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Chapter 1 - Introduction

1.1 Aims and Objectives of the Handbook

The objective of this handbook is to compile all of the information needed to effectively plan and carry out forest road construction and maintenance operations in one location. Many handbooks exist on forest road construction and maintenance, but none have been written for the South African forest industry. A wide-ranging group of experts was brought together to determine the content and layout of this publication.

Forest roads provide required access for management of forest resources. Timber harvesting, fire protection, recreation, and administrative activities are highly dependent on access through a good forest road network.

The replacement value of the South African forest road network is conservatively estimated to be R900 million. It is also estimated that the industry collectively spends R45 million per annum on road maintenance and upgrading. The South African forest road network density is estimated to range from 55m/ha to as high as 150m/ha.

While roads are viewed as an asset to the forest, they are also a source of erosion and sediment input to dams, lakes, rivers, and other waterways. These effects negatively impact aquatic and terrestrial wildlife, and present a negative public image of forest management. Additionally, forest roads remove valuable forestland from active production. A well-planned road network minimises the amount of roads built by optimising road location and spacing, reducing construction and maintenance costs, while ensuring maximum productivity of the forest estate.

This handbook provides state-of-the-art information on planning, managing, and constructing forest roads. In the current regulatory and social climate, a well-planned, -constructed and -maintained forest road network is critical to economically and environmentally sustainable forestry operations.

Throughout this handbook, careful attention is paid to minimising environmental impacts, while maximising efficiency and usability of the transportation network. Another factor, which must never be overlooked, is safety. Every operator is responsible for complying with all safety regulations on every operation.

1.2 Layout of the Handbook and how to use it

The handbook is divided into five chapters, each covering a specific topic related to forest road management. Each chapter contains sections on the various sub-topics. The reader simply looks up the topic in the table of contents and turns to that section. All of the information likely to be needed will be found there, along with a list of additional references, should more information be needed.

The compilers of this handbook hope that the engineers and foresters who use it will be able to do a more efficient, more effective, and therefore a better job of planning and executing forest road projects.

The information contained in this handbook is not to be interpreted as legally required methods or procedures. This handbook is to be used for guidance, in conjunction with engineering methods to achieve a desired outcome. There are many methods to achieve engineering solutions. If you have any concerns about your abilities to properly achieve a solution, it is strongly recommended that you consult a qualified, registered professional.
1.3 International Trends

The international community is driving forest management towards new levels of sustainability and transparency. Forest certification programs such as Forest Stewardship Council (FSC) and International Organisation for Standardisation (ISO) are being demanded by consumers to ensure that timber products are being sourced from sustainably-managed forests. South Africa has been at the forefront of sustainable plantation forestry, however, South African forest roads have not always been constructed or managed to world-class standards. The following trends will shape forest road management in the future:

- Forest roads and the associated environmental impacts will become increasingly important in the total forest management strategy.
- Road networks should be established that minimise the amount of road length and density, while optimising harvest and transportation systems.
- Implementation of reduced-impact construction techniques, including the use of equipment and methods that minimise environmental impact and the risk of sedimentation and mass soil movement.
- The impacts of forest roads on aquatic life should be considered. Where necessary, stream crossing structures that permit unhindered two-way fish passage should be constructed.
- The impacts of forest roads on local and indigenous communities will factor into management strategies. Access to traditional areas for subsistence agriculture and hunting, and for religious purposes will be provided.

1.4 Environmental Considerations

Forest road construction and management impacts the environment in many ways. The road manager or engineer must analyse the effects (positive and negative) to formulate an appropriate management strategy. Forest roads interact with the environment in different ways depending on where and how they are constructed. Forest road management requires tradeoffs between the need to access the forest and the need to protect the environment. This section discusses the environmental considerations involved in forest road management.

Road impacts and uses may be divided into beneficial and detrimental.

Beneficial effects of forest roads:
- Access for timber harvesting and extraction of other forest products;
- Access for grazing, mining, recreation, fire protection, land management, research and monitoring;
- Access to private holdings within the forest estate;
- Public access to forests;
- Jobs associated with road construction and maintenance.

Detrimental effects of forest roads:
- Adverse effects on hydrology and geomorphic features (such as landslides and sedimentation);
- Degraded water quality and chemical contamination;
- Degraded aquatic habitat;
- Destructive human actions (e.g. dumping, poaching and fires);
- Reduced solitude and wilderness values;
- Reduced plