up by passing vehicles creates a nuisance and a health hazard in villages. Highways, within built-up areas should certainly be primed and surface dressed to full width when traffic densities reach 100 vehicles per day.

e. Equipment

The equipment requirements for gravel surfacing operations are those described under ***Soil Aggregate***

f. Construction Methods

The following description is largely applicable both to naturally occurring and artificially manufactured soil aggregate material. The latter will rarely be used in gravel surfacing operations due to its higher cost. Areas where naturally occurring gravels are unobtainable the artificially manufactured soil aggregate will usually be laid as a base and overlaid with a prime and surface dressing.

(i) Inspection

A thorough inspection must be carried out, both on the highway to be resurfaced and in the gravel pit, or pits to be used. Available routes between locations must be checked for transport planning.

The purposes of the inspection are:

- Measurement of work
- Determination of preliminary repairs
- Determination of preparatory work

These factors combine to produce the final planning of the operation.

○ *Measurement*

Site measurements are required to determine pavement width, shoulder requirements if paved with gravel, size and number of turnouts at junctions, and access roads and thickness requirements.

Measurement of material availability at gravel must be made visually and samples taken for laboratory analysis and determination of optimum moisture content for compaction. Traffic should be checked to determine the extent of disruption caused by full width working and available bye-pass routes examined.

- *Repair*

The inspection will detail all necessary repair works to be undertaken in respect of culverts, drains, shoulders and bridge approaches. A check should be made on the adequacy of existing highway furniture. If shoulders are to be raised with material other than that of the gravel surfacing works, provision must be made for its procurement and placing, either as part of the operation or as a supplementary task to be completed simultaneously by the resident routine maintenance crews.

Repairs to potholes, ruts and corrugation in the old pavement may be ignored since they will be dealt with during the preparatory works.

- *Preparatory Works*

▪ Gravel Pits

From the inspection and study of availability of gravels it may be necessary to undertake preliminary works to facilitate speedy loading and start with the operation.

Overburden: If the suitable gravel beds are overlaid by undesirable material, this must be stripped back prior to excavation.

Conglomerates*:* Should conglomeratic laterite be present in the gravel pit it will be necessary to request advance use of a bulldozer and ripper to break out the material and reduce it to usable size or set it aside for subsequent use elsewhere.

Haulage Distance*:* Should the gravel pit be distant from the working site it may be necessary to load and transport material t to a more convenient stockpile site prior to commencement of the operation.

▪ Existing Pavement Surface

The existing surface is likely to be deformed and eroded to an imperfect gradation of particle sizes. It will therefore require scarifying and reshaping prior to laying the new gravel surfacing material. Since the reshaped old surface will have to be compacted thoroughly, it will be necessary to take a representative sample of material to determine its optimum moisture content for compaction. Where the existing surface is heavily rutted, potholed or corrugated, the operational efficiency can be improved by regarding it as described under GRAVEL GRADING prior to commencement of the operation.

(ii) Planning

The normal sequences of planning may now be carried out involving:

- Site requirements
- Sequence of operations
- Loading capacity
- Transport requirements
- Equipment requirement
- Material quantities
- Measurement and testing
- Chains of command
- Traffic control

Particular attention must be given to transport needs. Although only 10cm thickness of material is likely to be laid on most operations, this will amount to some 200 truck loads per kilometre on a two lane highway. Material should always be available ahead of the grader to avoid uneconomic loss of extensive equipment time but stockpiles on the pavement should not be so far forward as to cause a traffic hazard or result in segregation.

(iii) Safety

Gravel surfacing operations do not employ any dangerous or harmful materials or machines. The only concern therefore is with the safety of traffic, workmen and the gravel surfacing work being undertaken. These can be accommodated by the provision of the standard range of warning signs, barriers, cones, stop-go boards or signals and flagmen. Where by-pass or diversion routes are planned the assistance of the local police and advance warning of the public should be sought.

(iv) Operation

- *Preparation of Existing Surface*

The existing surface, unless previously re-graded, will require reshaping to remove ruts, corrugations and potholes and thoroughly blended to correct dust patches and irregular gradation due to traffic and weather erosion.

- Scarifying

This is first affected by scarifying to the full depth of the residual old gravel surfacing of the pavement. The appropriate number of times on the scarifier bar of the grader should be used depending upon the strength of existing material. The work may be carried out by watering the surface within 30 minutes prior to scarifying.

- Blending

The full depth of residual gravel surfacing should be brought to a space on the centre line of the pavement with one grader pass in each lane. The material in the space may then be spread evenly back into shape to the correct camber selected for the final surface. In this loose condition the surface must be regularly checked with a camber board and string line. Should the existing surface be badly segregated with windrows of coarse material brushed to the pavement shoulder edge, it may be necessary to repeat the above procedure again to achieve a reasonably even blending.

- Watering

The shaped material must now be watered with a water bowser to bring it to the predetermined optimum moisture content for compaction.

- Compaction

The shaped and watered material may now be compacted as described below with continual checking with a camber board and string line. Extreme care should be taken to achieve the highest possible degree of accuracy as this will simplify the spreading and grading of the new gravel surface materials to be laid.

- *Delivery to Site*

The material will be brought to site in tipping trucks which will spread the material onto the lane or lanes being worked as accurately as possible. Where available, tippers which do not have the capability of spread-tipping, should clump the materials in one-load stockpiles off the centre line in one lane only, so as to present the minimum obstruction to traffic and construction machine movements.

- *Spreading*

The spread-tipped or dumped material is evenly spread over the full width of the pavement or lane being worked and checked for average depth of loose layer. The depth of layer laid shall not exceed 15cm compacted thickness for any one course of construction.

- *Watering*

The loose layer of material spread as above should now be watered with a water bowser to bring it to the optimum moisture content for compaction, as predetermined from the samples of pit gravel taken earlier. If the work has been planned to be carried out near to the beginning or end of the wet season the watering can be kept to a reasonable minimum. It is however still necessary to know the optimum moisture content and to supplement possible rain fall.

- *Grading*

The loose layer of material, approximately spread and accurately watered, may now be shaped to level and cambered by grader. Very careful and frequent checking with the camber board and a string line is necessary to ensure the accuracy of camber, evenness of surface and constant depth of the course.

- *Compaction*

Initial compaction should be carried out with one pass of a 6-8 ton steel wheeled tandem roller, commencing at the edges of the pavement and progressing to the centre line. On super-elevated sections of highway, the rolling will commence at the lower edge of the pavement and progress to the higher edge. Intermediate compaction is best undertaken with a pneumatic tyred roller at low tyre pressure but may be carried out by steel wheel rollers if only those are available. 2-4 passes of a pneumatic tyred roller are usually sufficient to achieve satisfactory compaction if the moisture content is correct. Where pneumatic tyred rollers are used it is usually necessary to make one final and finishing pass with a 6-8 ton steel wheeled tandem roller to erase wheel marks.

g. Defects

Naturally occurring gravels are less susceptible to segregation than artificially manufactured materials. However, defects can materialize due to errors of workmanship and weathering damage in stockpiles. The main defects that can materialize during construction are:

(i) Segregation

Segregation patches may appear after compaction as areas of the surface showing lighter or darker appearance relative to the general colour. Where excess fines are present the patch will remain moist longer and appear darker than the surrounding area. The converse applies to patches of excessively coarse material.

The most likely causes of segregation are either damage by weathering in long standing stockpiles or overworking the material with the grader. The latter is a frequent occurrence with trainee grader operators.

Segregated patches must be cut out to the full depth of the course, constructed and replaced with well graded soil aggregate material and compacted at optimum moisture content.

(ii) Corrugation

Corrugation is a series of undulating lateral waves in the surface. Generally, corrugation is caused by traffic and weathering removing a proportion of the fine cohesive material and resulting in loose coarse particles being free to move under the action of traffic. Corrugation may however occur during construction as a result of high speed rolling while the gravel surfacing material still contains a high proportion of water in a semi- compacted state. Evidence of corrugation must immediately be corrected by scarifying the material to the full depth of the course and re-grading and compacting.

(iii) Ruts

The formation of ruts is a defect to which gravel surfacing materials are prone. Generally, as with corrugations, ruts will appear under the load of traffic. Should ruts appear in construction, they are almost certainly due to inadequate or no preparation of the old surface. The new material overlaying the old surface will therefore be of unequal thickness resulting in signs of the defects below.

There is no alternative corrective measure other than total removal of the material and reinstatement of the old surface prior to relaying.

8.6.2 Gravel Dressing

a. General Theory

(i) Definition

Gravel dressing is the process of replacement of missing fractions of a soil aggregate to correct imbalances due to losses attributed to weathering and traffic.

(ii) Functions

Gravel dressing when applied to gravel surfacing wearing courses fulfils the following functions:

- It extends the life of gravel surfacing
- It reduces the tendency to corrugation of gravel surfacing

- It economises on wastage of natural resources.

b. Application

Gravel dressing may be applied to any soil aggregate surfacing material, both natural gravels and artificially manufactured materials that is showing signs of decomposition. These signs of decomposition may become visible as:

- A tendency to dry out quickly and become very dusty
- A loose or coarse surface appearance
- Subject to corrugation.

c. Strength

Gravel dressing does not necessarily increase the strength of gravel surfacing materials nor does it add any significant new depth to the pavement courses. It can however make a partial compensation for loss of thickness due to losses of fine grained particles.

d. Design Principles

(i) Decomposition of Gravel Surfacing

Gravel surfacing materials are continuously eroded under the influence of weather and traffic on a highway carrying an ADT of 200 vehicles per day. Approximately 1cm of surfacing material is lost each year. Further physical changes occur to individual particles that cause additional loss and disintegration of the surface. The decomposition may be classified as being:

- Losses of material from weathering and traffic
- Wear and tear due to traffic
- Wastage by maintenance techniques

- *Losses of Material*

Gravel surface are made up of soil aggregates, which are homogeneous blends of gravels, sands, silts and clays. The finer material, primarily clays, acts as a binder to give the whole mass stability. The action of wind and rainfall tends to remove a proportion of the clays in the surface and carry them away as windblown dust and into drainage channels.

Vehicle tyres loosen the surface, throw up more dust and expose more clay to weathering. The continued effect of weathering and traffic is shown in Figure 56, above.

- *Wear and Tear by Traffic*

With the coarser gravel and sand fractions of the soil aggregate at the surface held less firmly by the reduced clay fraction, friction between individual particles is caused by further traffic movements. This results in wearing down gravel particles to sand sizes and sand particles to silt sizes. Thus, further material is created and available for loss by weathering and traffic and the surface becomes progressively looser.

- *Wastage by Maintenance*

Traffic movements tend to brush the loose coarse fraction material to the side of the pavement where it builds up into loose granular windrows. If returned to the pavement surface in this condition the coarse material would present hazard to traffic, would tend to corrugate and would be an agent to accelerate further attrition. Maintenance techniques therefore favour the removal of windrows of loose gravel and dumping them in low areas within the right of way.

(ii) Change of Gradation

Measurement of the changes occurring in soil aggregates used in gravel surfacing has shown major changes in the grading of the gravel due to the three factors described above. In Figure 80 below, curve 1 shows the original grading of a typical soil aggregate used for a gravel surface. Curve 2 shows the grading of the residual material after 3 to 4 years of traffic usage under continual routine maintenance.

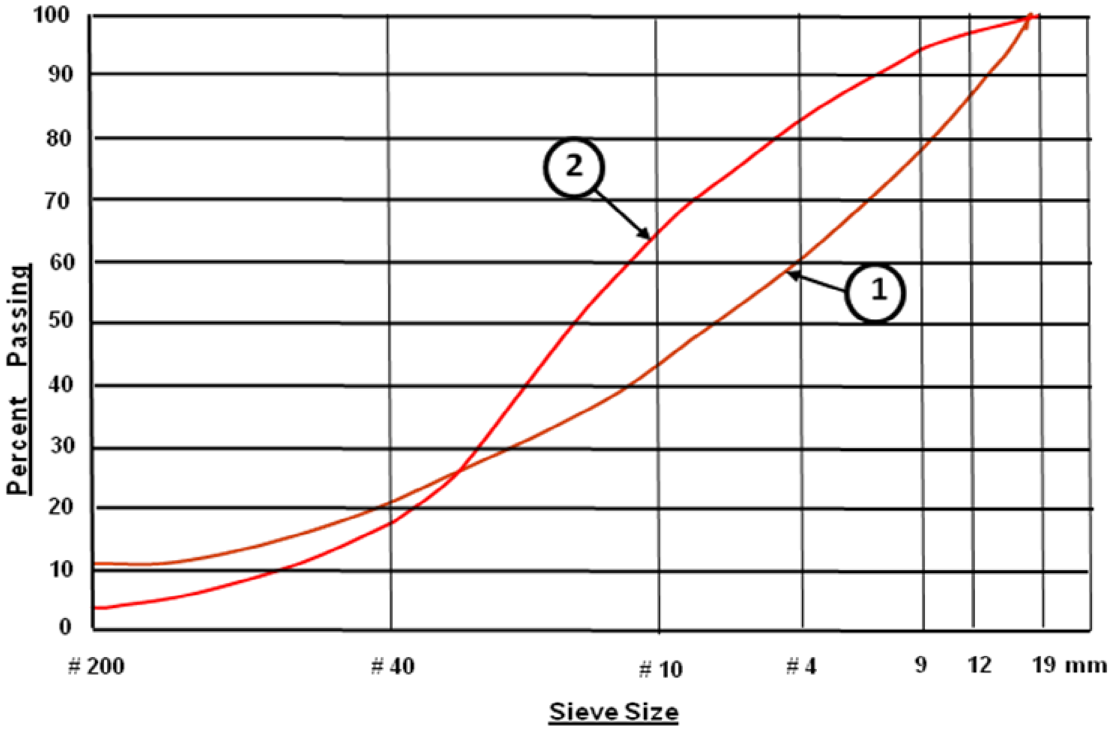


Figure 80: Gravel Surfacing – Change in Grading

(iii) Analysis of Materials

The first step in the design is to analyse the existing gravel surfacing material and the aggregates available for correction by blending. As shown in Figure 80 above, after 3 to 4 years the existing gravel surfacing is very short of material in both extremes of coarse aggregate and fines. Therefore, research in the field should be restricted to screened gravels or crushed stone and clays without too high a silt or sand content. As an example, Table 53 below shows typical grading curves of screened gravel and silty clay n, together with the grading of the existing material illustrated above, in both its original and eroded conditions.

Table 53: Typical Grading

Sieve Size	Old Surfacing		Available Material	
	Original	Eroded	Silty Clay	Screened Gravel
	Percentage Passing			
19 mm	100	100	-	100

12 mm	88	97	-	63
9 mm	80	94	-	54
No. 4	62	82	-	25
No. 10	43	63	100	7
No. 40	23	18	85	2
No. 200	12	4	65	1

(iv) Proportioning Materials

Using the Rothfuch Method of proportioning described fully under ***Soil Aggregate, Section 8.8.1(d) (vi)*** the required proportions can be determined as summarized below.

Construct to any scale a Rothfuch diagram as shown in Figure 81 using tire diagonal OM as the original gravel surfacing material grading.

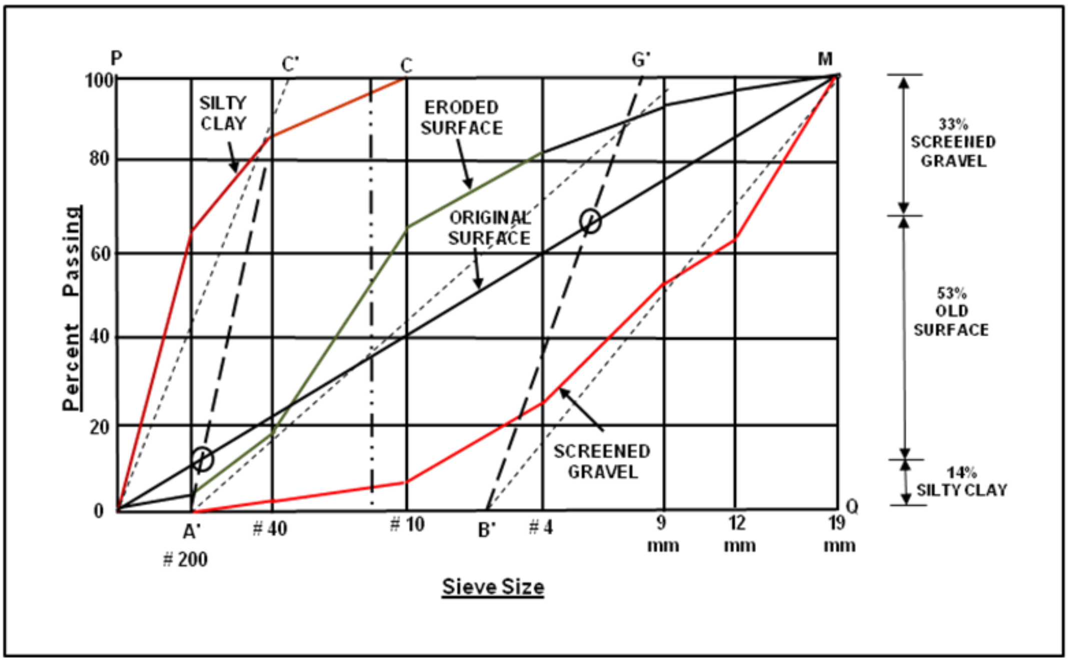


Figure 81: Rothfuch Diagram

Plot eroded gravel surfacing material, silty clay and gravel. Construct the straight lines by the minimum balanced area method for the three materials.

These are shown as dotted lines:

- OC' for the silty clay
- A'G' for the eroded gravel surfacing
- B'M' for the gravel

Join the points A'C'. and B'G'. Their intersections with diagonal OM give the following proportions:

- Silty clay = 14%
- Gravel = 33%
- Eroded gravel surfacing = 53%

A recalculation of those proportions compared with the grading of the original gravel surfacing is shown in Table 54 below:

Table 54: Grading of Blended Gravel

Sieve Size	Original Gravel	Blended Material
	Percentage Passing	
19 mm	100	100
12 mm	88	86
9 mm	80	82
No. 4	62	66
No. 10	43	50
No. 40	23	22
No. 200	12	12

This result is sufficiently close to the original and well within the range acceptable tolerances to ensure adequate compaction and stability. The example chosen was of very badly eroded gravel surfacing, which would have required about four years of traffic to reach this degree of decomposition. A loss of at least 4cm of depth or about 40% of the gravel surfacing could be expected in this time. Gravel dressing would have been more economical and more easily achieved at an earlier date.

(v) Moisture Content

A blended sample using the proportions determined above should be made up and tested to determine the optimum moisture content for compaction.

e. *Equipment*

The equipment requirements are those defined under ***Soil Aggregate*** for on-site manufacture of blended material.

f. *Construction Methods*

(vi) Inspection

A thorough inspection must be carried out on site and in all existing and potential new gravel pits. These inspections will determine:

- Nature of work to be undertaken
- Quality of materials available
- Equipment and material requirements
- Repairs to be undertaken
- Traffic control problems

- *Measurement*

On site measurements are required to determine:

- Surface widths, levels and thickness

- Size and location of turnouts for junctions and access roads
- Material requirements for shoulders

- *Repair*

All defects to drainage, culverts, shoulders and bridge approaches must be measured for repair prior to commencement of the gravel dressing operation.

(vii) Planning

The most efficient method of carrying out gravel dressing operations is on full width pavements. However, should total closure create too much disruption to traffic it is quite possible to perform the operation in single lanes. Once a decision has been made on this the remaining aspects of the work may be coordinated, for:

- Sequence of operations
- Design
- Material quantities
- Transport requirements
- Equipment requirements
- Measurement and testing
- Chains of command
- Traffic control

(viii) Safety

All normal safety precautions are required for protection against injury and damage to the public, work force and the pavement works being undertaken. Warning signs, barriers, cones, stop-go boards or signals and flagmen are required.

(ix) Operation

- *Preparation of Old Surface*

The existing road surface must first be corrected for all faults. This is best achieved in the following sequences.

- Grading

All material available on the pavement should be graded to the centre line or to the centre of the lane being worked. This may consist of one lane and one shoulder if the surface dressing material brought into the windrow should include loose windrows of coarse material and if these are present and have been included in the representative samples taken.

The windrows will next be graded uniformly across the working width correct to grade and level and of uniform depth. Camber boards and string lines will be used to ensure accuracy. Should the old surfacing material be in a hard compacted condition it should first be scarified carefully to the depth of the gravel surfacing?

- Compaction

The old surfacing material will show a more or less even bending and true to camber with all ruts, corrugations and potholes removed, it should be lightly watered and if necessary and partially compacted with one or two passes of a steel wheeled tandem roller.

- *Addition of Gravel Fraction*

- Spreading

The gravel fraction should be delivered to site in tippers and either spread-tipped onto the worked lane or, if mainly single sized, laid with a chipping spreader. If spread-tipping is used it should be spread evenly over the reconstituted old surface by a grader and should be continuously checked with camber board and string-line to ensure accuracy.

- Compaction

The gravel fraction should be watered if necessary and partially compacted with one or two passes of a steel wheeled tandem roller.

- *Addition of Clay Fraction Spreading*

- Spreading

The clay fraction should be delivered to site in tippers and spread-tipped onto the working lane. It should be accurately spread to camber and levelled with a grader to achieve a uniform thickness. In the worked example above, 14% clay fraction would amount to a layer of 1.6cm on a residual old gravel surface of 6.0cm thickness. Had the quantity to be laid been less and had the material contained little or no silt, the clay fraction could have been added as slurry with a water bowser.

- Compaction

The clay fraction should be lightly compacted in a dry condition by one or two passes of a steel wheeled tandem roller in order to make a smooth level platform for the mixing operation.

- *Blending materials.*

The three materials are now loosely compacted in three separate layers of uniform depth in the proportions determined during the design stage. Blending is achieved by a single pass of a pulvimixer set to the total depth of the three layers. This will to some extent disturb the evenness of the surface, which will therefore require a final grading to correct the camber.

- *Watering*

The moisture content should now be brought to the optimum moisture content for compaction by watering with a water bowser.

- *Compaction*

Compaction is achieved with a single initial pass of a steel wheeled tandem roller and followed by 2 to 3 passes with a pneumatic tyred roller. One final pass with a steel wheeled tandem roller will erase wheel marks. Rolling sequences in all cases will be from the lower edges to centre line and to higher edges on super-elevated curves.

g. Defects

The resultant pavement after gravel dressing operations is subject to all possible defects occurring naturally or due to blended soil aggregates used in gravel surfacing. One major risk of defects in this operation occurs from inaccuracy of workmanship and resulting in segregated patches.

(i) Segregated Patches

These segregated patches, which may materialize immediately after compaction is complete, will become visible as patches of material which appear to be drier or wetter than the surrounding area.

This is most frequently caused by high and low spots in the surface of the old gravel surface, or more likely, by the surface of the first added material laid. This causes an imbalance in the design blending. Correction of the defect can only be accomplished by removal of the defective patches to the full depth of the course (all three-material) and replacement by correctly graded material manufactured off-site.

8.7 Bases

8.7.1 Soil Aggregate (Laterite Gravel)

a. General Theory

(i) Definition

Soil aggregates are composite materials made up of a homogenous blend of gravels, sands, silts and clays. The larger sized particles provide strength and mechanical stability while the smaller sized particles provide the cohesive binder.

Soil aggregate may be found as naturally occurring soils such as lateritic gravels (‘pea’ gravel with lateritic clay) and quartz gravel (quartz gravel and sands with silty clay). Soil aggregate may also be artificially manufactured by mixing available aggregates and soils.

(ii) Functions

Soil aggregates, depending upon their make-up, use within the paving courses provide:

- A means of transporting loads from the surfacing courses to the weaker materials in the sub grade.
- A platform upon which a higher quality base, or a wearing course can be constructed.

b. Application

A soil aggregate is a versatile, easily constructed and relatively cheap material, which may be used in the following courses:

(i) Sub-Base

On heavily trafficked roads soil aggregates are used as sub basses to transmit loads from the higher quality base to the weaker sub grade.

(ii) Base

On light to medium trafficked roads soil aggregates may be used as a base, being primed, surface dressed and occasionally overlaid with bituminous carpets.

(iii) Wearing Course

On very lightly trafficked roads soil aggregates and particularly naturally occurring lateritic gravels are used as surfacing and wearing courses. For this purpose the material requires a higher proportion of fine cohesive material specified under ***Gravel Surfacing***.

c. Strength

Soil aggregates are medium to strong flexible bases, which, depending upon their content and grading, will show CBR values of between 15 and 80%. Thicknesses of soil aggregate courses must be included in depth/strength calculations for pavement design.

d. Design Principles

As with all coarse granular material the most stable mix is likely to be the one which conforms most closely to the appropriate Fuller Curve for that size of aggregate. The design table below provides data based on AASHTO standards..

The grading tolerances are usually expressed in terms of percentages passing each of a series of square mesh sieve sizes. See Table 55 below:

Table 55: Grading Tolerances

Nominal Maximum Size: 40mm	
Sieve Size (mm)	Percentage Passing
40	100
25	75 – 95
9	40 – 75
4.75 (No.4)	30 – 60
2.0 (No. 10)	20 – 45
0.425 (No.40)	15 – 30
0.075 (No. 200)	5 - 20

Two dangers occur with these methods of presentation, namely, inadequate fines by fuller curve calculation and the risk of gap grading.

(i) Plastic Fines

The fuller curve, as shown below, is based on the theory of minimum voids for granular and non-plastic material. Practical results conform to the theory very closely with dry stone bases that are genuinely non-plastic. However, a soil aggregate must contain plastic cohesive fines as a binder and practical results show that the percentage passing sieve 0.075mm (No. 200) as shown by the fuller curve (4%) is inadequate for cohesive stability.

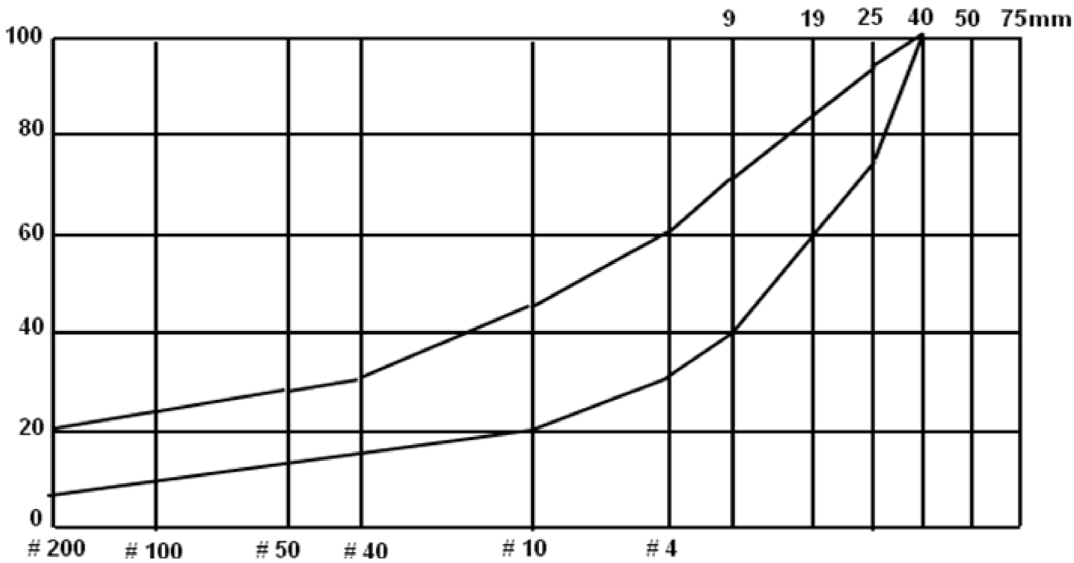


Figure 82: Fuller Curve of Soil Aggregate Base

The lower limits specified for materials finer than sieve No. 40 (0.425mm) have therefore been increased and must be regarded as the absolute minimum if the materials are to be satisfactorily compacted.

(ii) Gap Grading

With tabular presentation as shown in Table 55 above, it is possible to obtain a material with 80% retained on sieve No.10 (0.425mm) and 20% passing sieve No. 200 (0.075mm), thereby exposing a gap through the entire sand range. Such gap graded material is not normally mechanically stable.

Some authorities recommend the inclusion of a clause in specifications requiring a minimum 10% retained between each pair of sieve sizes. This is not always easy when artificially blending materials without the introduction of a third or fourth material and greatly increased cost and complexity.

It is recommended that in all cases where blending of two or more materials is carried out, that the proposed mix be plotted on a mechanical analysis graph (as shown in Figure 82) and that gap grading be avoided by obtaining as smooth a single curves as possible.

(iii) Aggregate Grading

In Table 56 below three aggregate grading specifications are provided for material suitable for bases and sub-bases.

Table 56: Base and Sub-Base Gradings

Nominal Maximum Size:	50mm	50mm	25mm
Sieve Size (mm)	Percentage Passing		
50	100	100	
25	-	-	100
9	30 - 65	40 - 75	50 - 85
4.75 (No.4)	25 - 55	30 - 60	35 - 65
2.0 (No. 10)	15 - 40	20 - 45	25 - 50
0.425 (No.40)	8 - 40	15 - 30	15 - 30
0.075 (No. 200)	2 - 8	5 - 20	5 - 15

The grading shown above are not normally suitable for wearing courses and should be restricted for use as bases and sub-bases. They will however readily accept a prime for subsequent overlay by surface dressing.

Two additional gradings are available for bases, being multipurpose materials, which are capable of use as wearing courses in stage construction techniques.

It can be seen that the materials in Table 57 below require increased fines and a greater percentage of cohesive material (passing sieve No. 200). This is required for greater cohesion as a surfacing material and to resist the loss of moisture due to evaporation.

Table 57: Multi Purpose Base Grading

Nominal Maximum Size:	25mm	25mm
Sieve Size (mm)	Percentage Passing	
25	100	100
9	-	-
4.75 (No.4)	55 - 100	70 - 100
2.0 (No. 10)	40 - 100	55 - 100
0.425 (No.40)	20 - 50	30 - 70
0.075 (No. 200)	6 - 20	8 - 25

The two multi-purpose gradings are likely to be weaker than the three shown in the previous Table 57and should only be used therefore where there is a temporary requirement to act as wearing courses.

(iv) Plasticity

The material must be cohesive for stability but as a base or sub-base an excessively large quantity of fines will render it too malleable and susceptible to failure by water penetration. For bases the liquid limit should therefore not exceed 25% and the plasticity index should not exceed 6%.

(v) Moisture Content

The final proposed blend of soil aggregate or the naturally occurring material must be tested to determine the optimum moisture content for compaction prior to laying. The material, if artificially manufactured off site, should be transported to site in a moist condition to avoid segregation.

(vi) Aggregate Blending

In the majority of cases within highway maintenance operations blending of aggregates will involve the use of only two materials for the purpose of:

- Addition of clay fraction to old traffic and weather worn lateritic gravels
- Addition of clay fraction to quartz gravels
- Addition of sand fraction to excessively plastic lateritic gravels

To obtain the correct proportions it is sufficient to plot the mechanical analysis of each material on a grading chart and match them to the appropriate grading curve. Greater difficulty occurs by the occasional need of blending three materials such as crushed river gravels, sands and silty clays in areas where naturally occurring soil aggregates are rare. The tri-axial chart method of proportioning as illustrated under ***Asphaltic Concrete*** is not recommended for use with soil aggregates since it is highly sensitive to the correct selection of sieve sizes used. A simple and more flexible proportioning method is that developed by Rothfuchs.

- *Rothfuch Method*

The blending method is best illustrated with an example of blending three aggregates, namely a crushed river gravel, sand and silty clay, which are first mechanically analyzed as shown in Table 58 below:

Table 58: Gradings for Blending

Sieve Size (mm)	Blended Material		Available Materials		
	Range	Average	Crushed Gravel	Sand	Silty Clay
40	100	100	100		
25	75 - 95	85	90		
9	40 - 75	57	17		
4.75 (No.4)	30 - 60	45	9	10	

2.0 (No. 10)	20 - 45	32	5	80	
0.425 (No.40)	15 - 30	22	2	55	
0.075 (No. 200)	5 - 20	12	0	0	100

The average blend material required is shown in the Table 58 above. It is first necessary to plot this as a straight line on a grading chart.

Any suitably dimensioned rectangle is drawn as shown in Figure 83 below. The diagonal OM represents the average blend required.

Taking first the percentage passing sieve size 25mm (85% on the diagonal) a vertical line is drawn to represent sieve 25mm. Similarly, the remaining sieve positions are established on the horizontal axis in accordance with the required percentage on the diagonal OM (i.e. 57% for 9mm, 45% for 4, etc).

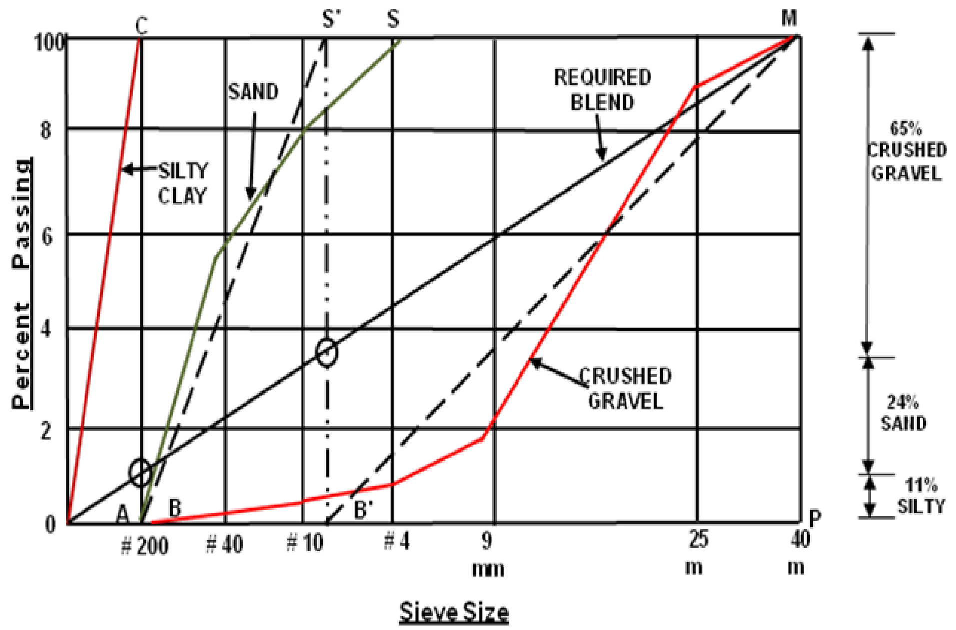


Figure 83: Rothfuch Blending of Aggregates

The chart is now calibrated and the three available materials can be plotted. **OC** shows the silty clay representing the sand and **BG** (which coincides with **M**) representing the crushed gravel.

It is now necessary to replace the grading curves of the available aggregates by straight lines on the minimum balanced area method. This is shown in Figure 82 where **AS'** replaces the curve **AS** and **GB'** replaces the curve **GB**. The opposite ends of these three aggregate straight lines are now joined giving demarcation lines **AC** and **B'S**. The points where these two demarcation lines cut the require blend – diagonal **OM** – provide the percentages of material proportions (11% and 35%).

Thus the blending of the three materials will be in the following proportions:

- Crushed Gravel = 65%
- Sand = 24%
- Silty Clay = 11%

Table 59 shows the blending split as per the above percentages:

Table 59: Combined Grading of Blended Mix

Sieve Size (mm)	Crushed Gravel		Sand		Silty Clay		Combined Grading
	100%	65%	100%	24%	100%	11%	
40	100	65		24		11	100
25	90	58		24		11	93
9	17	11		24		11	46
4.75 (No.4)	9	6	100	24		11	41
2.0 (No. 10)	5	3	80	19		11	33
0.425 (No.40)	2	1	55	13		11	25
0.075 (No. 200)	0	0	0	0	100	11	11

The blend obtained above is plotted on the grading chart and shown in Figure 84 below. It is relative to the fuller curve and lies comfortably within the tolerances of the required grading.

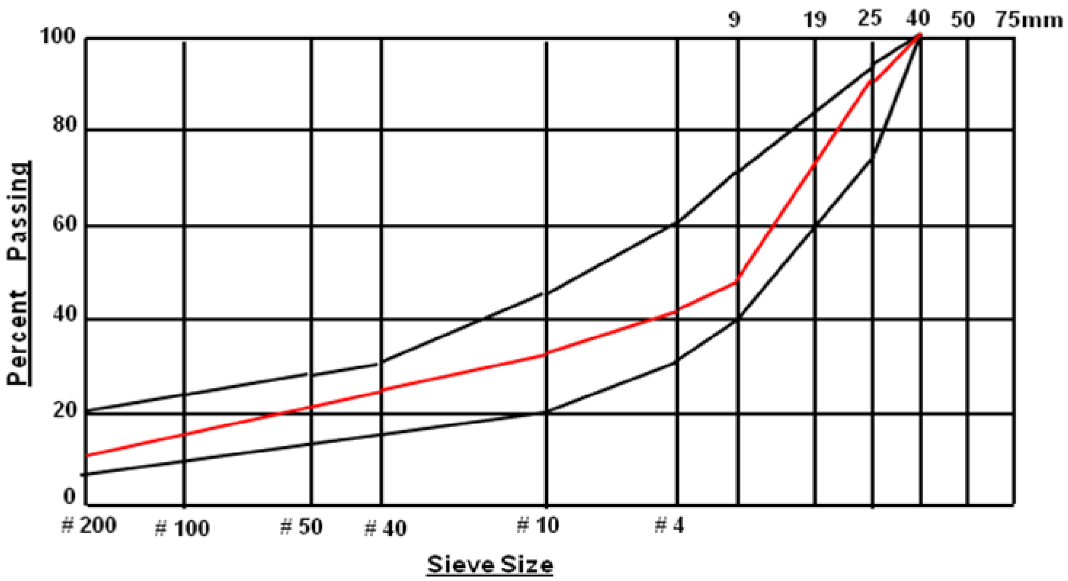


Figure 84: Grading of Blended Gravel

e. Equipment

(i) Off-Site Manufacture

Soil aggregates can be obtained from naturally occurring gravel pits or manufactured by blending materials off site. In either case, they will be transported and laid on the sub-grade or sub-base in their completed blending. For the purpose of manufacture of artificially blended materials, the following equipment can be used.

- *Batch-Mix Plant*

For large scale manufacture a standard batch-mix plant as described under 'ASPHALTIC CONCRETE' or a more suitable and available continuous mix plant may be used.

- *Concrete Mixer*

For small scale jobs and repair to localized base failures consistently good blending can be achieved with a weigh-batch concrete mixer. Provided a small amount of water is added to each mix, the material may be stockpiled in dry seasons for subsequent use. Laying soil aggregates may be carried out with the following equipment.

- *Aggregate Spreader*

For large scale works, particularly where artificially blended materials have been used, an aggregate spreader provides fast and accurate work and avoids the risk of subsequent minor segregation due to overworking the material by graders. The aggregate spreader is described under DRY STONE BASE.

- *Graders*

The most common method of laying the soil aggregate material is by grader. Provided the operators are reasonably skilled little segregation will occur in spreading and shaping soil aggregate.

(ii) On-Site Manufacture

For reasonably large areas and for correction of grading of existing bases the most common method of blending aggregates is by road mixing. For this operation only one specialist machine is required.

- *Pulvimixer*

Where materials are mixed on site they are usually spread in volumetric proportions on the road-bed and blended together with a pulvimixer working to the required depth. The machine consists of a large number of tines set at varying angles on a drive shaft, which is operated by the power take-off unit of a tractor. The mechanism is enclosed in a hood, which prevents loss of material and acts as a drag screed plate to level the resulting surface.

(iii) Other Equipment

Other equipment requirements for laying soil aggregate include graders, water bowsers and compaction equipment usually consisting of pneumatic tyred rollers and non-vibrating steel tandem rollers of 6-8 ton capacity.

f. *Construction Methods*

(i) Inspection

A thorough site inspection is required prior to construction, reconstruction or repair of soil aggregation bases. The inspection will define:

- Nature of working to be undertaken
- Size of operation
- Quality of existing materials
- Construction technique
- Equipment and material requirements
- Repair to be carried out
- Traffic control problems

The inspection may also necessitate visits to existing and new borrow pits for:

- Assessment of quantities available
- Taking samples for laboratory analysis and design

o *Measurement*

On site measurements are required to determine:

- Base widths, levels and thicknesses
- Size and location of lay-bys
- Size and number of turn-outs for junctions and access roads
- Variations to shoulders.

- *Repair*

The inspection must detail all necessary repairs to be undertaken prior to base construction, especially in respect to drains, culverts, shoulders and bridge approaches.

- *Preparatory Works*

▪ Drainage

Adequate provision must be made for drainage of excess water during construction, especially if the work is to be undertaken against existing high shoulders.

▪ Road Bed

The surface onto which the base is to be laid, except in respect of on-site mixing techniques, must be cleaned and graded to the correct profile and level and thoroughly compacted.

(ii) Planning

The standard planning sequences are required as listed under ***Dry Stone Base***.

(iii) Safety

Safety requirements are the same as for those discussed under ***Dry Stone Base.***

(iv) Operation

- *Off-Site Manufactured Material*

The sequence of operations listed applies equally to artificially blended material and naturally occurring soil aggregates. The operation is restricted to grader use only since this will normally be adequate for the small to medium sized works carried out by maintenance crews.

- Delivery of Material

The material will be delivered to site by tippers and deposited along the centre-line of the section to be worked. Should the material be sufficiently loose it may be spread-tipped to ease the work of spreading and thereby reduce the risk of segregation.

- Spreading Soil Aggregate

The material should be spread uniformly by a grader to the correct camber and grades and to a maximum thickness after compaction of 15cm. Should a thicker base be required, it must be constructed in two or more separate courses. During the spreading and shaping stage the surface of the soil aggregate should be continuously checked with strong lines and camber boards.

- Moisture Content

The material which is now spread and shaped and in loose condition should now be brought to the predetermined optimum moisture level for compaction. This is achieved with tractor towed water bowsers. No rolling should be permitted until the addition of water has been completed and all visible surface water has soaked away. This will normally occur very rapidly since soil aggregates for bases do not contain a very high percentage of plastic fines.

- Compaction

Compaction should be carried out with a pneumatic tyred roller working from the outer edges to the centre line and completed by a smooth wheeled tandem roller of 6-8 ton size. Where the aggregate grading is fine, it is useful to give material a first pass with a smooth wheel tandem roller. This reduces early distortion and the tendency of fines to rise to the surface if the moisture content is too high.

- *On-Site Manufactured Material*

This technique of road-mixing should be confined to blending two materials, one of which is preferably an existing road bed material. Where three materials require blending the operation is more easily performed in a batch-mix plant for large volumes or in a concrete mixer for smaller jobs.

- Preparation of Road Bed

The existing road bed, base or first material laid and lightly compacted, should be scarified and graded to profile. It should be lightly watered with a water bowser and then lightly compacted with a smooth wheeled roller. The profile, camber and depth of material should be accurately checked.

- Addition of Second and Third Type of Material for Blending

The designed portion of second and third material is brought onto site by tippers and spread- tipped. It is then spread to full width and required thickness. Very careful control of thickness and profile is required by continual checking with camber boards and string lines. The loose material should be lightly watered and then lightly compacted with a single pass of a smooth wheeled roller.

- Mixing

With the correct proportions of all materials to be blended laid one over the other in even layers it is now possible to mix them together with a single pass of a pulvimixer set to the predetermined depth.

- Moisture Content

The moisture content of the residual loose mix should be checked and if necessary raised to optimum for compaction by watering with a bowser.

- Compaction

Compaction will follow the same sequences as described in *(iv)* (4) above.

g. Defects

As a base material, soil aggregates are not exposed to wear by traffic and weather. The only defects likely to materialize will be those created by segregation and errors of workmanship. These are extremely rare in the case of plant manufactured materials. On site mixing of aggregates can result in patches of excessively fine or excessively coarse material.

(i) Segregated Patches

These, which may materialize immediately after compaction is complete, will become visible as patches of material and appear to be drier or wetter than the surrounding area.

This is most frequently caused by high spots in the surface of the first material laid resulting in an imbalance in the design blending. Correction of the defect can only be effected by removal of the defective patches to the full depth of the course and replacement by correctly graded material manufactured off-site.

(ii) Other Defects

Where soil aggregate bases are employed temporarily as wearing courses they will be liable to the same defects as listed under ***Gravel Surfacing***.

8.7.2 Dry Stone Base

a. General Theory

(i) Definition

A dry stone base is a homogeneous base composed of crushed stone particles, mechanically interlocking with voids filled by smaller stone particles for maximum dry density and is maintained in a dry condition throughout its operational life. The material used for a dry stone base is commonly known as crusher-run or crushed-graded-aggregate. In principle the base is similar to concrete without the cement content. It is a flexible base capable of adjusting itself to minor deformation of the sub grade without failure.

(ii) Functions

In common with all other flexible bases a dry stone base fulfils the following functions:

- Transmits and distributes the concentrated wheel loads from the surfacing courses (wearing and binder if present) to the lower pavement courses of sub-base or sub grade.
- Reduces load intensity to acceptable levels for the lower grade materials underlying it.
- Provides a platform on which the surfacing course may be laid

b. Application

A dry stone base can be laid onto any lower base, sub-base or sub grade material, provided that care is taken to protect it from:

- Clay pumping
- Capillary rise of ground water

Where the base is to be laid direct upon a cohesive soil sub grade or material containing high moisture content a sand (drainage) blanket of not less than 10cm thickness should first be laid and compacted. Where the base is to be laid on a strong soil aggregate sub- base, such as lateritic gravels, a sand blanket of 2.5 - 3.0 cm will be sufficient to prevent the rise of clay into the base aggregate.

A dry stone base can be completed with a good quality of texture and evenness by, receiving a wearing course or preferably binder and wearing courses, without the necessity of inter- posing a regulating course.

c. Strength

Dry stone bases are the stronger and most versatile of flexible bases and thicknesses may therefore be included in depth/strength calculation for pavement design.

d. *Design Principles*

Before studying the design principles, it is necessary to consider the one major weakness of crusher-run materials, namely segregation, which plays a major part in every step of design, planning and construction.

(i) Segregation

Segregation is the tendency of crusher-run aggregates to separate into their coarse and fine particles under the influence of wind, gravity, rain, vibration and working.

- *Wind*

Crusher-run aggregates loaded off conveyors into tippers under windy conditions will deposit a surprisingly large quantity of their fine particles onto the downward side of the truck. The effect can be reduced by attaching a tabular canvas chute to the conveyor head.

- *Gravity*

Crusher-run aggregates loaded off conveyors into tippers will tend to segregate the larger stone particles by running down the side slopes loaded mound. The conveyor should be kept as low as possible and loads in tippers should be raked level continually during loading.

- *Rain*

Crusher-run aggregates stockpile exposed to rain will eventually concentrate the fine particles into the base of the stockpile as a normal drainage effect. Stockpiles have therefore to be reworked from time to time.

(ii) Construction Techniques

The problems of segregation have given rise to two primary construction techniques known as the “Wet Process” and the “Dry Process”.

- *Wet Process*

The wet process consist of adding a small amount of water, in no case greater than 5% by weight, to the combined aggregate either at the quarry site or at the construction site. The amount of water used will vary with the type of aggregate but should be sufficient only to bond temporarily the fine fraction particles to the larger stone particles. The complete graded material is laid as a homogeneous mass either by a spreader paver or by graders. This method reduces the risk of segregation but does not totally eliminate it. Care is still required at every step. The main advantage to the use of the wet process is that it utilizes standard maintenance equipment and can be employed (by grader spreading) on relatively short lengths of the highway.

- *Dry Process*

The dry process, also known as the segregated method, separates the aggregates at the quarry into its coarse and fine fractions (usually at the 9mm screen). The two types are transported separately and laid separately. The fine fraction, laid over the top of the compacted coarse fraction is vibrated into the voids.

This method totally eliminates the risk of segregation and produces a consistently dense base. The disadvantage is that an aggregate spreader is required for laying the coarse fraction and specialized, high frequency vibrating compaction equipment is necessary for inserting the fine fraction. As a result the method can only be used on relatively long construction lengths.

- *Wet Segregated Process*

A less efficient variation to the dry or segregated process, lays the coarse fraction as described above under DRY process and washes the fine fraction into the voids using plain rollers or very low frequency vibrating plate compactors. The only advantage of this variation is that it can be done by hand in relatively small areas where access of heavy equipment is not possible.

(iii) Choice of Construction Method

The first design step is to select the method of construction to be used dependent upon the nature and size of the job and equipment availability.

- *Extensive Base Construction*

Heavy base construction length in excess of one kilometre will normally constitute a part of a major rehabilitation or reconstruction programme, which will be planned and submitted for tender by the Federal Ministry of Works. Where such long lengths of base constructions are within the capacity of the maintenance organization the work may be undertaken by either:

- Dry process (if equipment is available).
- Wet process.
- Short Length of Base construction

- *Short Lengths of Base Construction*

Length of up to one kilometre may frequently require to be laid in major repair and upgrading exercises. The only practical method to be employed is:

- Wet Process

- *Small Area of Base Construction*

Short lengths of highway may require reconstruction in areas of washouts and low formations at valley curves over culverts. Under these conditions the short length or the need to work to half carriageway width may make the use of graders impracticable. The method to be used, dependent on site conditions is:

- Wet process.
- Wet Segregated Process.

- *Large Potholes*

Where large potholes have damaged the base and require removal and reinstatement of the damaged section the use of any wet method and construction may well cause further necessary damage. Under these conditions it is recommended that the replacement base be installed either by penetration macadam or bitumen macadam.

(iv) Determination of Depth of Course

The depth of base course to be implemented in any one lift is related to the following factors:

- Choice of construction method
- Nominal maximum size of grading
- Effective compaction equipment

- *Construction Method*

Once the construction method has been chosen dependent on conditions as discussed above, it will be possible to select the appropriate grading shown there in a tolerance of maximum and minimum thickness that may be laid in any one course of construction.

If, for example, the Wet Process is selected, only one grading is available and this material may only be laid in course thicknesses of 10 to 15cm. It will not be possible to achieve optimum compaction outside of this range.

- *Nominal Maximum Size of Grading*

Where the Dry Process is selected for use there is a choice available of four nominal maximum sizes of coarse aggregate allowing a range of course thickness varying from 8cm to 23cm of total compacted depth. Should it be necessary to exceed the compacted depth of 23cm, then two or more courses will have to be laid

- *Effective Compaction Equipment*

When designing the course depth to be laid at any one time careful consideration must be given to the available compaction equipment.

Where the dry process is used, high frequency vibrating compactors are necessary and if only vibrating rollers are available then the thickness of course to be laid should be reduced to the middle of the range as shown in Table 60 below.

Loose material for the wet process and for the coarse fraction of the Dry Process should be laid to 17-20% above the final compacted thickness required.

(v) Aggregate Grading

- *Wet Process*

Only one grading is given for this material since compaction will be by smooth steel wheeled rollers and pneumatic tyred rollers. Vibratory equipment is not recommended for compaction.

Table 60: Material Grading

Nominal Maximum Size: 50mm	
Sieve Size (mm)	Percentage Passing
50	100
25	60 - 90
9	40 - 60
4.75 (No.4)	30 - 40
2.0 (No. 10)	20 - 25
0.425 (No.40)	10 - 20
0.075 (No. 200)	3 - 10
Compacted Thickness (Single Course)	= 10 – 15cm

This material is laid in a moist to wet condition to minimize segregation. Further water may have to be applied rafter spreading to bring it to optimum moisture content for compaction.

This is almost certain to raise the moisture content above 2.5%, which on an average for limestone is the critical level at which high frequency vibration will result in floating the fine fraction towards the surface. For this reason, all vibratory equipment should be kept off the material until it is thoroughly compacted and dried.

- *Dry Process*

  - Coarse Fraction

Four gradings are given in Table 61 below for Nominal Maximum Sizes of 75mm, 60mm, 50mm and 40mm coarse aggregates:

Table 61: Material Grading for 75mm Aggregates

Nominal Maximum Size: 75 mm	
Sieve Size (mm)	Percentage Passing
75	100
60	90 - 100
50	35 -70
40	0 - 15
19	0 - 5
Compacted Thickness (Single Course) = 15 – 23cm	

Table 62: Material Grading for 60mm Aggregates

Nominal Maximum Size: 60 mm	
Sieve Size (mm)	Percentage Passing
60	100
50	95 - 100
40	35 -70
25	0 - 15
12	0 - 5
Compacted Thickness (Single Course) = 12 – 18cm	

Table 63: Material Grading for 50mm Aggregates

Nominal Maximum Size: 50 mm	
Sieve Size (mm)	Percentage Passing
50	100
40	90 - 100
25	20 - 55
19	0 - 15
9	0 - 5
Compacted Thickness (Single Course) = 10 – 15cm	

Table 64: Material Grading for 40mm Aggregates

Nominal Maximum Size: 40 mm	
Sieve Size (mm)	Percentage Passing
40	100
25	90 - 100
19	20 - 55
12	0 - 10
9	0 - 5
Compacted Thickness (Single Course) = 8 – 12cm	

- Fine Fraction

The grading for the fine fraction to be vibrated into the compacted coarse fractions listed above is one common size passing the 9mm screen, as listed in Table 65 below:

Table 65: Material Grading for 9mm Fine Fraction

Nominal Maximum Size: 9 mm	
Sieve Size (mm)	Percentage Passing
9	100
No.4	85 - 100
No. 100	10 - 30

- *Acceptable Materials*

Only mechanically crushed stone aggregate may be used for coarse and fine fractions of dry stone bases. Naturally occurring gravels and sands are not suitable due to their rounded shapes. Best results are obtained from homogeneous materials and it is not recommended to supplement the fine fraction material with material from another quarry if this can be avoided.

e. *Equipment*

(i) Aggregate Spreader

The aggregate spreader is used for laying the coarse aggregate in the dry process or total aggregate in the wet process. It consists of a crawler tractor mounted hopper, which is open to the road bed surface at its base, side forms and an adjustable tailgate. It is similar in appearance to a paver without bottom feed plate, lateral screws, screed and tamper. The aggregate spreader replaces the screed of the paver with two or more vertically adjustable gates, called strike plates, each of which can be raised at either end to vary the thickness of carpet and allow for variation to camber or super-elevation relative to the road bed on which the machine operates. The machine is illustrated below:

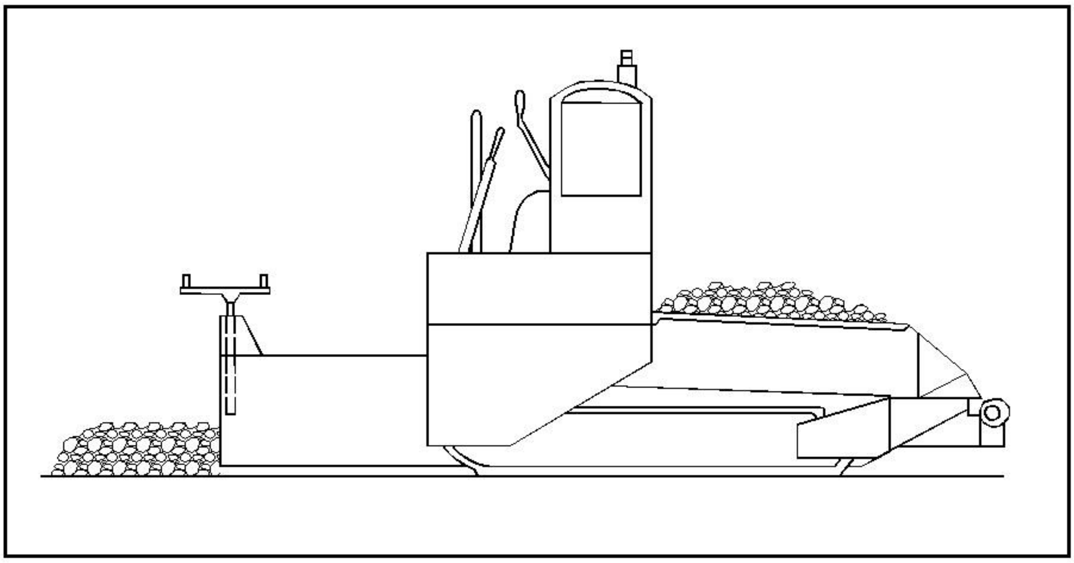


Figure 85: Aggregate Mixer

(ii) Paver

As an alternative to the aggregate spreader a paver may be used in the wet process. Under no conditions should pavers be employed to lay coarse fraction aggregates in the dry process since the aggregate without fines or water will cause irreparable damage to the screed plate and tamper. The paver is described fully under ‘Asphaltic Concrete’.

(iii) Grader

A standard maintenance grader of **110-130 HP** rating is suitable for spreading t h e total aggregate in the wet process.

(iv) Rollers and Compaction

- *Wet process*
  - Initial compaction

Initial compaction should be carried out with steel wheeled tandem rollers of approximately 8 ton size ***Without Vibration.***

  - Final Compaction

Final compaction is obtained in the wet process with a pneumatic tyred roller.

- *Dry Process*
  - Coarse Fraction

First compaction immediately behind the aggregate spreader is best obtained with a 12 ton three wheel steel roller. Compaction should be completed with a 6 ton steel wheeled vibrating tandem roller.

  - Fine Fraction

The fine fraction is most easily inserted into the voids with a high frequency vibrating multiple plate compactors.

In the absence of such a specialized tool, insertion of the fine fraction can be achieved with more passes using a self-propelled vibrating roller of 6-8 ton size or a towed vibrating roller, provided that the frequency of vibration is not less than 1800 cycles per minute.

f. Construction Methods

(i) Inspection

Inspection is a vital exercise that must be carried out by those persons responsible for planning, design and construction. Its aim is to check measurements, determination of work techniques, equipment and material requirements and preliminary works in repair and preparation.

- *Measurement*

On-site measurement is required to obtain:

- Pavement widths and levels
- Size and location of lay-bys
- Size and number of turnouts for junctions and access roads, making allowance for tapering to levels
- Location and length of bridges. New bases will not be laid over bridge decks but will be either feathered out to abutments or cut into abutment backfill
- Increase in height and width requirements of shoulders
- Increased dimensions of culverts head and wing walls
- Relocation details for highway furniture.

- *Repair*

Details are required for planning and pre-repair to drains, shoulders, culverts and bridge approaches.

- *Preparatory Works*

- Shoulders

For dry process construction and occasionally for wet process construction, it is necessary to lay dry stone base against a pre-repaired side form, usually the completed compacted shoulder.

- Drainage

Where shoulders are completed ahead of the work relief drains must be cut to drain the road in the event of rain and during wet process construction. These lateral drains should be placed one every 20 metres either side and may be temporary for the construction period or permanent sub-soil drains where a sand blanket is used.

- Road Bed

The surface on which the dry stone base is to be laid (sub grade, sub-base) must be prepared to receive the material.

The surface must be shaped to an adequate camber, particularly if the wet process is to be used and thoroughly compacted. If clay is present in the sub grade or sub-base material the surface must be overlaid with a minimum of 2.5cm of compacted sand. Where the sub grade or sub-base is in naturally damp condition or where the wet process is to be employed within pre-constructed shoulder the minimum of 10cm sand blanket will be placed over the surface and laterally drained.

(ii) Planning

Planning exercises will be needed to coordinate all aspects of the work, namely:

- Site requirements
- Sequence of operations
- Production capacity
- Transport requirements
- Equipment requirements
- Material quantities
- Measurement and testing equipment and personnel
- Chains of command
- Traffic control

(iii) Safety

Danger to persons is not as great as with bituminous pavement work nor is the material so likely to be damaged by traffic. However, normal safety precautions must be taken and the provision of warning signs, barriers, cones, stop-go boards, signals and flagmen will be required.

(iv) Operation

- *Wet Process*

The most frequent usage of this technique for laying dry stone bases will be on relatively short lengths of highways utilizing such equipment as is available from standard stock holding in maintenance districts. The following brief description is therefore confined to such methods.

- Open-Sided Construction

The normal method of laying dry stone bases with the wet process is by open-sided (unsupported) construction to facilitate drainage of considerable amount of water present. To ensure that there is no collapse of the unsupported edge it is necessary to allow an additional 10cm width on either side and a 2:1 side slope. Allowance must be made for this in setting out and ordering material.

- Delivery to Site

The material will be delivered to site in tippers and should be in a damp to moist condition. It should be unloaded in heaps along the centre-line of the section to be worked.

- Spreading and Blending

The material heaps will first be spread to full width and approximate camber by grader. In this loose condition water is uniformly added by water bowsers to bring the material to optimum moisture content for compaction. Since some segregation will undoubtedly have occurred in transport and unloading, blending of the aggregate will be necessary before compaction can start.

This is achieved by grader, by returning all material to a windrow along the centreline and then spreading it out to full width again. One more repetition of this process should be sufficient to obtain a good uniform mix. The spread material may now be finally dressed to the correct camber and graded by the grader.

- Compaction

Compaction should commence with an 8 ton steel wheel tandem roller and be completed with a pneumatic tyred roller. The latter should be used for compaction of the side slopes of each layer. One tandem roller and one pneumatic tyred roller will compact approximately 100 square metres per hour.

The work must be checked continuously for level, camber and segregated spots in the surface. Correction should be made wherever possible in the loose condition. Once the material has been compacted correction can only be achieved by scarifying and relaying with additional water to the full depth of the course.

- Finishing

When compaction is complete and surface has become thoroughly dry, all excess fines must be removed from the surface.

If a second course of dry stone base is to be constructed, it will be sufficient to broom the surface lightly with a power broom. This will leave the larger stones just visible in a dust mortar.

Where the base is to be primed prior to a bituminous surfacing, the brooming should be more firmly applied to depress the dust mortar about 3 mm below the stone surface.

- *Dry Process*

Before this method of construction can be employed the following condition are essential:

- Long length of base to be constructed
- Aggregate spreader available
- Shoulder to be pre- formed

- Coarse Fraction

The coarse fraction is delivered to site in tippers and tipped directly into the hopper of the aggregate spreader. The operation of the spreader is identical to that of a paver, pushing the tipper ahead as it shapes and levels the aggregate. Compaction is achieved with initial rolling by a 12 ton three, wheeled steel. Final compaction is carried out with a 6-8 ton vibrating tandem roller. One aggregate spreader backed by the pair of rollers referred to above will be able to lie and compact 250 –300 square metres per hour.

The compacted coarse fraction must be carefully checked for level and camber since it controls the quality and evenness of the finished surface of the base. Minor errors in low spot, caused by dragging of larger stone particles under the strike plate of aggregate spreader, can be corrected prior to final rolling by dressing with 19 mm single size chippings.

- Fine Fraction

The fine fraction will be laid by a chipping spreader as a uniform blanket over surface of the compacted course aggregate. Approximately 60 to 70 % of the total required quantity will be applied in this first layer. The fine fraction is inserted into the voids with a high frequency vibrating multiple plate compactors if available. A single pass with such a machine will normally suffice to make the fine blanket totally disappear. In the absence of such a compactor, a vibrating roller with frequency of not less than 1800 cycle per minute will achieve the same result in 2 to 3 passes.

The remaining fines should now be similarly applied. A further two passes by the plate compactor, or 3 to 4 passes by a vibrator, should succeed in choke filling all voids in the coarse fraction. Any remaining coarse aggregate visible should be hand dressed with fines and further vibrated. Care should be taken to stop vibration treatment at a time when open textured course stones become visible, as further vibration in this condition may loosen the coarse fraction interlock.

- Finishing

The compacted surface may be immediately lightly brushed with a power broom. The finished surface texture should be dust free with the high points of the coarse stone visible through a grit background.

g. Defects in Dry Stone Bases

Provided care is taken to check continuously with camber board and straight edge, defects should be reduced to the minimum.

(i) Ravelling

Ravelling will appear as patches of loose large stones lying on the surface. It is caused either by traffic on material deficient in fines or by over-vibration.

The affected area should be excavated to a minimum of 10cm depth and re-established with well graded material, watered and rolled.

(ii) Fine Patches

Fine patches appear as dusty pools or lines on the surface. The cause of this defect is usually due to segregation created by overworking material during the blending stage of Wet Process construction.

The cure follows the same procedure as described in ***(i) Ravelling*** above.

(iii) Ruts and Depressions

This defect may appear as tracking under construction traffic or as tracking in the course at a later date. The cause of this failure is usually due to poor grading or insufficient fines resulting in higher residual voids compacted by later traffic.

If the defect appears during construction, the affected area should be excavated and replaced with well graded material. Should the defect appear after surfacing the rut should be overlaid with wearing course material to return the surface to the correct profile.

(iv) Corrugation

Corrugation appears as lateral waves on the surface of the base. U sually with dry stone bases the wave length will be very short. Corrugation is caused by construction traffic driving over completed bases that have excess fine fraction material lying on the surface.

If evidence of corrugation can be seen early the defect can be corrected by lightly plaining the surface with a grader and heavy brooming. If the corrugation reappears or is too deep to be corrected by plaining then the entire affected areas must be removed to a depth of at least 10cmand a new course must be constructed.

8.7.3 Other Bases

Two other types of base in addition to those already described are in use in Nigeria:

- ***Cement stabilized base*** is in common use and there are many kilometres of road which have this material as a base
- ***Bitumen stabilized base*** is very rarely used and it is believed that only two roads in Nigeria amounting to about 200 kilometres have a bitumen stabilized base.

Both of these types of base require specialized machinery which is not normally held by a maintenance department and for this reason the design and construction of such bases is not covered by this manual.

For cement stabilized bases, the FMW General Specification (Roads and Bridges), Clauses 6220 to 6247, is applicable. There is no standard specification in Nigeria for bitumen stabilized bases and its use is not recommended in view of the fact that in the present world economic climate bituminous materials are rapidly becoming more expensive than locally produced cement-based materials.

8.8 Drainage Structure

8.8.1 Culverts, General

The need to differentiate between bridges and culverts within administrations responsible for the allocation of funds for design and construction of new highways in some countries has led to erroneous descriptions of culverts, such as:

- “A culvert does not form part of the highway surface”
- “A culvert is a drainage structure of less than 6 metres span”

Both description can be and frequently are breached by multiple box culverts.

A culvert is therefore defined as a minor drainage structure that fully encloses the water course that it transmits from one side of a highway to the other and may in its design be permitted to flow full to accommodate peak rainfall intensities.

Culverts are normally located on:

- Small water courses
- At the bottom of dry depressions
- At locations required for the release of surface water drainage
- In side drains beneath access roads and drives to adjacent property

Culverts are generally constructed of the following materials:

- Spun-reinforced concrete pipe-Precast concrete pipe
- Corrugated metal pipe
- Cast-in-situ reinforced concrete box sections
- Masonry box sections

8.8.2 Reinforced Concrete Pipe Culverts

a. Description of Pipes

Reinforced concrete pipes as referred to in this section are circular section, thin wall concrete pipes with a steel reinforcing cage, manufactured in a spinning machine.

(i) Available Sizes

The sizes of pipes that may be purchased locally will depend upon moulds available but normally these will be in the ranges of 0.60, 0.75, 0.90, 1.05 and 1.20 metres internal diameter. They will be manufactured in 1.0, 1.8and 2.0 metre length.

(ii) Joints

- *Butt Joint*

Butt joints are square ended pipes as illustrated in Figure 86. Joints are either completed with mortar surrounds or filled with oversize rings or collars.

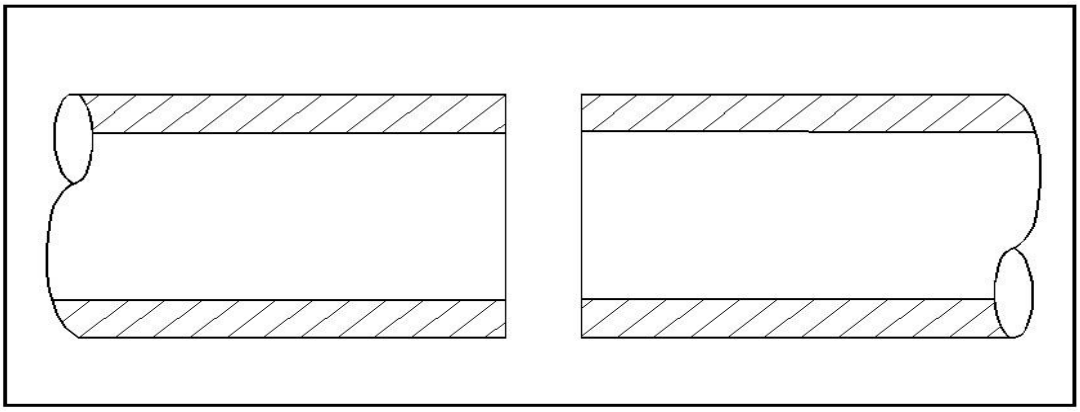


Figure 86: Butt Joint

- *Ogee Joints*

Ogee joints are tapered ends creating a spigot and socket effect without increase to the outside diameter of the pipe, as illustrated in Figure 87

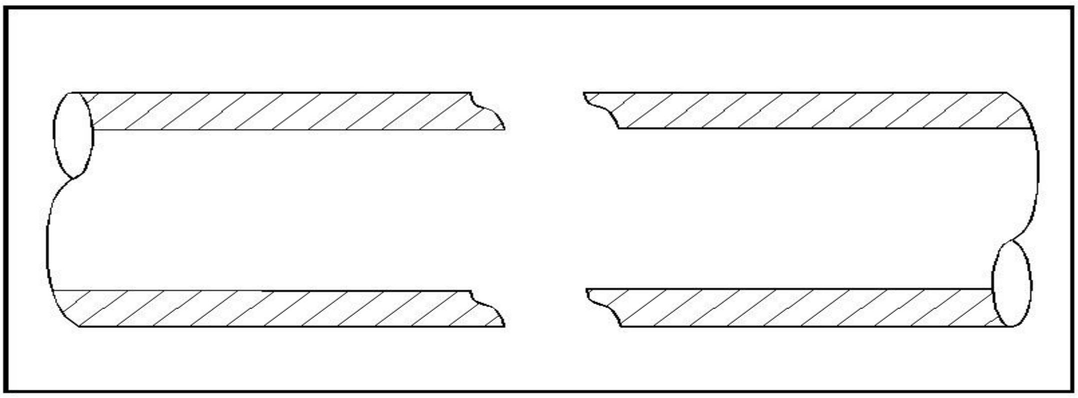


Figure 87: Ogee Joint

b. Application

The need to construct new culverts by maintenance personnel arises from:

- Replacement of broken sections or whole culverts
- Replacement of undersize culverts resulting in floods and washouts
- Construction of additional culverts due to omissions in early drainage designs

c. Limitations of Responsibility

Culverts are drainage structures and consequently a thorough understanding of drainage technology is necessary for their design. The responsibility of the maintenance engineer is therefore restricted to the design and installation of small culverts for the purpose of providing surface water drainage outlets and carriage of small streams. This may be defined as a catchment area of 500 hectares or a culvert opening area of 3.5 square metres. The latter is equivalent to a triple barrel pipe culvert of 1.20 metre diameter.

Any larger culvert or catchment area should be referred to higher authority for specialist design or approval of design proposals.

d. Design Principles

For large culverts it is necessary to make a study of the hydrology of the catchment area and a complete analysis of the hydraulics of the proposed design. For smaller drainage structures within the limits of responsibility of the Maintenance Engineer this study may be simplified but is still necessary for both new culverts and replacement of existing structures. This analysis or design will cover the following aspects:

- Size or cross-sectional area
- Slope of culvert
- Location of culvert
- Depth of fill, or surcharge of culvert

(i) Size of Culvert

- *Drainage Outfall Culverts*

Where the culvert to be installed is accommodating only the surface water run-off from side drains it is possible to complete the peak flow by the method discussed under ***SIDE DRAIN LINING***. The quantity or quantities thus obtained in cubic metres per second may be inserted into formulae for:

- Circular pipe culverts

$Q = 1.5\ d^{2.5}$

Where Q is the total flow in m^3/sec

d is the internal diameter of the concrete pipe in metres

And for:

- Rectangular entrance pipe culverts

$Q\ (max) = 1.7a^{1.5}.b$

Where:

a = Height of opening in metres

b = Width of opening in metres

Q (max) = Capacity in cubic metres per second

These formulae are valid under the following conditions:

- *The slope of the culvert shall be equal to or greater than critical slope*
- *The head at inlet shall be equal to the top of the pipe*
- *The outlet shall be free*
- *The velocity at entry shall be less than the velocity at outlet*

It is possible to obtain a greater capacity by increasing the head at inlet. This however involves ponding of water on the inlet side, using the highway embankment as a temporary demand thus greatly increase the velocity and hence the scour at outlet. All of these conditions are basically undesirable in highway maintenance and should be avoided wherever possible.

For standards pipe sizes the capacities are given in Table 66 below:

Table 66: Pipe Culvert Size and Capacities

Concrete Pipe Diameter (metres)	Maximum Capacity (m^3 / sec)
0.60	0.42
0.75	0.73
0.90	1.15
1.05	1.69
1.20	2.37

The minimum size of pipe culvert that may be used under a main highway, i.e. Truck ‘A’ and Trunk ‘F’ highways, is 0.75 meter. Culverts smaller than this are extremely difficult to clean due to the relatively long lengths in these conditions.

- *Culverts for Watercourses*

For all culverts on watercourses and drainage outfall culverts that receive the discharge from cut-off drains, it is necessary to consider the size and nature of the catchment area. The most suitable design method for this purpose is the Talbot Formula which has the following advantages over other methods.

- Simplicity
- Gives culverts size directly
- Accurate and safe within limits specified ***Section (c)*** above
- Based on actual observations in rural conditions where the bulk of maintenance problems arise.

The formula is expressed as:

$A = 0.188CM^{3/4}$

Where : A = Waterway opening in m^2

M = area drained in hectares

C = coefficient, based on the contour of the land drained.

C = 1 for steep and rocky ground with abrupt

= 2/3 for rough hilly country of moderate slopes

= ½ for uneven valleys, very wide as compared to length

= 1/3 foe rolling agricultural country where the length of the valley is three or four times the width.

= 1/5 for level country with gentle slopes.

(ii) Slope of Culvert

Three factors of pipe flow, such as quantity velocity and slope, are governed by a correlation expressed by the Manning formula. Various charts exist in part 1 of the highway manual (Highway Design) for the determination of velocity and depth of flow, given the discharge, the slope and the pipe size. From these charts it can be concluded that:

- Too shallow a slope results in considerable reduction of capacity, reduced velocity and likelihood of deposition
- Maximum discharge (Culvert Capacity) is at the critical slope at which critical velocity occurs.
- Any increase in slope above the critical slope will result in no increase in discharge, but will result in an increase in velocity

From practical observations it has been found that concrete pipe culverts laid at slopes less than 0.5% will be liable to silting and a slope of 0.5% can thus be considered as design minimum.

On the other hand, slopes in excess of the critical slope probably do more harm than good because they create increased velocity (and thus scour) and decreased capacity. So the ideal slope lies somewhere between 0.5% and critical slope and as close as possible to the latter.

(iii) Location of Culverts

The fundamental principle in establishing the location of culverts is to follow as closely as possible the alignment of the natural water course.

- *Replacement Culverts*

Where new culverts are being constructed to replace old or defective ones on water courses, the opportunity exists to make improvement to drainage alignment.

Many old culverts were located at right angles to the highway alignment for economy of pipe length. These may, when necessary, be replaced at a skew location as shown in Figure 88, giving the advantage of reduction of bank erosion at the outlet end and better stream flow characteristics. A secondary advantage exists in that the new location enables the new culverts to be constructed totally in the dry.

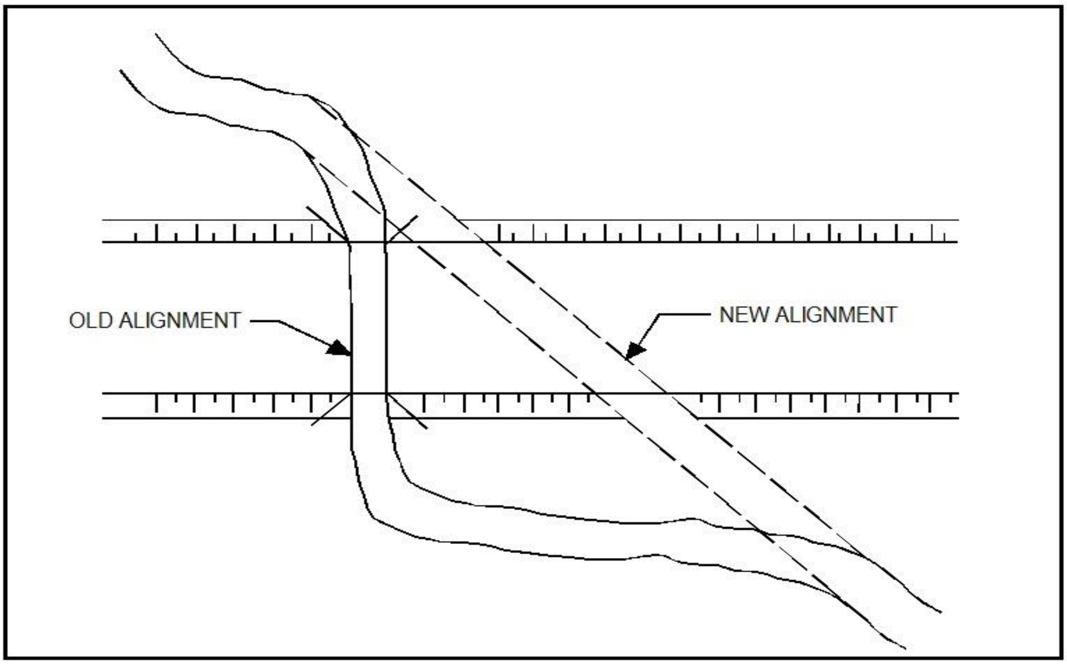


Figure 88: Replacement of Culvert to Prevent Soil Erosion

- *Drainage Outfall Culverts*

Drainage outfall culverts normally cater for relatively small volumes and low velocities. Thus, little advantage will be gained by placing these culverts at a skew.

(iv) Depth of Fill

The loads to which pipe culverts are subjected to are the live load of the traffic using the highway, intensity reduced with depth and the dead load imposed by the weight of fill over the pipe.

The most critical factor in the design of culverts is therefore the depth at which they are placed. Similarly, given a standard factory produced spin reinforced concrete pipe, its strength will predetermine the limits of maximum and minimum depth at which it may be safely installed. The strength of such a pipe is dependent upon three main factors:

- Wall thickness
- Quantity of reinforcement
- Position of reinforcement

A fourth factor, the grade or quality of concrete, may also be introduced but since this is incorporated only for large diameter pipes and very high strength under heavy fill, it is of minor importance to maintenance engineers. The standard grade of concrete used in the range of pipes discussed below is U.4000.

- *Factory Specifications*

Reinforced concrete pipes produced by factories and major contractors may be marketed with full detailed specifications as being in accordance with certain standards. The most common standard used in pipe manufacture is AASHTO: M 170-74 (ASTM: C 76-72a).

Where this is quoted then the permissible limits to which pipes may be installed are:

- Class I from 0.6 to 5.8 metres
- Class II from 0.6 to 3.9 metres
- Class III from 0.6 to 5.1 metres
- Class IV from 0.6 to 7.9 metres

- Class V from 0.6 to 10.0 metres

- *Unspecified Pipes*

In many instances pipes will be available without specification detail but with data of available reinforcement. To assist maintenance engineers in analysing such pipes the following simplified presentation is made drawn largely from AASHTO: M 170

- Reinforced Cages

Three basic reinforcement cage types are employed for reinforcing pipe culverts:

- a single inner circular ring, usually for small diameter pipes or
- an inner circular ring together with an outer circular ring, usually for medium and
- large sized pipes or
- an epileptical ring for all diameters of pipe.

- Reinforced Fabric

Reinforcement cages are usually made up from welded reinforcing steel fabric in which the main bars at closer spacing are circumferential and the transverse bars, usually a smaller diameter, run parallel to the axis of the pipe. In Table 67 below the area of steel quoted in cm²/m of pipe refers to the total cross sectional area of the main bars only.

- *Use of Tables*

The tables below are restricted to the standard range of pipes referred to in ***8.9.2(a)(i) Available Sizes*** above, namely 0.60, 0.75, 0.90, 1.05 and 1.20 metre internal diameter respectively. The tables show the range of wall thickness, standard reinforcement cage types, cross-sectional area of main steel per linear metre of pipe and equivalent depth of fill limits. From these tables the maintenance engineer will be able to identify the class of pipe offered and obtain direct or by interpolation the safe depth to which it may be installed.

Table 67: 0.60 Metre Diameter Pipe

Wall Thickness (mm)	Reinforcement (cm^2 / m)			Permissible Fill Depth (m)
	Circular		Elliptical	
	Inner	Outer		
63	2.8	-	2.3	0.6 – 3.9
	3.6	-	3.0	0.6 – 5.1
	6.1	-	5.7	0.6 – 7.9
76	1.5	-	1.5	0.6 – 3.9
	1.5	-	1.5	0.6 – 5.1
	5.7	-	4.9	0.6 – 7.9
95	1.5	1.5	1.7	0.6 – 7.9

A standard type of 63mm wall thickness and internal diameter 0.60 metre reinforced with an inner circular cage of 6mm steel at 7.5cm centres spacing would provide 3.7cm^2/metre of reinforcement. Such a pipe could be safely installed with not less than 0.6 metre fill over the pipe and not more than 5.1 metres of fill over the pipe.

Table 68: 0.75 Metre Diameter Pipe

Wall Thickness (mm)	Reinforcement (cm² / m)			Permissible Fill Depth (m)
	Circular		Elliptical	
	Inner	Outer		
70	3.2	-	3.0	0.6 – 3.9
	4.0	-	3.8	0.6 – 5.1
	8.0	-	7.4	0.6 – 7.9
89	3.0	-	2.5	0.6 – 3.9
	3.8	-	3.2	0.6 – 5.1
	7.4	-	5.9	0.6 – 7.9
108	1.9	1.5	2.1	0.6 – 7.9

Table 69: 0.90 Metre Diameter Pipe

Wall Thickness (mm)	Reinforcement (cm² / m)			Permissible Fill Depth (m)
	Circular		Elliptical	
	Inner	Outer		
76	3.0	2.1	3.2	0.6 – 3.9
	4.4	3.4	4.7	0.6 – 5.1
101	2.5	1.9	2.8	0.6 – 3.9
	3.6	2.8	4.0	0.6 – 5.1
	6.3	4.7	7.0	0.6 – 7.9
120	1.5	1.5	1.7	0.6 – 3.9
	1.7	1.5	1.9	0.6 – 5.1
	3.0	2.1	3.2	0.6 – 7.9

Table 70: 1.05 Metre Diameter Pipe

Wall Thickness (mm)	Reinforcement (cm² / m)			Permissible Fill Depth (m)
	Circular		Elliptical	
	Inner	Outer		
89	3.4	2.5	3.8	0.6 – 3.9
	5.3	4.0	5.9	0.6 – 5.1
114	3.2	2.5	3.6	0.6 – 3.9
	4.4	3.4	4.9	0.6 – 5.1
	7.4	5.5	8.3	0.6 – 7.9
133	2.1	1.7	2.3	0.6 – 3.9
	2.5	1.9	2.8	0.6 – 5.1
	4.2	3.2	4.7	0.6 – 7.9

Table 71: 1.20 Metre Diameter Pipe

Wall Thickness (mm)	Reinforcement (cm² / m)			Permissible Fill Depth (m)
	Circular		Elliptical	
	Inner	Outer		
101	4.5	3.4	4.9	0.6 – 3.9
	6.8	5.1	7.4	0.6 – 5.1
127	3.8	3.0	4.2	0.6 – 3.9
	5.1	3.8	5.7	0.6 – 5.1
	8.9	6.8	9.9	0.6 – 7.9
146	3.0	2.3	3.2	0.6 – 3.9
	3.4	2.5	3.8	0.6 – 5.1
	5.5	4.2	6.1	0.6 – 7.9

- *Exceptional Conditions*

Where the available cover over the top of the pipe culvert is less than 0.60 metres then the whole of that deficiently covered length within the pavement and shoulders shall be haunched and fully clad with 15cm of concrete.

Similarly, culverts requiring to be installed at depths greater than the limits shown as permissible in the tables above may be haunched and clad with 15cm of concrete.

e. *Equipment*

Standard equipment requirements for culvert construction are:

- Tractor and backhoe
- Concrete mixer

- Vibrating plate compactor
- Vibrating roller, hand operated

Additionally, it is desirable to allocate a flatbed truck to the team. The truck should be fitted with a 3 ton hydraulically operated crane arm and out-riggers to facilitate off loading and placement of the relatively heavy culvert pipe sections.

f. *Construction Methods*

(i) Inspection

The primary purpose of the site inspection is the collection of data necessary for design, essential repair works and planning.

- *Factors Governing Design*
  - New Drainage Outfall Culverts

Measurement must be made of side drain length and cross fall detail of highway, where cut-off drains feed into the proposed outfall culvert estimation must be made of the catchment area of the cut-off drain and observation of the type of topography in the area should be noted.

Levels of drain inverts on either side of the highway and pavement crown levels should be recorded together with lowest available outfall level at the discharge end of the proposed culvert.

  - Replacement Culverts on Water Courses

Observation and estimation of the catchment area is necessary as for cut-off drains above. Levels must also be recorded as above.

- Repair Works

The only essential repair works that must be undertaken prior to installation of new culverts are those involving repair or lining to side drains discharging into the proposed location. It is desirable to ensure that new culverts are not exposed to unnecessary scour or silting.

- Alignment Improvements

Every opportunity should be taken to improve alignment when replacing culverts. Thus, all evidence of scour and tendencies of streams to meander should be recorded. However, the full volume of all existing serviceable culverts and structures, aprons, wing walls, spillways and control works should be noted.

(ii) Planning

The construction of a culvert on an in-service highway constitutes a major observation to traffic. One of the primary objectives of planning is therefore the choice of culvert type, design and operational technique that enables this obstruction to be reduced to a minimum.

The factors that will be studied and carefully analyzed are:

- Half width construction or bypasses
- Stream by-passes
- Sequence of operations
- Material requirements
- Transport requirements
- Stockpile areas
- Traffic control

(iii) Safety

Safety measures must be provided for the safety of highway users with the provision of warning signs, cones, stop-go boards or signals and flagmen. Since the works cannot be completed and the site closed up within one working day, lamps and watchmen must be provided for overnight safety

The safety of workmen must be provided for with adequate barriers. Where excavations are deep the trench sides must be adequately shored to prevent collapse. Safe working depths will vary depending upon the nature of soil in the formation but as a general rule any excavation of depth greater than 2.0 metres should be shored in the interest of workmen‘s safety, if not for the preservation of the pavement stability.

(iv) Operation

Prior to initiating the construction of a new or replacement culvert, it is advisable to bring to the site the materials plants, signs and tools envisaged to be necessary for the work. This should ensure that the construction will take the minimum time and shorten the period in which the road user will face a major obstruction in the highway.

Half-width construction is the most usual way of building culverts. The engineer should give thought to the layout of the plants and materials for most economic operation, bearing in mind also that space must be reserved for dumping of spoil from the excavation. Pipes should be stored as near as conveniently possible to the design alignment in order to minimize handling, which frequently can give rise to broken pipes.

The length of road to be closed, usually one lane wide, should be long enough to provide space on the carriageway for all of the excavation and concrete materials and machinery.

Work will commence on the lowest (outlet) side of the culvert and progress toward the higher (inlet) side. The sequence of operations is normally.

- Excavation and shoring
- Concreting of culvert base
- Pipe installation
- Concrete hunching or surround, if required

- Removal of shoring and backfill
- Pavement reinstatement (to release the road to traffic)
- Construction of end structures (headwalls, wing walls, spillways, splash areas)
- Reinstatement of embankments, verges and shoulders

- *Excavation*

Excavation may be carried out manually or with a tractor and backshore. The sides must be vertical and the trench width restricted to minimum necessary for installation and consolidation of backfill. Recommended excavation widths are shown in Figure 89 and Figure 90 below:

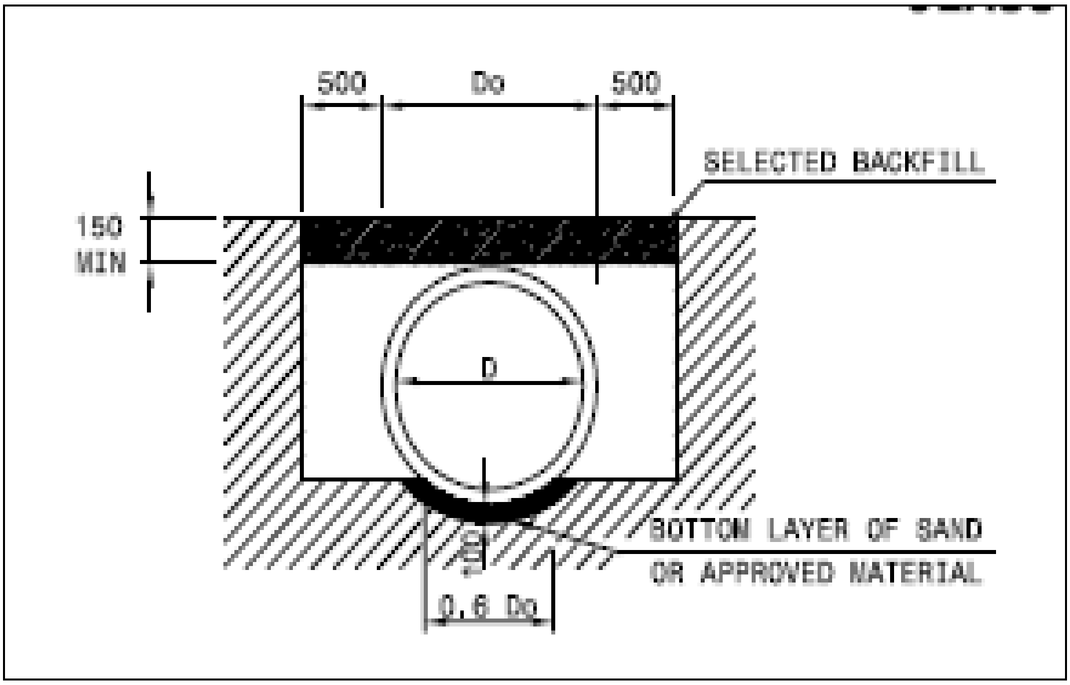


Figure 89: Single Pipe Recommended Excavation Widths

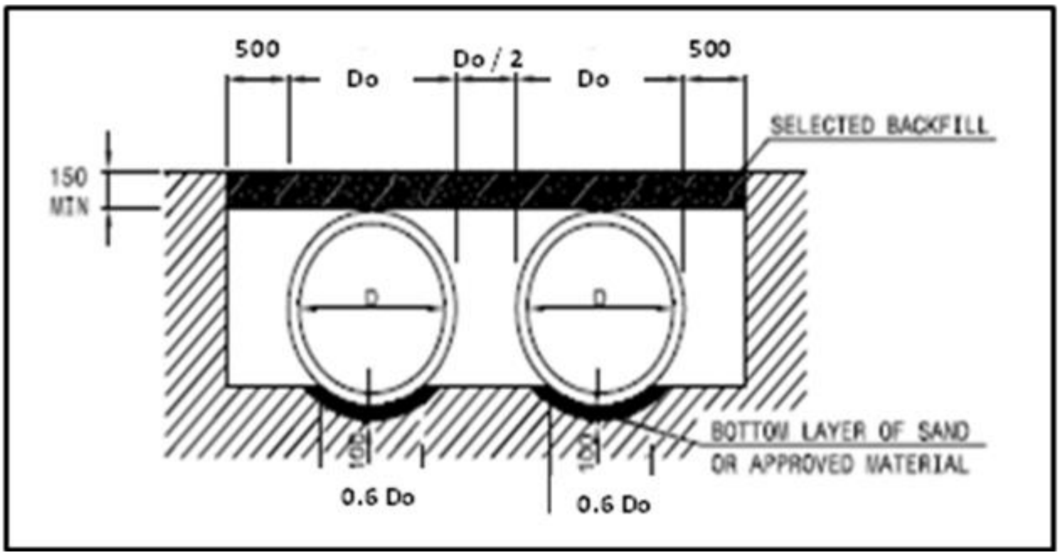


Figure 90: Multiple Pipe Recommended Excavation Widths

Where multiple pipe culverts are being constructed, a gap of width equal to half the diameter of the pipe must be left between pipes to allow space for compaction of backfill and to provide adequate lateral support.

If the excavated material is of good quality and it is intended to re-use it for backfill, the spoil should be dumped in a place where it will not deteriorate due to becoming wet or soaked. If the spoil is unsuitable, it should be either dumped in thin layers elsewhere within the right-of-way or taken to tip by lorry or dumper.

The bottom of the trench should in any case be manually trimmed to correct level..

- *Shoring*

Excavations in excess of 2 metres will require shoring using either timber planks or steel trench sheet and timber or adjustable steel struts (e.g. Acrow).

Many trenches of less than 2 metre depth will also require shoring and the engineer should inspect the state of the sidewalls of the trench. The presence of soft, wet or unstable earth will indicate the need for shoring.

Placing of the struts requires some planning in order not to interfere with the concreting and installation operations. Normal minimum strut requirement are at the bottom, middle and top of the trench. The bottom strut to be removed after the concrete base has been poured and set as the base itself then acts as the strut. The middle struts should preferably be place high enough to get the pipe comfortably underneath. The whaling (longitudinally placed to take the earth pressure to the struts) should be long enough and strong enough to give strut spacing, longitudinally of about 2 to 3 metres, for convenient working space. For deep (over 3 metres) excavations, proper design must be made in advance by the engineer, taking into account anticipated earth pressures.

CAUTION: There are more deaths caused in works of civil engineering by trench collapses than in any other operation and the engineer must satisfy himself that the excavation is safe. If he has doubts about safety due to a possible trench collapse, he must consult higher authority and in any case ensure that no personnel are allowed inside or adjacent to the excavation until its safety has been ensured.

- *Culvert base.*

Concrete pipe are constructed as rigid structures and therefore require a sound, unyielding base. Occasionally, a well compacted granular material is sufficient for small culvert or if the base of the trench is rock, normally a 15 cm bed of concrete is used as the culvert base.

The top of the base can be either shaped or flat to receive the pipe. , A good standard of finish is desirable to prevent any undue point loading on the installed pipe.

In wet trenches, the concrete can be mixed relatively dry on the assumption that some of the free water will combine with the mix to give a not too sloppy and unworkable concrete.

The concrete base must be given enough curing time to develop its strength, particularly if the base is intended to replace the bottom struts of a shored trench and three days is normally sufficient for average situations.

- *Pipe Installation*

Commencing at the outlet end, the first pipe is installed in such a way that it is in the correct longitudinal position relative to any intended headwall. The pipe, if it is Ogee or any other male/female type of joint, must be installed with the female socket facing upstream. The pipe is firmly wedged to line and level using pre-formed concrete blocks or sound rock or gravel stones.

The next pipe is laid so that the joint is not tight but snug and with a gap between corresponding features of 1-2cm. This process is continued and jointing can then commence. For small pipes jointing, 1:3 cement/sand mortars will have to proceed as each pipe is installed. But for bigger sizes, in which a man can comfortably work, jointing can be done after all the pipes are laid. Care should be taken that the jointing mortar completely fills the gap around the full perimeter of the joint and special attention should be given by the engineer to the areas of difficult access, which is usually at the invert of the pipe.

To secure a good straight line of pipes it is helpful to fix a tight string line at around “10 o'clock” or “2 o'clock” on the outside perimeter of the pipeline, running longitudinally over several pipes. A long spirit level is also an invaluable aid to install pipes to a good line and level.

- *Concrete haunch or surround*

No further operations should be carried out until the engineer has checked and satisfied himself that the pipeline is satisfactory as to line and level. This can be done by eye and by checking the invert with a level. When checking is complete, other operations may proceed. If a haunch or a surround is specified, this can now be placed using a stiff, fairly dry, concrete.

Care should be taken to ensure that the specified thickness or width of concrete is obtained.

- *Backfill*

On completion of pipe installation, hunching or surround the trench may be backfilled in layers not exceeding 15cm each. Granular materials should be used if there is no haunch or surround up to 1.5cm above the top of the pipe.

It is essential to ensure that backfill material is placed so that no voids are left, particularly near the underside of a pipe run. Compaction by any suitable means must be thorough. The shoring sheet can be removed as backfill proceeds.

From 15cm over the pipe and upwards any suitable backfill material may be used and compacted with a vibrating plate compactor. Finally, the pavement courses should be reinstated with new material and finished to match the existing pavement condition.

- *Completion*

For half width construction methods, the above process is repeated on the second half after opening the downstream half to traffic. Note that the construction of headwalls and wing- walls being normally well away from the carriageway edge, need not prevent that the road is opened to traffic prior to construction of these end structures.

g. *End Structures*

The purpose of end structures is to channel the flow of water into, or away from, the culvert pipe in such a way as to prevent scour or erosion to road embankment, to the culvert foundation or to the stream banks themselves.

For small flows and culvert alignments at or near 90° to the road centre-line, a simple rip- rap headwall is normally sufficient. See Figure 91.

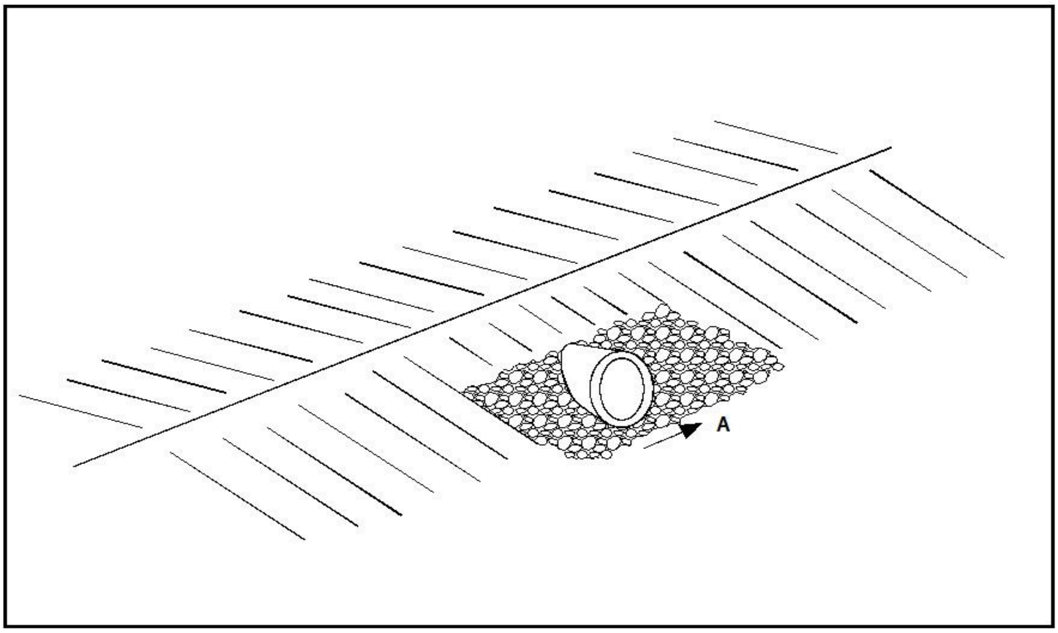


Figure 91: Simple Rip-Rap Headwall

Figure 92 below shows a concrete headwall and rip-rap embankment toe protection.

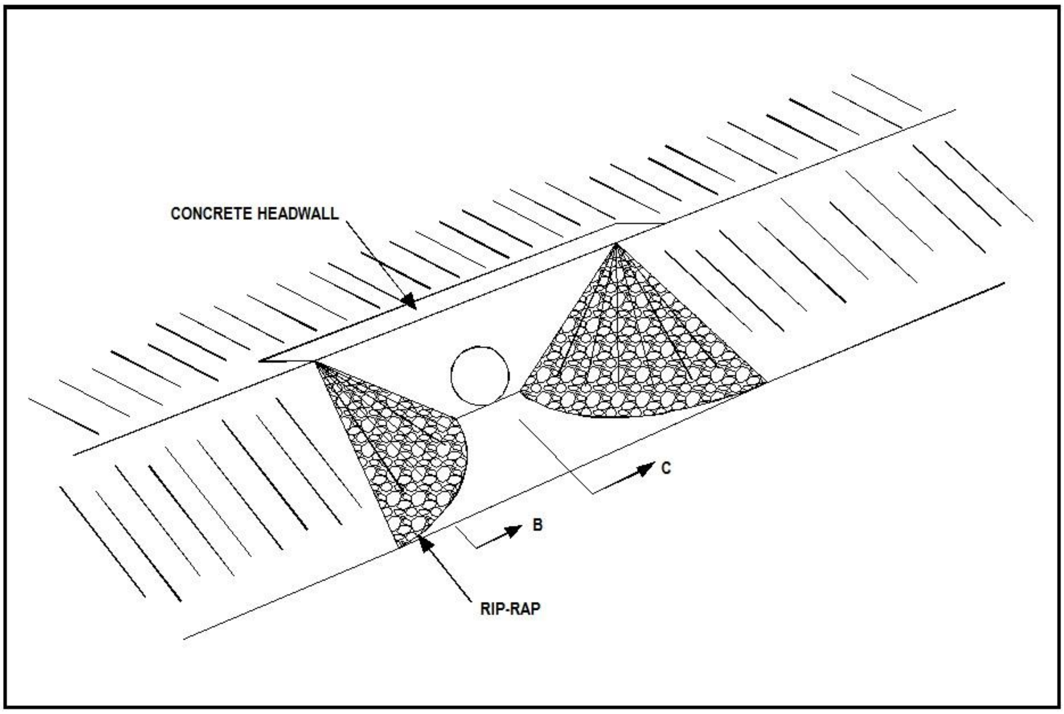


Figure 92: Concrete Headwall and Rip-Rap Embankment Protection

For larger flows and normally for larger angles of skew, a more sophisticated structure is called for such as that shown in Figure 93

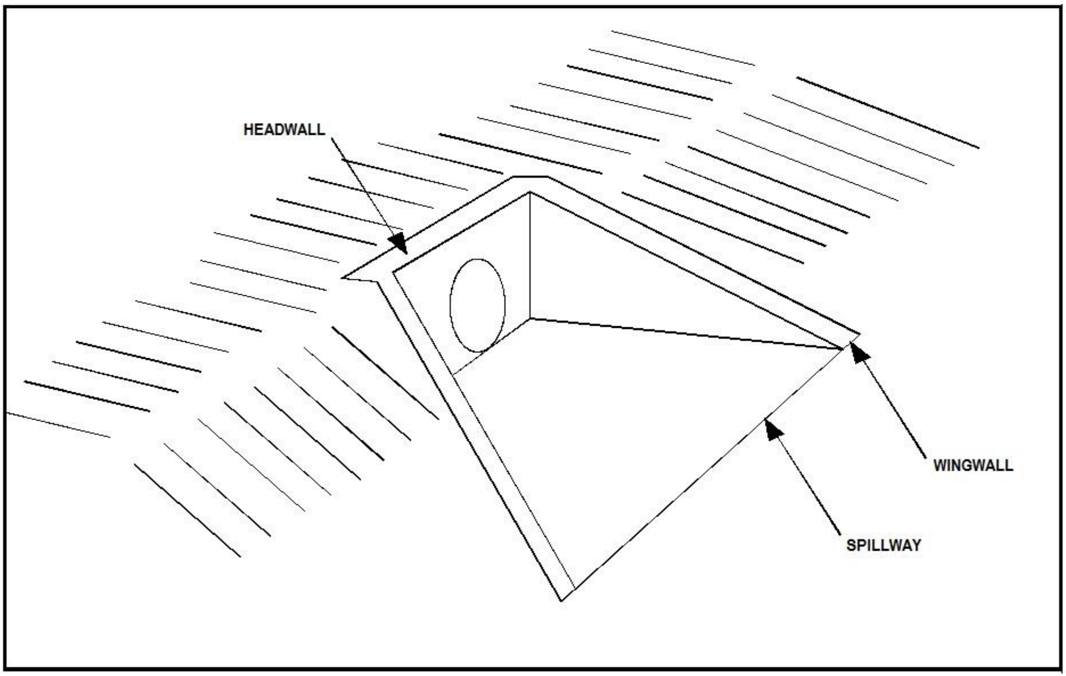


Figure 93: End Structure for Larger Flows

Construction details for the typical end-structures described above are shown in the following diagrams.

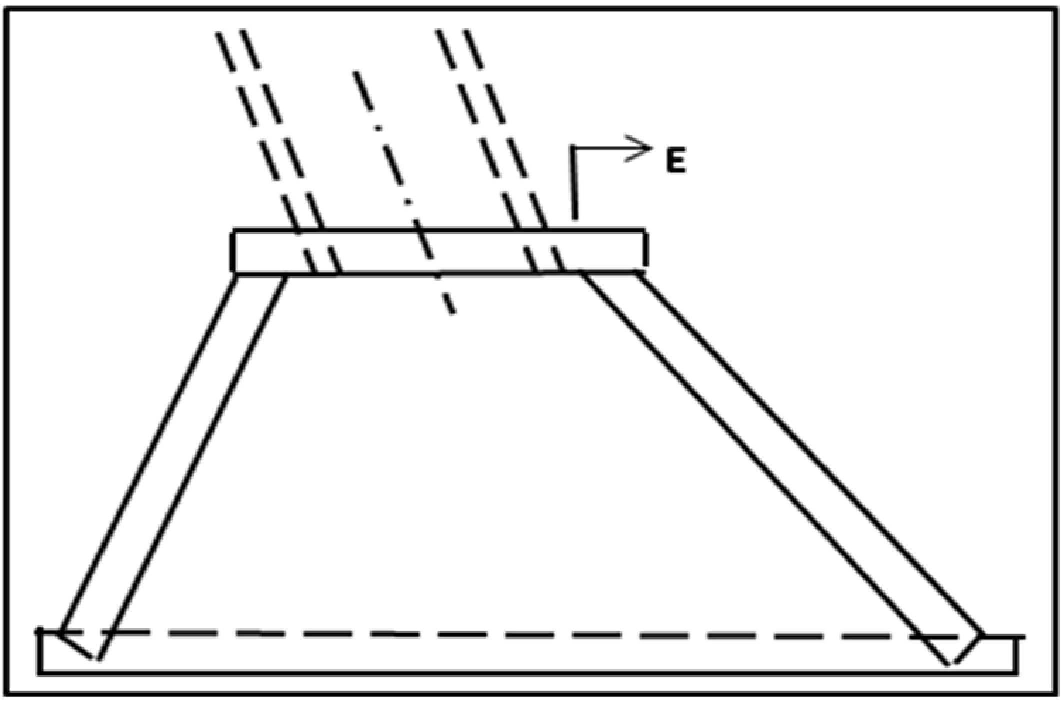


Figure 94: Plan View of End Structure

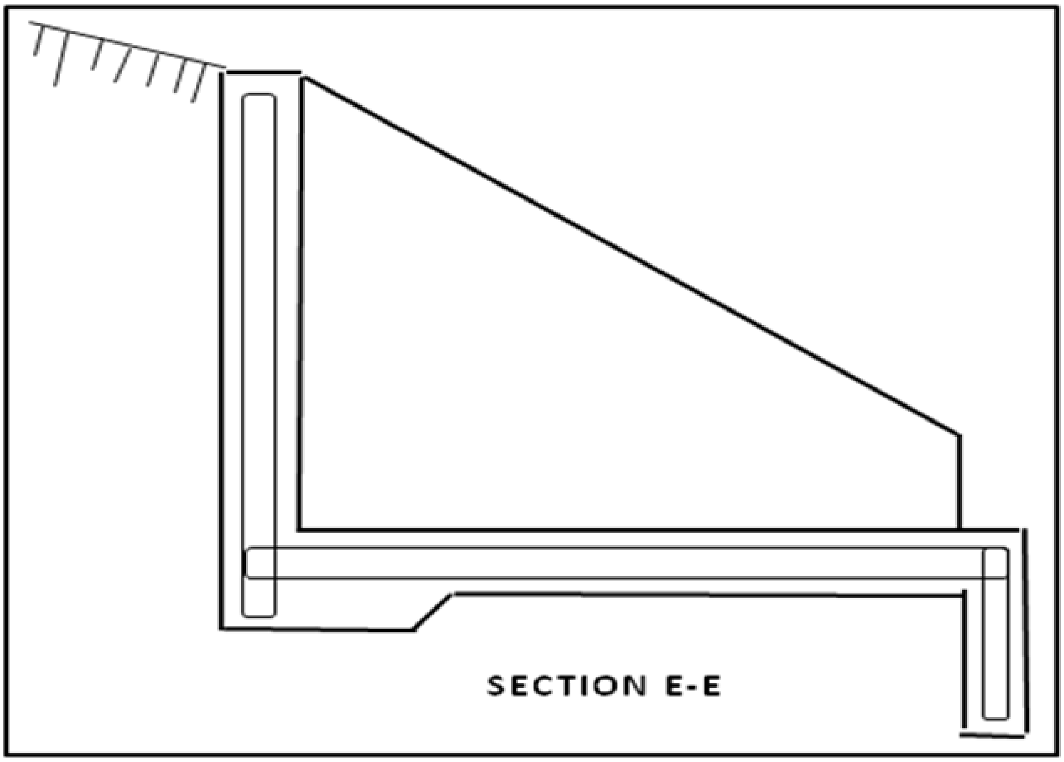


Figure 95: Cross Section of End Structure

After all headwall or wing wall work is completed, reinstatement of the embankment, verges and shoulders should be carried out to the same standards as existed prior to the culvert construction works.

8.8.3 Corrugated Steel Pipe Culverts

a. Description of pipes

Corrugated steel pipes as referred to in this section are circular section steel pipes, which are corrugated along the axis of the pipe to 12.7mm depth and 67.7mm pitch. The pipes are obtainable in the market as prefabricated pipes with riveted or welded seams, as semi circular sections usually called “Nestable” for assembly on site and as multi plate pipes for assembly on site in larger diameter pipes. A similar range is available in pipe-arches, which have the advantage of requiring less headroom for a given waterway opening. Within the limits of responsibility of maintenance engineers and within the limits of practical use on maintenance sites this section is restricted to use of nestable pipes and nestable pipe-aches of the sizes and strength most commonly required.

(i) Available Sizes

Corrugated steel pipe is manufactured in a range of diameters from 29 cm up to 183cm within the nestable class. The range of standards most useful to maintenance works and normally available on the market is 60, 75, 90 105 and 120cm diameter respectively.

Corrugated steel pipe arches are manufactured in a range from 46cm span, 33cm rise up to 183cm span and 122cm rise within the nestable class. The range of standards most useful to maintenance works is 76/50, 91/57, 107/66, 122/75, 137/84 and 152/93cm span/rise respectively.

(ii) Strength of Pipes

Both nestable pipes and nestable pipe-arches are manufactured in a range of sheet thickness to suit loading and depth of fill conditions A standard range of five gauge thickness is quoted for most sizes in sales brochures. The gauges quoted are usually U.S. standard for sheet and plate, which refer to constant standard weight per area (kg/m²).

The actual plate thickness will therefore vary dependent upon the base material used in manufacture. Table 72 below gives the standard gauge, numbers, weight in kg/m² and equivalent thickness for steel plates.

Table 72: Specifications of Corrugated Steel Pipe Culverts

U.S. Gauge No.	Weight (kg/m²)	Thickness of Steel (mm)
8	33.57	4.176
10	27.46	3.416
12	21.36	2.657
14	15.26	1.897
16	12.21	1.519

(iii) Coating

Nestable corrugated steel pipes and pipe arches are normally available in galvanized coated finish. This has become a standard and it is recommended that only this class be purchased for use in maintenance works.

Factory produced pipes are also available in bitumen coated, asbestos-bounded and bounded-bitumen coated. These provide added protection in water courses of corrosive or abrasive nature. However, it has been found that the general purpose maintenance pipe, which undergoes variable storage and transport handling, becomes easily damaged in respect to specialist coatings.

- *Acidic Watercourses*

Where old culverts show signs of corrosion, which is quite common in streams in lateritic soil areas, the standard galvanized sheet can be hot dipped in straight run bitumen prior to assembly.

o *Abrasive Watercourses*

Streams carrying sands and gravels in suspension will greatly reduce the life of the zinc coating on standard galvanized sheets. Under these conditions it is advisable to hot dip or internally paint the lower sheet in bitumen and then apply a hot-mix bituminous paving material to the pipe invert. The paving should fill the corrugation troughs and cover the crest paving by 3mm within the lower 60° segment of the pipe. A suitable paving material for this purpose is specified in ***Section 8.5.5, BITUMEN MACADAM.*** The fine-graded material is being recommended.

(iv) Joints

Nestable pipes are supplied in standard 0.61 metre length and that is overlapped one corrugation longitudinally. The joint between the top and bottom holes of the pipe is established by inserting the plain edges into the saw tooth parts of the offset edge as shown in Figure 96(a).

The top and bottom sections are staggered as in stretcher bond brick work. The joint is secured with metal stitches for pipes of 61cm and 76cm diameter or with hook and eye bolts for larger size pipes and all pipe-arches. Stitches and hook and eye bolts are illustrated in Figure 97

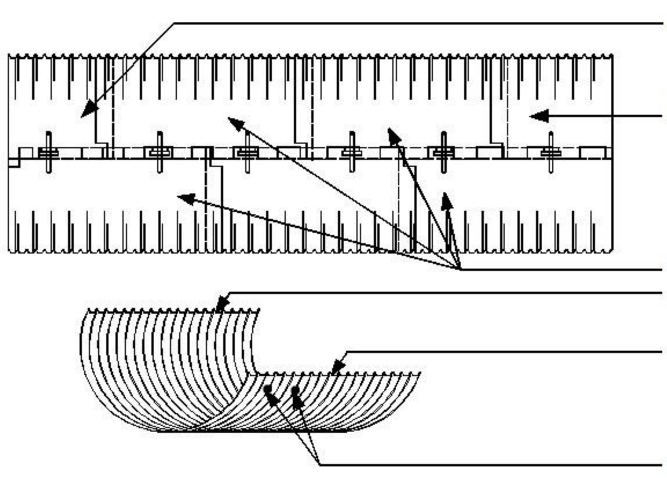


Figure 96: Corrugated Steel Pipe Culvert

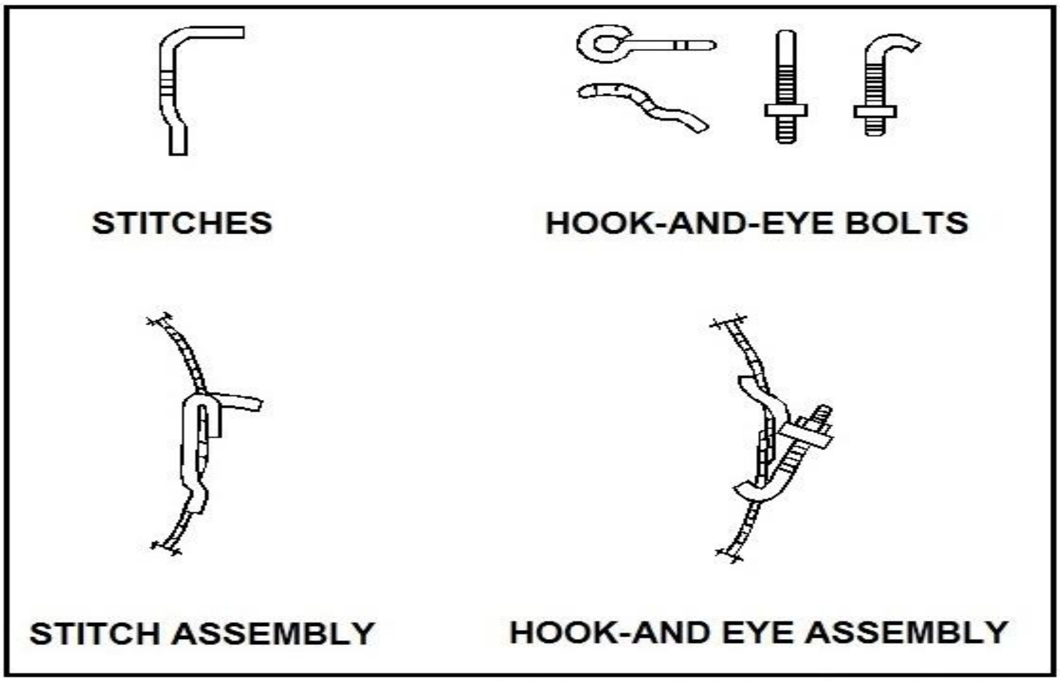


Figure 97: Stitches and Hook and Eye Bolts

(v) Advantages of Corrugated Steel Pipe.

There is little difference in cost between a complete culvert constructed in reinforced concrete and a complete culvert constructed of corrugated steel pipe. The primary advantages of corrugated steel pipe are therefore individual to the maintenance engineer and offer

- Fast and simple construction
- No heavy concrete bases
- Ease of transport and storage

o *Fast and Simple Construction*

In the assembly and reinforcement of corrugated steel pipe culverts there is no time delay in waiting for concrete to cure. A culvert may therefore be excavated, assembled and backfilled in two successive halves in one working day. The disruption of traffic is therefore kept to a minimum.

- *No Heavy Concrete Bases*

Corrugated steel pipe culverts are flexible structures and are therefore laid upon compacted granular soil bases. They are not hunched with concrete. Thus no concrete mixer or crane for handling materials or pipes is required on site and the necessary equipment is minimal.

- *Ease of Transport and Storage*

The entire pipe requirement for a single barrel pipe or pipe arch culvert will fit into a pick- up. Similarly, large quantities of nestable pipe or pipe-arch can be stocked in a warehouse under cover and secured and held for planned programmes or emergencies.

b. Application

Corrugated steel pipe-arch culverts may be applied to the situations listed in Section 8.8.2 (b) Reinforced Concrete Pipe Culverts.

c. Limitation of Responsibility

The limitations, as discussed in ***Section 8.8.2 (c) Reinforced Concrete Pipe Culverts***, apply equally to corrugated steel pipes.

d. Design Principles

The simplified design data presented here is applicable within the limitation of the small culvert sizes permissible for design and installation by maintenance engineers and within the limitations of the maintenance control conditions, which are:

- The slope of the culvert shall be equal to, or greater than, the critical slope
- The head at inlet shall be equal to the top of the pipe
- The outlet shall be free.

Under these conditions, the factors governing the design of culverts are

- Size or cross-sectional area of culvert
- Slope of culvert
- Location of culvert
- Depth of fill over the culvert

(i) Size of Culvert

o *Drainage Outfall Culverts*

Where the culvert to be installed is accommodating only the surface water run-off carried by side drains the quantity of peak flow may be calculated by the method discussed in ***Section 8.2.6 Side Draining.***

The quantity so obtained may be used to select the appropriate size of pipe or pipes by use of the maximum capacities shown in Table 73 below:

Table 73: Pipe Size and Capacity

Diameter (cm)	Area (m^2)	Max Capacity (m^3 / sec)
61	0.29	0.42
76	0.45	0.73
91	0.65	1.13
107	0.89	1.67
122	1.17	2.35

Similarly where the need arises to reduce headroom and where nestable pipe arches are available, Table 74 may be used to select the appropriate pipe arch size or sizes to satisfy capacity requirements.

Table 74: Pipe Arch Sizes per Capacity

Size (cm)		Area (m^2)	Max Capacity (m^3 / sec)
Span	Rise		
76	50	0.32	0.43
91	57	0.44	0.64
107	66	0.59	0.92
122	75	0.74	1.24
137	84	0.93	1.64
152	93	1.14	2.12

It should be noted that the minimum size of culverts for use under main highways, i.e. Trunk “A” and Trunk “F” highways, are 76cm diameter round corrugated steel pipe and 97/57cm corrugated steel pipe arches respectively. The smaller sizes are included here for possible use as continuation of side drains under access roads and secondary feeder roads.

- *Culverts on Watercourses*

For all culverts on water course and drainage outfall culverts, that receive the discharge from cut-off drains, the calculation of water way required should be made using the Talbot Formula as described in ***Section 8.8.2 Reinforced Concrete Pipe Culverts.*** Applying the values of the Coefficient “C” described therein, the equivalent drainage area capacity of standard size corrugated steel pipe culvert is given in hectares as follows:

Table 75: Drainage Area Capacity

Pipe Diameter (cm)	Equivalent Catchment Area (Hectares)				
	C = 1	C = 2/3	C = 1/2	C = 1/3	C = 1/5
61	1.9	3.0	4.7	7.5	15.9
76	3.4	5.8	8.5	14.6	28.9
91	5.5	9.4	13.8	23.8	46.9
107	8.3	14.2	20.9	35.8	70.8
122	11.9	20.4	29.9	51.3	101.5

Similarly, the equivalent catchment areas for corrugated steel pipe arches are given in hectares in Table 76.

Table 76: Drainage Area Capacity for Pipe-Arches

Pipe – Arch (cm)		Equivalent Catchment Area (Hectares)				
Span	Rise	C = 1	C = 2/3	C = 1/2	C = 1/3	C = 1/5
76	50	2.1	3.6	4.8	9.0	17.7
91	57	3.2	5.4	8.0	13.8	27.2
107	66	4.7	8.1	11.9	20.4	40.3
122	75	6.5	10.5	16.3	28.0	55.4
137	84	8.7	15.0	22.0	37.7	74.6
152	93	11.5	19.7	28.9	49.7	98.2

(ii) Slopes of Culvert

The comments contained in ***Section 8.8.2 (d)(ii)*** apply equally to corrugated steel pipes.

(iii) Location of Culverts

The recommendations in ***Section 8.8.2 (d)(iii)*** are relevant to corrugated steel pipe and pipe arch culverts.

(iv) Depth of Fill

Corrugated steel pipe and pipe arch culverts derive their strength from the thickness of steel (gauge) and by virtue of their flexibility which enables them to balance the direct vertical loads with the lateral soil pressures within the highway formation. The depths, both minimum and maximum to which they may be safely installed, are therefore dependent solely upon the gauge of steel but subject to the condition that they must be maintained as flexible structures. The tables given below are therefore accurate provided that the structure is NOT built upon a concrete or similar rigid base.

- *Corrugated Steel Round Pipes*

Table 77: Depth of Fill for Corrugated Steel Round Pipes

Diameter (cm)	Depth of Fill Over Top of Culvert (m)			
	14 gauge	12 gauge	10 gauge	8 gauge
61	13.5	21.0	30.0	-
76	9.0	13.5	21.0	30.0
91	-	9.0	13.5	30.0
107	-	7.5	10.5	30.0
122	-	6.0	7.5	10.5

The gauges referred to above are US standard gauges for steel sheet and are defined in ***Section (a)(ii)*** above.

The depths are the maximum permissible depths of fill over the top of the culverts. The minimum permissible depth of fill is 0.60 metre in permanent construction. Some manufacturers of corrugated steel pipe recommended minimum fill down to 23cm.

This is the absolute minimum that may be permitted during construction if the highway must be reopened to traffic prior completion of pavement courses. Under these conditions, it is advisable to insert temporary internal timber struts into the pipe to protect it from distortion by impact loads.

- *Corrugated Steel Pipe-Arches*

Corrugated steel pipe arches cannot carry such heavy loads of fill as the round pipes but since pipe arches normally used only in conditions of limited headroom this disadvantage is not relevant. Limits of fill depth are as follows:

Table 78: Depth of Fill for Corrugated Steel Pipe-Arches

Size (cm)		Depth of Fill Over Top of Culvert (m)		
Span	Rise	14 gauge	12 gauge	10 gauge
76	50	6.0	-	-
91	57	6.0	-	-
107	66	-	6.0	-
122	75	-	4.5	6.0
137	84	-	2.5	6.0
152	93	-	2.5	6.0

The gauges referred to are US standard gauges for steel sheet and are defined in ***(a)(ii)*** above. The minimum permissible depth of fill over top of the culvert is in all cases 0.60metres.

e. Equipment

Equipment requirements for corrugated steel pipe arch culverts are minimal. No concrete mixer is required except in so far as there is need for end structure construction .

f. Construction Methods

Inspection, planning and safety sequences are the same as those listed in ***Section 8.8.2 (f)(i) to (f)(iii)*** inclusive

(i) Operation

Site layout and organization considerations are the same as those applying to reinforced concrete culverts except that it must be borne in mind that all corrugated steel pipe and pipe arch construction will always begin at the up-stream or inlet of the culverts.

o *Excavation*

Excavation may be carried out manually or with a tractor and back-hoe. The trench sides must be vertical and the trench width restricted to the minimum necessary for installation and consolidation of backfill. Recommended excavation widths are shown in ***Figure 89 and Figure 90 of Section 8.8.2(f)(iv).***

Where multiple pipe culverts are being constructed a gap of width equal to half the diameter of the pipe must be left between pipes to allow space for compaction of backfill and to provide adequate lateral support. Similarly, spacing between pipe arches should be one third of the span of the pipe arch, as shown in Figure 98 below:

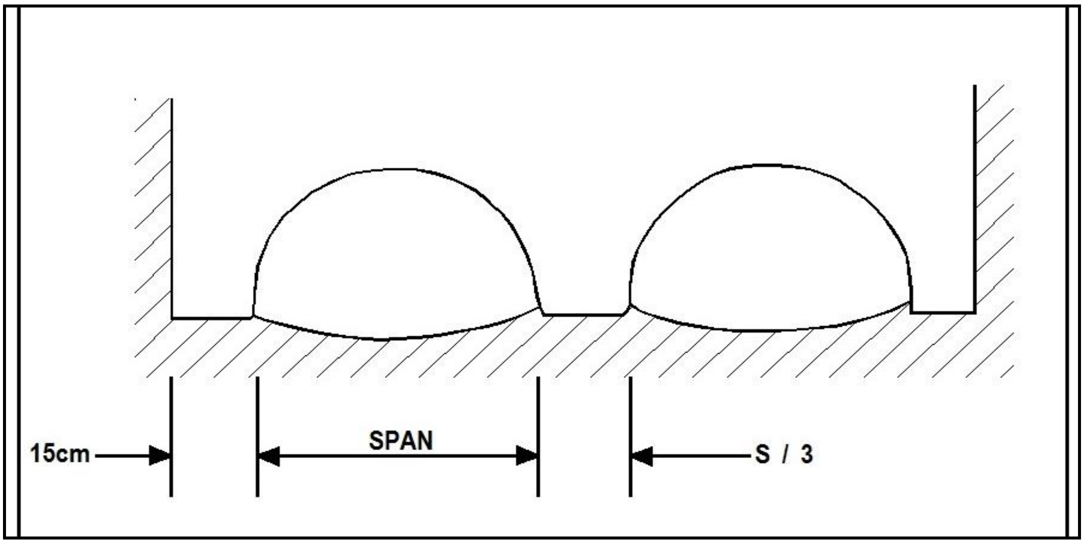


Figure 98: Pipe-Arch Excavation

- *Shoring*

Excavations in excess of 2 metres will require shoring as described in ***Section 8.8.2(f)(iv).*** Safety measures will be required to ensure that no superimposed load of machinery or material is placed closer than permitted by the angle of repose of the soil.

- *Culvert Base*

Corrugated steel pipe and pipe arch culverts are flexible structures and as such must not be placed on concrete or rigid foundations. However, the base or foundation is equally as important for these structures as it is for concrete pipes and requires careful preparation. The pipe or pipe arch must be bedded on well compacted granular material as illustrated in Figure 99 below:

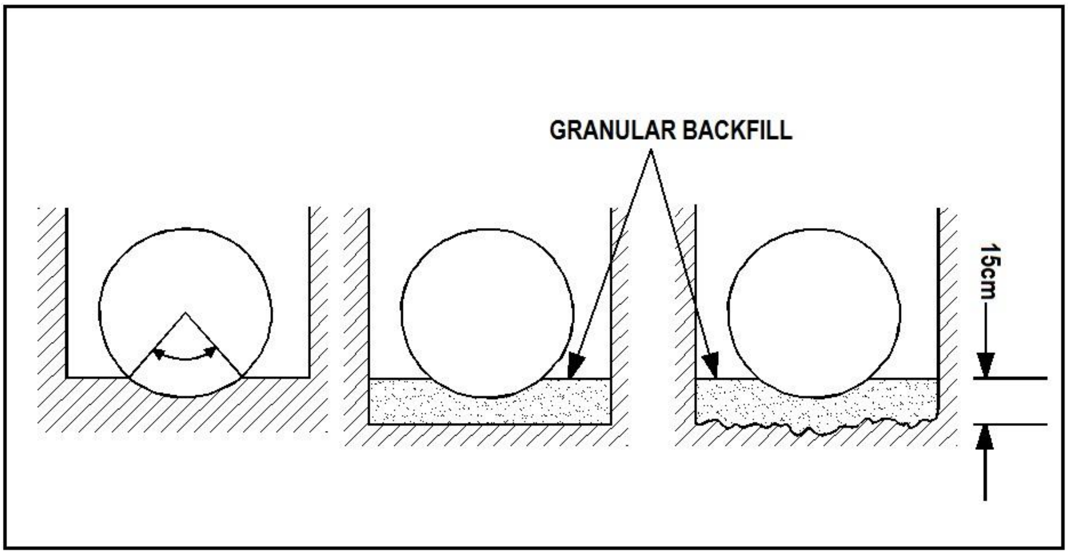


Figure 99: Backfill for Corrugated Steel Pipe Culverts

Where the trench is carried down into good granular soils the trench bed should be well compacted and shaped to receive the lower quarter of the perimeter or the base of the pipe arch. Where soft soil or rock is encountered, a further 15cm of the trench will be excavated and replaced by 15cm of good granular material, such as sand or sand- gravel. In the absence of naturally occurring materials a dense crusher-run aggregate may be used.

- *Pipe Installation*

Nestable type corrugated steel pipe and pipe arches are supplied in bundles of 6-10 sheets each as described in ***Section (a)(i) to (iv)*** above. Standard hand tool sets are available consisting of drawbar, pinch bar, mallet and bending bar or open-ended spanners. Assembly of both pipe and pipe arch is simple providing that the sequence of operations shown in Figure 100 below.

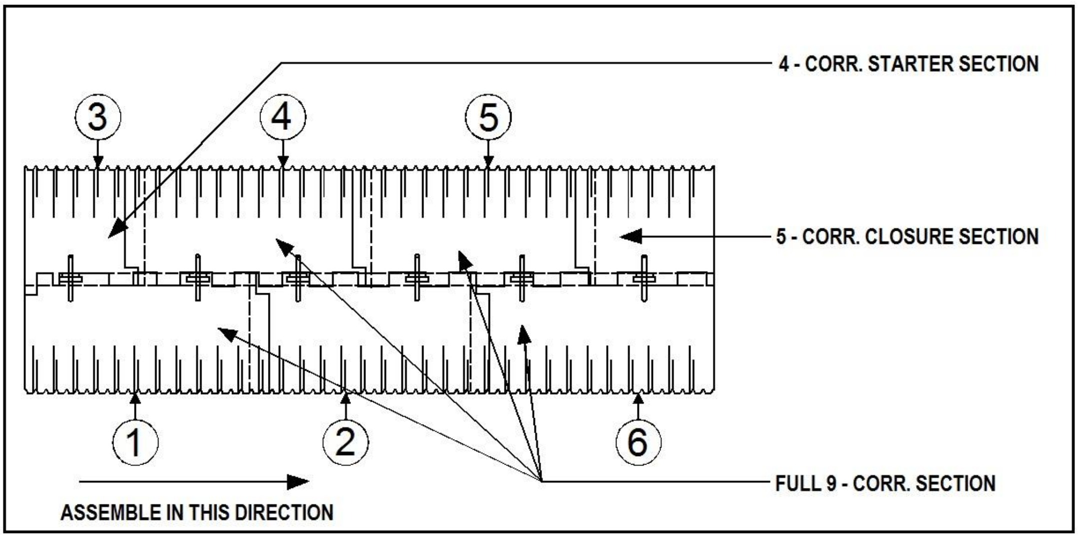


Figure 100: Assembly of Corrugated Steel Pipe

Referring to Figure 100 above, the following steps are taken commencing construction at the up- stream or inlet end of the culvert.

- Lay section (1) with twin holes at the upstream end
- Insert section (2) under section (1) with a one corrugation overlap
- Place end closure section (3) (4 corrugation length) over the top of section (1) and insert the plain edges into the offset edges
- Bring holes into line with the drawbar
- Insert stitches or hook-and-eye bolts and close the joint
- Place section (4) over the top of section (3), with one corrugation overlap, bring edges into position, align holes and make the joint between section (4)-(1) and (4)-(2)
- Continue in sequence (5), (6), etc.

- *Backfill*

On completion of the pipe installation the trench may be backfilled in layers not exceeding 15cm each. Granular materials should be used up to the top of the pipe and approximately 10cm above it. Care should be taken to water and ram the material under the pipe haunches and at its sides without disturbing the pipe, which is relatively light in weight. From 10cm over the pipe and upwards any suitable backfill material may be used and reinstated with new material and finished to match the existing pavement condition. Where the material used to bed and surround the pipe is sand, it will be necessary to contain the ends with a one metre plug of cohesive soil or soil aggregate at either end of the trench and embankment side slope.

- *Completion*

For half width construction methods, the above process is repeated on the second half after opening the up-stream half of the highway to traffic.

g. End Structures

The purpose of end structures and the forms in which they may be constructed are basically the same as those described in ***Section 8.8.2(h)*** of ***Reinforced Concrete Pipe Culverts.***

However, bearing in mind the flexible nature of corrugated steel pipe and pipe-arches, it is generally undesirable to build heavy rigid end structures, which may restrict the ability of the culvert to adjust itself to minor deformations of the embankment in which it is constructed. The most common end condition for these pipes and pipe arches is therefore the open end with rip-rap dressing.

(i) Bevelled Ends

Some manufacturers of corrugated steel pipe produce bevelled end sections, which are cut to conform to standard side slopes. y They greatly enhance the beauty of the installation.

(ii) Fish Tail Ends

Standard fish tail shaped end sections are available from most manufacturers in both pipe and pipe -arches. These spread to approximately twice the diameter or span of the pipe and are cut away to 2,5: 1 side slope. They may incorporate a toe-plate to reduce erosion undermining and are effectively apron and wing wall installations that may be bolted to pipe ends.

8.8.4 Reinforced Concrete Box Culverts

a. Description of Reinforced Concrete Boxes

Reinforced concrete box culverts are thin wall reinforced concrete boxes consisting of a floor, which serves as a spread foundation, two walls and a roof, which may either act as a pavement base or support the embankment fill. The box may terminate in truncated ends to match the embankment side slopes or be provided with wing walls and aprons as end structures.

b. Application

The fabrication of a reinforced concrete box culvert necessitates high quality concrete, a large percentage of steel reinforcement, a lot of high quality form work and extreme accuracy of workmanship in all areas of operations. All of these factors result in a high cost of construction compared to a similar span of bridge at one end of the scale and compared to pipe culverts at the lower end of the scale

In ***Section 8.8.2: Reinforced Concrete Pipe Culverts*** it was stated that the limit of practical use of pipe culverts prior seeking specialist design advice was a 3 x 1.22 metres diameter culvert, providing 3.5 square metres of water way opening and a capacity of a little over 7 cubic metres per second at beyond the critical slope under ideal maintenance control conditions. It follows therefore that it would be practical to utilize reinforced concrete box culverts in the following circumstances:

- Where the watercourse flow demands a waterway opening greater than 3.5m²
- Where the available headroom, i.e. difference in level between culvert invert and pavement edge, does not allow for at least 0.60 metre cover over the top of the pipe.

- Where foundation conditions for a small bridge demand the use of spread foundations.

c. Limitations of Responsibility

Where the demand capacity is small and the deciding factor is one headroom restriction, consideration should be given to the use of small simple box culverts as described in ***Section 8.8.5 Masonry Culverts.***

Elsewhere, where the governing factors include a demand for a waterway opening larger than 3.5 square metres, the proposal to construct a reinforced concrete box culvert must be referred through the State Maintenance Engineer for advice and specialist design by Federal Ministry of Works, Housing and Urban Development.

d. Design

A number of standard designs of reinforced concrete box culverts are available but extreme care is required in their use since the reinforcement designs of single and multiple boxes and of boxes for zero fill to many metres of fill varies fundamentally.

A reinforced box culvert is designed for one specific set of conditions of loading and may not be structurally capable of operating outside these conditions. Even where standards are available the criteria in ***(c) Limitations of Responsibility*** above, apply and the District Maintenance Engineer shall refer to his State Maintenance Engineer for approval prior to committing the operation.

e. Construction

The construction of reinforced concrete box culverts entails the opening of a larger excavation, the provision of wherever possible a byp a s s and a length sequence of operations in bar bending.

Fixing, formwork assembly and placement of concrete is time-consuming. It is therefore an operation, which places a long duration obstruction upon the highway. Maintenance engineers should therefore give their full consideration to all possible alternatives, such as for each pipe, pipe arches and masonry culverts before committing themselves to reinforced concrete box culvert operations.

Similarly, long duration of construction operations make reinforced concrete box culverts uneconomic and impracticable for direct labour utilization of the small maintenance crews available to the District Maintenance Organization. The average district cannot afford to have its bridge crew tied up at one side for such a long period of time.

The construction of reinforced concrete box culverts will therefore be put out to tender for construction by contract. Although the standing supervision of such works may well become the responsibility of then District Maintenance Engineer such tenders should normally be called through the State Maintenance Engineer's office.

8.8.5 Masonry Culverts

a. Description of Masonry Culverts

(i) Definition

Masonry culverts consist of two parallel masonry or block walls upon a mass concrete floor, which act as their foundation supporting a precast sectionalized reinforced concrete deck slab as shown below.

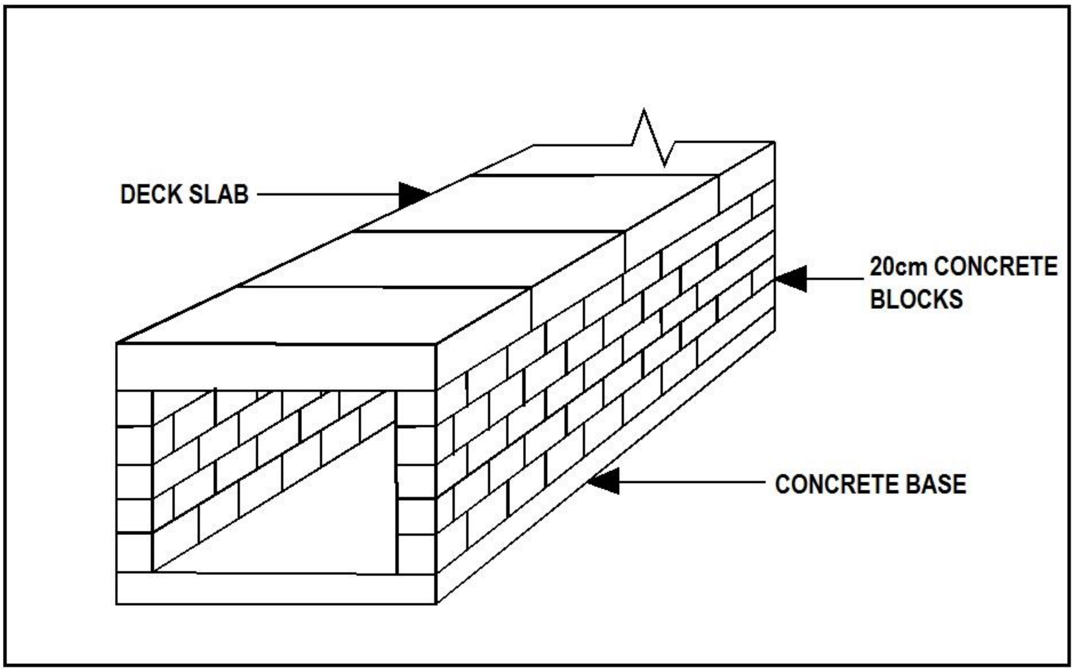


Figure 101: Masonry Culvert

In Figure 101 and elsewhere within this section the walls are shown or referred to only as block work since this is the most commonly available material.

(ii) Available Sizes

A masonry culvert may in theory be built to almost any dimension. However, bearing in mind that it can never compete economically with pipe or pipe arch culverts and due to a more lengthy time obstruction upon the highway, its practical use will be restricted to relatively small drainage outlet culverts where headroom is restricted. A range of four standard design deck slabs has been produced for use with zero cover, i.e. to be provided with a wearing course only over the concrete slab. These are listed in Table 79 below and details of design are given in ***Section (d)*** below:

Table 79: Deck Slab Alternatives

Length (m)	Clear Span (m)	Weight per 50cm. width (kg)
1.10	0.70	260
1.30	0.90	300
1.60	1.20	360
1.80	1.40	400

b. Application

The masonry culverts detailed in this section may be used for

- Replacement of old broken culverts
- Replacement of old undersize culverts
- As new culverts at transverse drainage outlets

All of the above are conditional on the necessity of providing a culvert where restricted headroom makes the more practical pipe culvert impossible to install. The masonry box culverts are not designed for placement under heavy fill conditions.

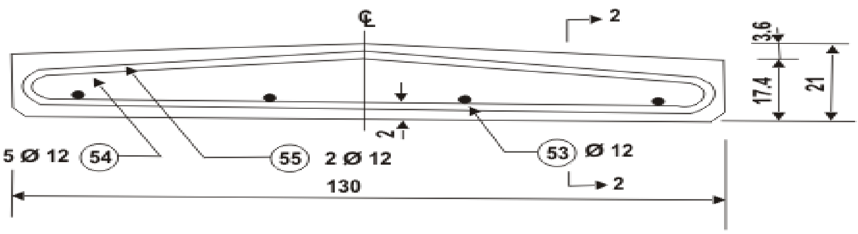
c. Limitations of Responsibility

The maximum size specified herein is a single cell of 1.40 metre by a maximum height of 1.00 metre of block walling. This provides a waterway opening of 1.40 square metres, which constitutes a minor watercourse within the limits of responsibility of District Maintenance Engineers. It should be noted that multiple boxes of masonry culverts are not recommended in this design since intermediate walls would require design with concrete caps and dowels to resist lateral displacement of the slabs.

d. Design Principles

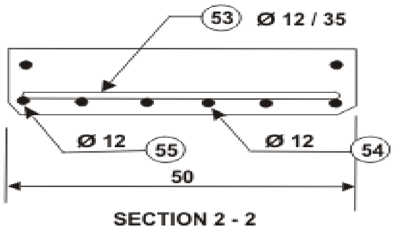
(i) Deck Slabs

The deck slabs should be pre-cast using U.4500 grade of concrete and be reinforced in accordance with the details in Figure 102 to Figure 105



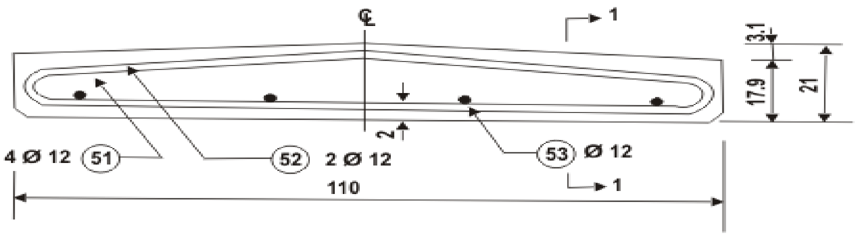
DECK SLAB DETAILS
TYPE 2
$0.125m^3$ 260kg

Bar N°	Dia mt	Length L m	N° of m	n x l m	Description	WT kg
54	12	1.55	5	7.75	126	6.3
55	12	3.20	2	5.40	30 30 12 126	5.7
53	12	0.45	4	1.80	45	1.6
					TOTAL	14



SECTION 2 - 2

Figure 102: Type 1 – Deck Slab Details



DECK SLAB DETAILS
TYPE 1
0.107 m³ 250kg

Bar N°	Dia mt	Length L m	N° of m	n x l m	Description	WT kg
51	12	1.35	5	7.75	106	4.8
52	12	2.85	2	5.40	30 30 12 106	5.1
53	12	0.45	4	1.80	45	1.6
					TOTAL	12

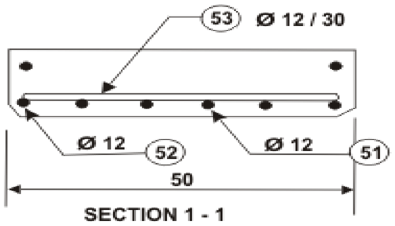
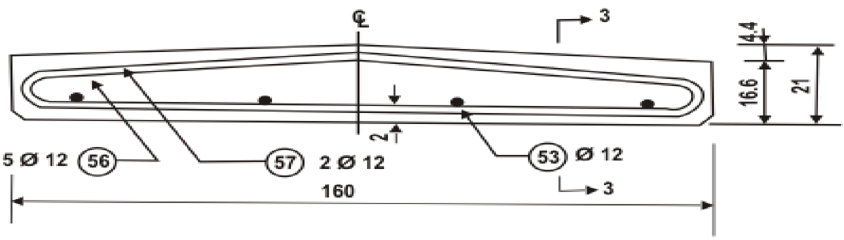


Figure 103: Type 2 – Deck Slab Details



DECK SLAB DETAILS
TYPE 3
0.150m³ 360kg

Bar N°	Dia mt	Length L m	N° of m	n x l m	Description	WT kg
56	12	1.65	5	9.25	156	8.2
57	12	3.80	2	7.50	30 30 12 156	6.8
53	12	0.45	4	1.80	45	2.0
					TOTAL	17

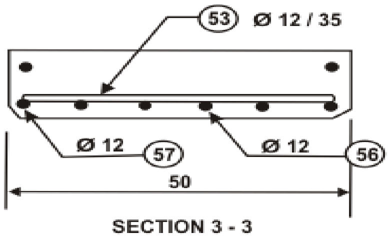
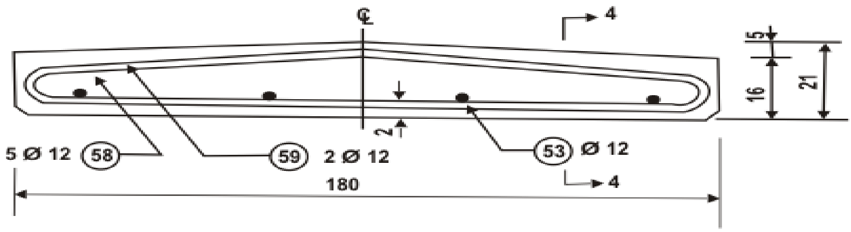


Figure 104: Type 3 – Deck Slab Details



DECK SLAB DETAILS
TYPE 4
$0.167m^3$ 400kg

Bar Nº	Dia mt	Length L m	Nº of m	n x l m	Description	WT kg
58	12	2.05	5	10.25	176	9.2
59	12	4.20	2	8.40	30 30 12 176	7.4
53	12	0.45	4	1.80	45	2.4
					TOTAL	18

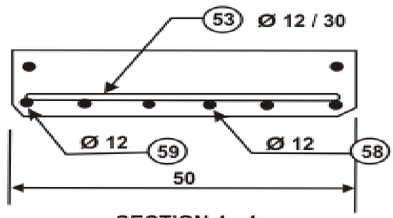


Figure 105: Type 4 – Deck Slab Details

(ii) Pre-casting Yard

The slabs should be manufactured under ideal conditions in a pre-casting yard where they may be cured and stocked pending requirement on site.

The size of the slabs shown in Figure 102 to Figure 105 and the weights shown refer to a standard slab width of 50cm. Slabs of this size and weight will require the use of a hydraulic crane on a flat-bed truck for handling and placement of culvert walls.

If these are found in practice to be too cumbersome, they may be reduced to 33.5cm in respect to type 1and 28cm in respect of type 2 to 4 inclusive (i.e. to include for main reinforcement links). This will result in reduced weights of 175, 170, 200, 225kg respectively. In no case should the slabs be reduced to elements of less than 150kg each since this would render them less stable under traffic.

(iii) Size of Walls

Masonry culvert side should be constructed in stretcher bond block work up to a height of 1.00 metre.

(iv) Floor Slab

The floor slab should be cast in U: 1800 grade mass concrete to a thickness of 18cm and to full width extending 20cm beyond the outer faces of the walls.

(v) Culvert Capacity

The capacity of masonry box culverts, when laid under ideal conditions, i.e. at critical slope and head entry equal to height of opening and outlet free, is given by the formula:

$$Q\ (\max) = 1.7a^{1.5}.b$$

where:

a = Height of opening in metres

b = Width of opening in metres

Q (max) = Capacity in cubic metres per second

For ease of reference, maximum capacity tables are included in ***Section (d)(vii)*** below.

(vi) Critical Slope

The critical slope at which maximum culvert capacity is obtained lies in the range of 0.5% to 0.6%. A lesser slope will result in silting and unnecessary increase in routine maintenance cleaning. A greater slope will not result in capacity increase but greatly in increase of velocity and scour.

(vii) Culvert Capacity Chart

As an aid to the selection of appropriate span of deck slab, Table 80 below gives the maximum capacity of each span type for variations of wall heights. These are the maximum capacities under the ideal control conditions referred to in ***Section (d)(v)*** above.

Table 80: Culvert Capacity

Wall Height (m)	Maximum Capacity (m^3/sec)			
	Type I	Type II	Type III	Type IV
0.34	0.24	0.31	0.41	0.48
0.46	0.37	0.47	0.63	0.71
0.57	0.51	0.66	0.88	1.03
0.69	0.68	0.87	1.16	1.35
0.80	0.85	1.09	1.46	1.70
0.91	1.04	1.34	1.78	2.08
1.03	1.24	1.60	2.13	2.48

e. Equipment

Equipment requirements for the construction of masonry culverts are the same as those listed in ***Section 8.8.4(e) - Reinforced Pipe Culverts***. It should be noted that a flat bed truck fitted with a hydraulically operated crane arm is essential for handling and placing the precast deck slabs.

f. Construction Methods

The requirements for inspection, planning and safety are precisely the same as those detailed in ***Section 8.8.4(f)(i – iii) - Reinforced Pipe Culverts*** with allowance made for the additional time factor for the casting and covering of the necessary deck slabs.

(i) Operation

Where possible a bypass should be constructed or provided by diversions. Where this cannot be undertaken, as in built up areas, half width working may be employed.

- *Excavation*

Excavation should be carried out with a tractor mounded back-hoe making the relatively shallow cut with vertical sides. Shoring should not normally be a provision for its transport to suitable spoil areas and should be allowed for in planning.

- *Culverts Base*

On completion of excavation the trench bed will be trimmed and shaped to the design slope and prior to laying the base be given a 5cm thick dressing of sand or lean mix concrete in wet conditions..

The mass concrete base is most easily constructed starting at the downstream or outlet end. To maintain profile and thickness string lines and level used.

- *Side Walls*

The position of walls will be marked out on the mass concrete base and the surface area within these lines shall be thoroughly cleaned and, if necessary, hacked back to remove all surface laitance prior to laying the initial mortar bedding. The walls will be constructed in stretcher bond with 1:3 cement and mortar joints and will be struck flat or weather jointed.

- *Deck Slabs*

The deck slabs should be placed on mortar bedding on the side wall heads with a clearing width of 20cm at either end. Provided that individual section weights are not less than that specified in ***Sub-section*** **(*d)(ii)*** above, no lateral restraint is required.

- *Backfill*

On completion of decking the excavated volume between the side walls and trench, sides may be backfilled in layers not exceeding 15cm in thickness and thoroughly rammed. This part of the operation will not however be undertaken until the side walls are at least 36 hours old. Selected and undamaged material from the excavation may be used for backfilling.

The highway base should be made up to the ends of deck slabs in dry stone (crushed) base or with block pitching to provide longitudinal support.

- *Completion*

With the surface profile of the deck slabs shown in Figure 102 to Figure 105, it is necessary to allow for a binder or regulating course prior to reinstatement of the wearing course to match the existing pavement. This can be carried out in penetration macadam or bitumen macadam as described in ***8.5.4 and 8.5.5*** of this manual.

Where half width working has been undertaken the second half work will follow precisely the same sequence of operations after the first half has been opened to traffic.

g. End Structures

End structures are required for all masonry culverts and will consist of at least a headwall in blocks carried up to finish flush with the outside edge of the shoulder. The headwall will be supported either with wing walls and apron or quarter-cones as described and illustrated in Section 8.8.4:

Reinforced Concrete Pipe Culverts.

(i) Finishing

End structures may be finished off with a cement mortar or plaster rendering to external block work or masonry faces. If however the quality of course construction is high and joints have been well struck joining the raw block work or masonry racing is an attractive furnishing to a highway.

8.9 Bridges

Many of the operations required for periodic maintenance of bridges will normally be beyond the anticipated capacity of maintenance departments and will require specialist services from contractors or suppliers.

There are however some operations, which are within the capacity of the maintenance departments and these are outlined further below. However, the most important operation that the maintenance department will be called upon to execute is a thorough and systematic inspection of its bridges, annually around the middle of the financial year, so that if major periodic maintenance is planned for the following financial year.

8.9.1 Inspection Of Bridges

a. Purpose

The purpose of bridge inspections and reports is to bring to the attention of the responsible authority (FMW - Director of Federal Highways) any defects which may require a more detailed investigation and for which a well qualified senior engineer will be assigned to assess the necessary remedial action.

b. Frequency of Inspections

Inspections should normally be carried out annually, but if the maintenance engineer has any suspicion of a defect or malfunction in a bridge structure, an inspection of the causes and effects should be made immediately and a report marked as 'Urgent' be forwarded to higher authority . In a possibly dangerous situation the e ngineer should also state what measures he has taken to safeguard the public from danger and to prevent further deterioration of the affected structure.

c. Inspection Procedure

(i) Record Drawings

The inspection engineer will obtain a set of as-built- drawings of the entire structure. If such drawings are available, a set of drawing will be prepared by taking measurements of the piers, abutments, beams and bearing and by taking levels along the centre-line of the bridge deck.

(ii) Scouring at Piers and Abutments

Where possible, a record of the "high water level" will be maintained and evidence of changes in the profile of the water course will be investigated by carrying out a thorough inspection, sounding and underwater surveying as necessary. For the major crossings in Nigeria, a specialist company may have to be contracted for this work as maintenance departments are not normally in possession of some of the special equipment needed for these types of surveys.

(iii) Erosion of Embankments

Approach embankments will be checked for erosion from any cause.

(iv) Settlement

The level of the bridge deck will be checked by means of an instrument survey and compared to the record drawings. Any settlement in excess of 0.03 metres will be reported as a matter of urgency and weekly checks will be instituted where progressive settlement is suspected.

(v) Concrete Flaws

Concrete surfaces will be examined for spilling, cracking, scaling, exposure of reinforcing bars and any other deterioration. The presence of dark stalactites is usually evidence of advanced deterioration. Cracking at points of maximum bending and maximum shear stress must be carefully examined and recorded.

(vi) Steelwork Flaws

Steel trusses must be examined for links, bends or deformation of any member and structural welds should be visually inspected for cracks or damaging corrosion. Rivets and bolts must be individually checked for looseness and rusting. Any evidence of excessive vibration under load must be fully investigated. Bearings of the roller should be examined for dirt, corrosion or deformation.

(vii) Timber Flaws

Timber members should be examined for decay, crushing, splitting, insect-attack or loose connections. Timber in areas subject to wetting caused by the ebb and flow or rivers or sea water should be tapped with the pointed side of a shipwright's hammer to detect any attack by “dry rot” or marine animals.

(viii) Paintwork Defects

Painted surfaces should be examined for the condition of paint, existence of bare spots or blisters.

(ix) Abutment and Anchorage Defects

Abutments should be examined for evidence of setting, sliding, tilting, scouring or cracking under load or as a result of movement either of the abutment or of the associated bridge beams and deck. The bridge seat should be checked for harmful accumulation of debris or rubbish. Exposed piles should be examined for corrosion and deterioration in the splash zone and at ground line.

(x) Piers and Bearings

Piers should be checked for verticality, settlement, horizontal displacement and scour. Signs of shear failure such as cracks or spalling should be carefully investigated. Signs of deterioration or excessive vibration under load should be recorded and reported without delay.

(xi) Bridge Decks

The bridge deck should be inspected both from above and from beneath the bridge. Signs of cracking at the centre of the span, at the supports or at changes of section should be carefully noted and investigated. Signs of deterioration or excessive vibration under load should be recorded and reported without delay.

(xii) Guardrails and Handrails

Guardrails and handrails on walkways should be inspected for damage from traffic.

(xiii) Wearing Surfaces

Wearing surfaces on the bridge decks should be inspected for failures and uneven wear.

(xiv) Expansion Joints and Bearings

Bearing and expansion devices such as rockers, rollers, hangers, rocker-arms, plate bearings and rubber members should be examined for position, deformation, condition, corrosion and freedom of movement. Bolsters and fixed plate bearings should be checked for fullness of bearing, condition and security of attachment to the pier or abutment.

Elastic and laminated fabric bearings should be checked for oxidation, tears, position and general condition. Expansion combs and similar devices should be examined for condition and adequate space for movement.

(xv) Main Truss Members and Cables

Main support members of the bridge trusses should be checked for alignment, buckling or signs of fatigue. Locking bolts, pins, braces and spacers should be checked for wear and rigidity.

(xvi) Connectors

Connecting cleats, web connectors, cross frames, diaphragms and all other secondary members should be checked for function and condition and any looseness, excessive corrosion, cracking or spalling should be carefully checked and recorded.

(xvii) Moving Parts

Moving parts of bridge structures must be examined for cleanliness, adequacy of lubrication and proper function free from obstruction and distortion.

(xviii) Vibration and Deformation

The performance of the bridge under heavy load conditions should be observed and where excess vibration or deformation is noted urgent report should be forwarded for action.

d. Non-Destructive Testing

The extent of cracks and flaws and the approximate strength of structural concrete can be determined and investigated by the use of non-destructive testing aid.

For steel members, radiographic techniques employed in conjunction with ultra sonic testing are recommended. Magnetic particle inspection and the use of cleaners and dye penetrators are also recommended to disclose surface cracks and discontinuities.

With regard to concrete members the soniscope, reinforcing steel indicator, rebound hammer or sounding bar are advised. Examinations by soniscope, ultrasonic testing or radiography should only be carried out by thoroughly trained experts and for the present it is recommended that such examinations should be carried out by an experienced service company that specializes in this type of work and provides the equipment necessary to carry it out.

e. Reporting

The form of report recommended is the one in use by the Ohio Department of Highways, modified for use in Nigeria and shown in Figure 106 and Figure 107.

8.9.2 Periodic Maintenance of Bridges

Some defects can be dealt with locally with the available resources of the maintenance department. The operations, which can be done locally include:

- Correction to embankment erosion
- Minor concrete flaws
- Tightening of loose steel connections replacement of minor timber members
- Paintwork
- Removal of accumulated debris or rubbish
- Cleaning out of all joints and bearing areas lubrication of roller bearings
- Guardrail, handrail and walkway repairs

- Vehicular speed and/or load restriction measures if excessive vibration or other condition warrants it
- Replacement of timber decks on Bailey Bridges
- Replacement of bridge surfacing. In this case, it is essential to remove the existing surfacing and replace it with material of the same weight as existed prior to replacement.

Most other items or elements that requiring periodic maintenance will almost certainly be beyond the intended capacity of maintenance crews. Thus, the larger jobs, if they do become necessary, will need to be carried out by contractors and the design and tendering of such work be referred to the construction divisions of the State or federal ministries.

8.9.3 Bailey Bridges

It is not uncommon for maintenance departments to be called upon to provide an emergency water crossing with great urgency. The Bailey bridge was originally invented to solve such problems for military uses and the advantages of such a simple solution were rapidly appreciated in civilian applications.

There are now many active Bailey Bridges in Nigeria and all municipalities should aim at procuring sufficient components to be able to provide a 50 metre crossing a short notice. It is also recommended that a special crew be trained to assemble and launch Bailey Bridges but the crew members, who could be taken from other routine or periodic maintenance crews would have to be available at short notice to respond to the emergency.

The design and construction of Bailey Bridges is well covered by manufacture‘s literature and is therefore not repeated here. The major suppliers of such components and manuals in Nigeria have so far been Messrs. Thos Storey (Engineers) Limited, London and Messrs. Mabey and Johnson Limited, London.

8.10 Highway Furniture

Highway furniture includes all items erected or constructed to improve the serviceability of the highway to vehicles or pedestrians and which belong to the authority under whose jurisdiction the highway falls.

8.10.1 Pavement Markings

Pavement markings consist of centrelines and edge lines, information, directives (e.g. STOP) and directions, applied to the road surface to assist the motorist in using his vehicle in a safe way without danger to himself or to other road users.

All pavement markings, even regular maintenance, eventually deteriorate to such a point that they become ineffective and hence no longer serve their original purpose. This is manifested in the wearing away of the markings by the combined effects of traffic and weather and ultimately the marking completely disappears.

Well before this occurs, the engineer should assess the areas where markings are fading and implement a programme of renewal. Some markings are a lot more durable than others and the frequency of replacement will depend directly on the durability. The durability in turn depends mainly on the traffic intensity. Therefore it is not possible to give hard-and-fast rules about probable durations of markings. Types of markings available, in ascending order of durability (and cost) are:

- Road Paint
- Spray thermoplastic
- Screed thermoplastic
- Cold-applied resin based materials.

Road studs (cat's eyes) are the most durable of all markings but their use is not common in Nigeria, probably because of their high initial cost.

All new pavement markings should be reflective, which is achieved by the addition, at a specified rate at the time of application, of tiny glass spheres usually called Ballotini.

Most likely, the only marking which the maintenance department can apply is road paint, as more expensive markings require more sophisticated application machinery normally not owned by maintenance departments. The maintenance engineer will thus have to consider the use of specialist road marking companies for the larger jobs and confine his own road marking team to more specialized situations requiring fairly frequent but small scale attention. On major highways with moderate to heavy traffic, the engineer will observe the deterioration on various routes or stretches and form a replacement plan which may span several years. For example, centre lines may be renewed on worn-out stretches in one year and edge lines renewed the following year, etc.

In general, the better-marked a road is the lower is the accident rate and the maintenance engineer is thus obliged to ensure that his roads are kept in well-marked state, while at the same time being aware of cost-effectiveness.

A cheap road paint which lasts only 6 months cannot be said to be cost-effective as a thermoplastic, which may last 5 or 6 times longer and cost only twice as much. Therefore, the use of more expensive materials should be given favoured consideration and be considered in the budget.

8.10.2 Road Signs

Road signs need periodic improvement or renewal either because of weathering, which renders the sign illegible, or a change in routes or destinations, which may arise when new roads are constructed in the area. In all cases, it is advisable to conduct an annual survey of signs and carry out corrective action. The need for new signs, for instance in accident black-spots, should also be considered. It may be advisable to apply a retro-reflective material on signs outside urban centres.

8.10.3 Kilometre Posts

While painting of kilometre posts is deemed to be a routine maintenance activity, the sitting of kilometre posts is considered as a periodic activity.

If new roads or by-passes are constructed in the area, the kilometre posts may become obsolete or in the wrong position (possibly due to a shortened distance which new roads normally bring about). In such cases the posts should be moved to their correct positions or repainted with new information.

Damaged posts should be either repaired or replaced and surveys for this activity should be carried out annually.

8.10.4 Guide Posts

These are commonly placed at edges of embankment or to alert the motorist to a specific hazard or danger. The need for them and their conditions should be reviewed annually and corrective actions should be taken.

8.10.5 Guard Rails

The condition of all guard rails should be examined annually taking particular note of loose posts, bent alignments, missing bolts, low-standard temporary repairs and the state of the rails galvanise.

All defects should be corrected and in the case of badly weathered or corroded rails these should be replaced from the stock and possessed by the district.

The need for additional guard rails should also be assessed in the light of accidents, etc., which the presence of a guard rail may have prevented or alleviated. It should be borne in mind however that guard rails in general are placed in locations where there are hazards and because guard rails themselves can be a hazard, they should only be used if the engineer considers that the overall safety in a particular location will be improved.

8.10.6 Lay-Byes

A periodic cleaning up of lay-byes should be conducted as they tend to become areas of collection of assorted traffic and vehicular debris. The drainage should be checked and the provisions for collection of rubbish (e.g. concrete bins) checked to see if they are sufficient in number.

8.10.7 Street Lighting

While the electrical system of street lighting is normally maintained by the M and E Division of Works ministries, the physical condition, particularly of the bottom 2 metres, is more usually the responsibility of the road maintenance department. Damaged posts should be removed and the bottom 2 metres of all posts should be given a coat of white or reflective paint once a year. The condition of lamp-post bases should also be examined to correct any defects, which for instance were caused by traffic accidents.

8.10.8 Other Furniture

There are a variety of other items of highway furniture, all of which should be checked periodically. These include:

- Culvert markers
- Public service authority markers (e.g. NEPA)
- Flower beds
- Public seating
- Bus-stops
- Posts for telephones, electricity, etc.
- Taxi-stands
- Anti-parking devices
- Speed bumps

In cases where another authority is the owner of such furniture, they should be requested to repair or correct any damages in coordination with the road department‘s own periodic operations.

BRIDGE NUMBER------------------ CODE: Good =1, Fair =2, Poor =3, Critical = 4 YEAR BUILT-----------

------------------ BRIDGE TYPE--------------------------- OVERALL LENGTH--------------

OVER OR UNDER------------------- NO. OF SPANS--------------------

MONTH												
DAY												
YEAR		80	81	82	83	84	85	86	87	88	89	90
SUPERSTRUCTURE												
1. DECK SLAB												
2. WEARING SURFACE												
3. CURBS & MEDIAN												
4. WALKWAYS												
5. RAILINGS												
6. JOISTS												
7. FLOOR BEAMS												
8. FLOOR BEAMS CONNECTIONS												
9. LONGITUDINAL BEAMS OR GIRDERS												
10. TRUSS ALIGNMENTS												
11.HIP VERTICALS												
12. END POSTS												
13. TOP CORDS												
14. BOTTOM CHORDS												
15. WEB MEMBERS - VERTICAL												
16. WEB MEWERS - DIAGONAL												
17. PORTALS												
18. SWAY BRACING												
19. LATERAL BRACING												
20. CROSS FRAMES OR DIAPHRAGMS												
21. DECK EXPANSION DEVICES												
22. BEARINGS												
23. DRAINAGE SYSTEM												
24. ARCHES												
25. MOVABLE BRIDGE MACHINERY												
26. SUSPENSION BRIDGE CABLE OR CHAIN BENT												
27. SUSPENSION BRIDGE TOWERS												
28. SUSPENSION SYSTEM - MAIN												
29. SUSPENSION SYSTEM SUSPENDER												
30. PAINT												
31. RESPONSE TO LIVE LOAD												
SUBSTRUCTURE												
40. ABUTMENTS												
41. BACKWALLS												
42. WINGWALLS												
43. BRIDGE SEATS - ABUTMENTS												
44. BRIDGE SEATS - PIERS												
45. PIERS												
46. SUSPENSION BRIDGE ANCHORAGE												
47. PILING												
GENERAL												
50. STREAM CHANNEL -	WATERWAY.											
	SCOUR ALIGNMENT											
51. BANK PROTECTION												
52. CULVERTS												
53. APPROACH GUARDRAIL												
54. APPROACH EMBANKMENT												
55. APPROACH PAVEMENT												
56. APPROACH ALIGNMENT & GRADE												
57. APPROACH SLABS												
58. SUMMARY,												
70. INSPECTED BY												

Figure 106: Bridge Inspection Record

BRIDGE INSPECTION REPORT

BRIDGE / CULVERT NUMBER: ______________ **DISTRICT:** ______________ **STATE:** ____________

ROUTE	TYPE	SPAN / SIZE	KILOMETRE	YEAR BUILT

SUPER STRUCTURE **REMARKS:** ....

	Type	Cond.		TYPE	COND.
DECK SLAB: REINFORCED CONCRETE = 1 TIMBER STRIP = 2 TIMBER PLANK = 3 FILLED STL GRID = 4 OPEN STL. GRID = 5 CORRUGATED STL. = 6 BUCKLE PL. = 7 CHECKER PL. = 8 JACK ARCH = 9 OTHER = 10					
WEARING SURFACE : Conc. = C Bituminous = B Other = 0					
CURBS & MEDIAN : Conc. = C Steel = S Timber = T Other = 0			WALKWAYS : See Deck Slab for Type Code		
RAILINGS : Conc. = C Steel = S Timber = T Conc + Aluminum = A Other = 0					
JOISTS : Steel = S Timber = T					
FLOORBEAMS : Conc. = C Steel = S Timber = T					
FLOORBEAMS CONNECTIONS : Rod = R Plate = P Angle = A					
LONGITUDINAL BEAMS OR GIRDERS : Steel = S Conc. = C Prestressed Conc. = P Timber = T					
TRUSS ALIGNMENT : Steel = S Timber = T					
HIP VERTICALS.					
END POSTS : Steel = S Timber = T					
TOP CHORDS : Steel = S Timber = T					
BOTTOM CHORDS : Steel = S Timber = T					
WEB MEMBERS - VERTICAL : Steel = S Timber = T			DIAGONAL: Steel = S Timber = T		
PORTALS : Steel = S Timber = T			SWAYBRACING : Steel = S Timber = T		
LATERAL BRACING : Steel = S Timber = T			CROSS FRAMES or DIAPHRAGMS : Steel = S Timber = T Conc. = C		
DECK EXPANSION DEVICES : Steel = S Other = 0 **Brief Description:**					
BEARINGS : Rockers = R Bolsters = B Rollers = N Plates = P Elastomeric = E Other = 0					
DRAINAGE SYSTEM : Trough Curbs = T Scuppers = S Scuppers with Downspouts = D Other = 0					
ARCHES : Conc. = C Steel = S Masonry = M Timber = T			MOVABLE BRIDGE MACHINERY : Bascule = B Vertical Lift =V Swing = S		
SUSPENSION BRIDGE CABLE or CHAIN BENTS :					
SUSPENSION SYSTEM MAIN : Cable = C Eyebar = E			SUSPENSION BRIDGE TOWERS : Steel = S Masonery = M Cable = C		
PAINT : Show Year Last Painted			SUSPENDER : Response to Live Load Excessive Defl. & Vib. = E Satisfactory = S		

SUB - STRUCTURE

	Type	Cond.		Type	Cond.
ABUTMENTS : Wall = W Gravbity = G					
BACKWALLS : Conc. = C Masonry = M Other = 0			WINGWALLS : Conc. = C Masonry = M Other = 0		
BRIDGE SEATS : Abutment : Pier : Conc. = C Masonry = M Steel = S Timber = T					
PIERS : Column = C Wall = W Capped Pile = P Other = 0					
SUSPENSION BRIDGE ANCHORAGES : Conc. = C Masonry = M			PILING : Steel = S Timber = T Cast-in-place = C Precast Conc. = P		
GENERAL : Waterway STREAM CHANNEL - Show in Left Block SCOUR - Show in Type Block Unrestricted = U Restricted = R Scoured = Y Not Scoured = N			ALIGNMENT: Show in Cond Block Faulty = F		
BANK PROTECTION : Show in Type Block : Additional Protection Needed = Y or No = N					
CULVERTS : Box = B Arch = A Slab. Top = S Conc. Ring = R Armco = M					
APPROACH GUARDRAIL : Deep Beam = D Cable = C Woven = W Armco = M Other = O			APPROACH EMBANKMENT : Show in Type Block: Settled=Y Not Settled= N		
APPROACH PAVEMENT : Conc = C Bituminous = B Other = O			APPROACH ALIGNMENT & GRADE : Satisfactory = S Poor = P		
APPROACH SLABS : Show in Type Block: Settled = S Not settled = N			SUMMARY : Satisfactory = 1 Needs Housekeeping Maint = 2 Minor Repair = 3 Major Repair = 4		

INSPECTED BY: ____________________ **REVIEWED BY:** ____________________

DATE: ____________ **DATE:** ____________

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DISTRICT MAINTENANCE MAINT. ENGINEER

Figure 107: Bridge Inspection Report

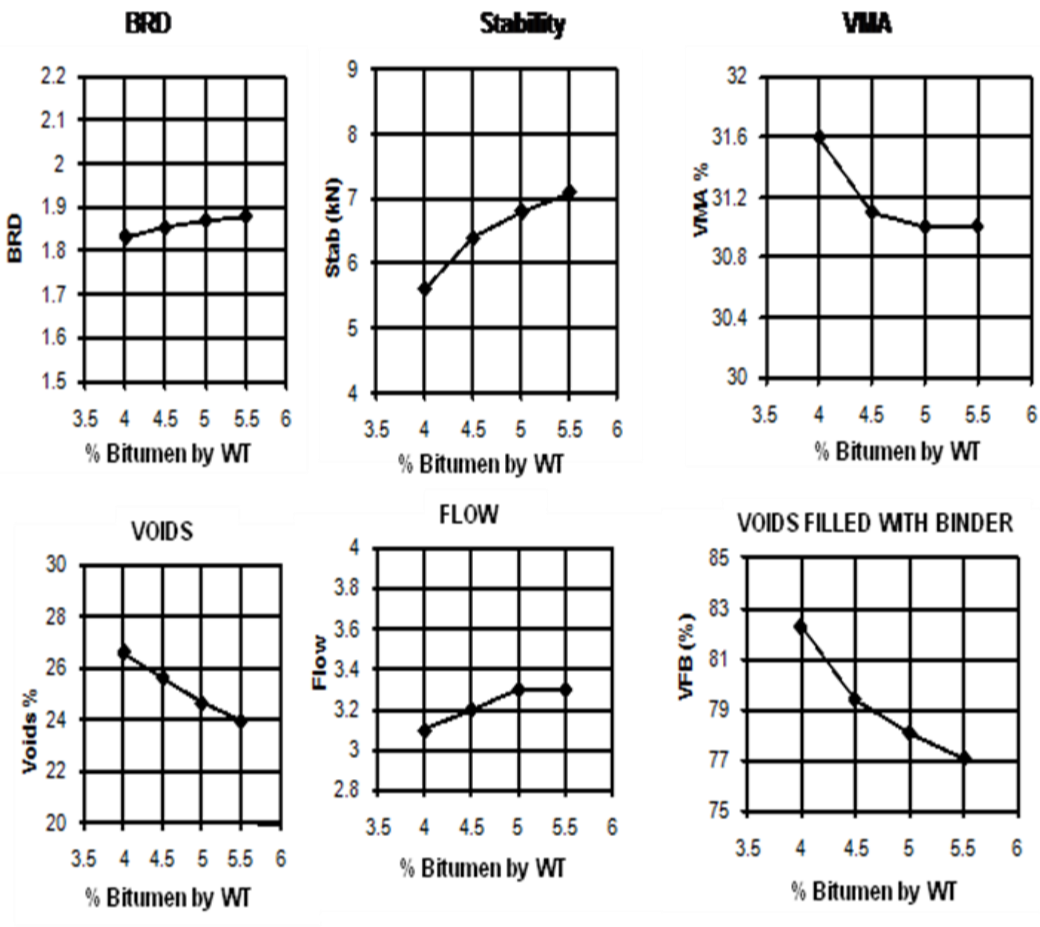

Figure 108: Asphalt Properties Plotted against Binder Content

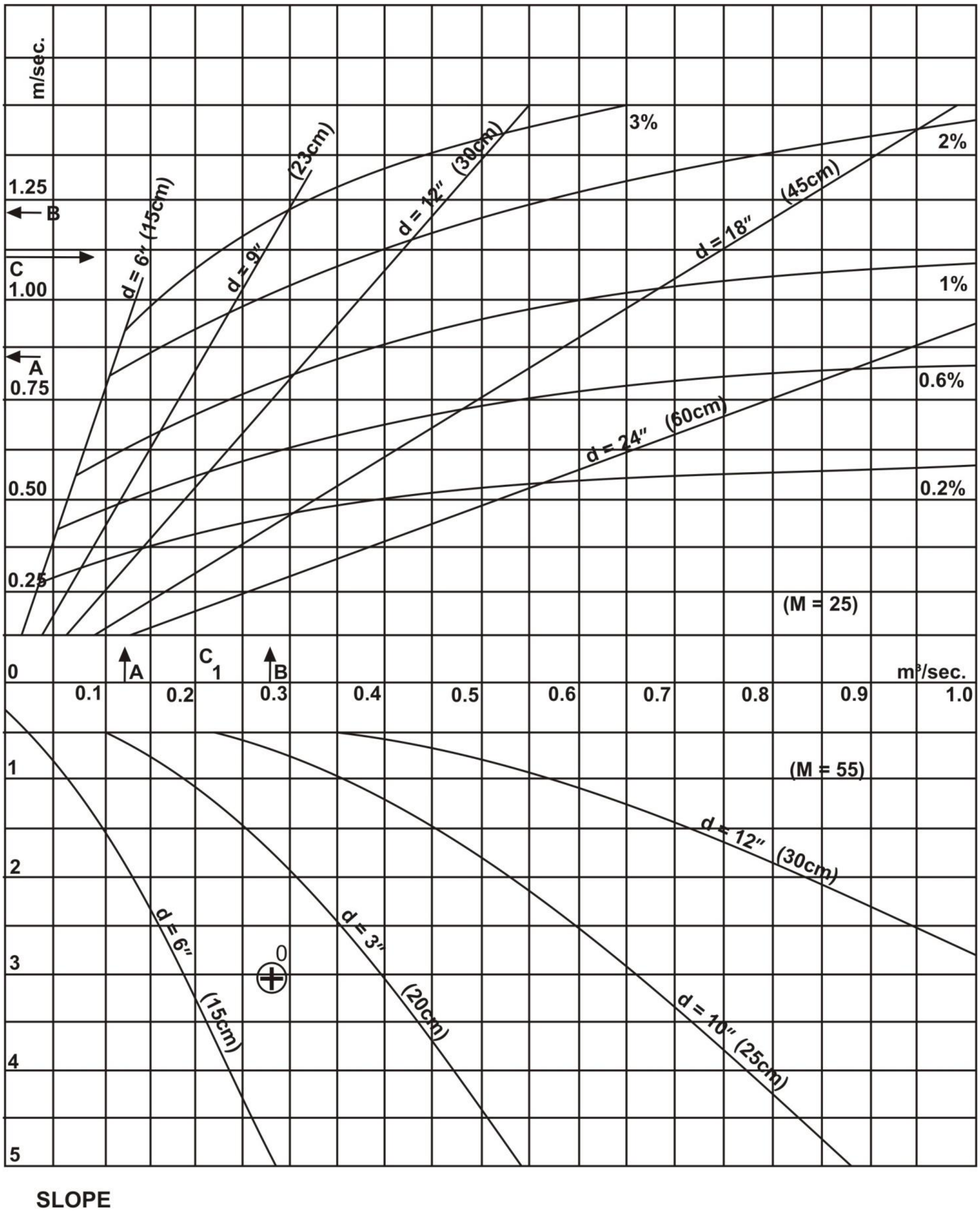

Figure 109: Side Drain Capacity Chart

9 Improvements

Improvements fall into two categories;

- Minor improvements which are within the technical capability and resources of maintenance departments; and
- Major improvements, which are normally beyond the technical capability and resources of maintenances departments and are therefore treated in the same way as new construction, i.e. design, tender and award of contracts.

Minor improvements are based on experience and are quite frequently made as a result of an engineer's observation of certain defects, which either present a hazard to road users or hazards to the road itself. This chapter, as such not exhaustive, will highlight a few examples of minor improvements.

9.1 Geometric Improvements

Geometric improvements to a highways alignment, cross section, or longitudinal section are normally made necessary to the roads by the inability of the road designer to foresee a certain combination of hazardous circumstances. This can be the case of older – undersigned – roads, with factors such as too-tight curves for the normal speed of the traffic and large erosions caused by a drainage system that occurred by nature, rather than by design. The need for most improvements will be indicative on the road itself by showing a higher than normal accident rate.

The maintenance engineer should be aware of such factors and should as a driver examine the circumstances, which tend to create the higher accident rate. Apart from the frequent cause of too high speed, it may be found that for instance the visibility, i.e. sight distance, is too low and thereby presenting a hazard to the driver, which he sees too late to take effective action. All roads should thus be examined annually for sight lines.

9.1.1 Sight Lines (Site Distance)

The safest roads are normally those on which the driver has the longest possible sight distance. By being able to see such hazards as oncoming traffic or bends in the roads, he can adjust his speed in accordance with the hazards he sees. Clearly, if he cannot see these hazards until it is too late for appropriate action, accidents may occur.

One of the most common causes of accidents in Nigeria is reduction of sight distance on horizontal curves either by vegetation growth or earthworks in cutting, both of which restrict the distance the driver can see.

Therefore, notwithstanding the remarks made in ***Chapters 7.4 and 8.4*** on the inside of some curves it may be necessary to cut the vegetation to a height of no more than 60 cm right to the fence line, every 2 months, in order to maintain a longer sight distance.

Some cutting may be found to give rise to the same problem—low sight distance and the engineer should give some thought to possibly widening the earthworks on the inside of curves in order to improve visibility. This may be a large operation but it should not be beyond the capability of maintenance departments. The job need not necessarily be done very quickly and the cutting may be improved by a small team or minor equipment working for several months.

Another situation which reduces sight distance is a convex vertical curve of short vertical radius in which the visibility to the driver is limited to the top or crest of the curve. He cannot see what is on the other side of the hill. This situation can only be resolved by earthwork and platform modifications. In some instances the m aintenance d epartment may have the resources to handle it. This is an expensive modification because the existing pavement has to be excavated and a new pavement must be provided at a lower level.

The engineer can only decide whether to do this sort of job with direct labour or contract after he has made a thorough survey of the new grade level required and the earthworks and paving works involved.

Many accidents occur where there are road junctions, slow moving traffic coming on to the main road or traffic crossing it. This traffic may be obscured to the fast moving main roads traffic by limited sight distance. In these circumstances, the possible solutions are.

- To improve the visibility, both to the side road traffic and main-road traffic;
- Move the junction to a safer place;
- In any case, erect special signs

Overtaking is probably the one manoeuvre that causes more road deaths in Nigeria than any other single action. The engineer should not close his eyes to this situation. Light vehicles will overtake lorries whenever they can and it is thus the engineer's responsibility to make this as safe as possible throughout the entire length of a particular road.

Hence, periodic maintenance can also include that the engineer should drive slowly along all his roads at least once annually to review such geometric defects.

9.1.2 Pavement Widening

With the increasing length of heavy vehicles, more accidents are being caused nowadays because the older type of roads are no longer suitable in width to allow safe passage of such vehicles without presenting a hazard to other road users. Long and heavy vehicles are now all articulated (i.e. tractor and trailer) and the rearmost axle will on curves follow a much flatter radius than the steering axle. To compensate for this, the vehicle driver must steer in a line, which allows the rear axle to remain on the pavement. He can only do this by driving to the left of the centre-line of the road. On-coming traffic is thus presented with an unexpected hazard, which can only be attributed to poor road geometry.

The solution to this particular problem is to leave the centre-line where it is, but increase the pavement width on the inside of the curve to accommodate the motion of long vehicles. There are well known formulae for calculating the pavement widening necessary for any particular curve radius. These can be found in the Highway Manual, Part 1and highway design. In the absence of this, a widening of up to 1 metre will accommodate most problems, although the normal widening is between 30 and 60cm.

9.2 Structural Improvements

Structural improvements become periodically necessary for reasons such as increased traffic and inadequate drainage systems.

9.2.1 Pavement Strengthening

Pavements do not get stronger with age. On the contrary, the effects of traffic and weather tend to make them weaker.

Traffic too, is constantly increasing and thereby accelerating the decay of the pavement. There comes a time when a pavement designed to take a certain number of traffic movement passes its design life and pavement strengthening is called for.

The maintenance engineer will not be taken by surprise by the above sequence of events if he maintains his highway register. Indeed, he will be able to fairly accurately predict when strengthening of the pavement will become necessary.

The decision as to whether to do pavement strengthening by own labour or by contract will obviously depend upon the scope of the work and the resources available to the engineer. However, ***"a stitch in time saves nine"*** and it may be more attractive in both, a political and engineering sense, to effect small strengthening's more frequently by direct labour rather than a major strengthening at infrequent intervals at perhaps 10 – 15 years.

There is no difficulty in predicting when a strengthening becomes necessary if regular traffic counts and assessment of the existing pavements are made.

The principles involved in this prediction are fully described in volume 1 of this manual – The Highway Register.

9.2.2 New Culverts

New culverts become necessary during a road's life either because of changing circumstances adjacent to the road or because the existing drainage system has proved to be inadequate.

a. Highway – Culverts

Highway culverts may need to be increased in either number or capacity because

- The existing drainage system is not capable of handling maximum flows
- Changing circumstances, for instance large scale agricultural or urban development, increase the amount of water to be handled by any particular culvert.

In these circumstances, the maintenance engineer should make a survey and determine the maximum flow which can be expected and design a new culvert or an addition to an existing culvert in accordance with the principles set forth in ***Chapter 8.9 Drainage Structures***, in this manual.

b. Access –Culverts

A commonly occurring situation in Nigeria is new roadside development in which the user of adjacent property requires access to his property from the road. He will normally make his own entrance without regard to the highway drainage system, thereby putting at risk, albeit innocently, the structure of the pavement.

The question of whether this adjacent land-user is entitled to do what he has done is better left for higher authorities. The job of the maintenance engineer is to see that his road is not endangered by such activities and if this involves the construction of an access culvert, he will be well advised to do it.

The cost of such culverts is small compared to the cost of a possible road closure through pavement or earthworks failure and although they may in some circumstances prove to be an annoying duty, which may keep an entire gang busy for the whole year. It is a better solution to put in the culverts now and argue later. The longitudinal flow of water along a highway is potentially the most damaging act of nature to the highway and the engineer should keep this constantly in his mind.

9.3 Ancillary Improvements

These improvements are too numerous to categorize but there are three particular items that should receive annual review.

9.3.1 Drain Lining

The engineer should make it his duty to occasionally drive slowly down a particular section of road during heavy rain and , examine the flow of water as regards both quantity and velocity of flow along every single metre of the road‘s drainage system. Quantity is on the whole less damaging than velocity, which can give rise to erosion and washing away of the road structure at an alarming rate.

If erosion is observed, the procedures detailed in ***Chapter 8.2.6: Side Drain Lining*** should be investigated.

9.3.2 Erosion Control Structures

In some instances, large flows and velocities may occur in a direction tending to be transverse to the highway. Such action of water may lead to scour of the toe if the embankment covers quite a length at each side of a culvert. If this is the case, the engineer should consider the protection of the embankment by either loose stone, rip-rap or concrete.

Similarly, the stream banks at either side of a bridge over water should be examined at seasonal maximum flows to ensure that no damage to the immediate vicinity of the bridge is occurring. Solutions such as those given above are all appropriate.

9.3.3 Lay-Byes

Traffic, particularly commercial traffic, develops habits which the maintenance engineer cannot ignore. Lorry drivers are gregarious worldwide and will stop where fuel, water and food are always plentifully available. If no proper provision is made for the parking of vehicles off the road, they will naturally park on the shoulders, which are seldom designed for heavy standing vehicles at frequent intervals.

So the engineer should always be alert for such developments and, in the interest of the safety of both stopping and passing traffics provide a properly constructed hard-standing or lay-byes as soon as the need becomes readily apparent.

No driver likes to park his vehicle where there may be danger to it from other traffic. He will readily use a lay-bye in preference to the shoulder even if some walking distance is involved.

Lay-byes are not cheap to build, so the Engineer must assess the need by constant observation of traffic habits. By proper planning and smart use of funds a number of lay-byes in the most necessary locations can usually be accommodated within a financial year.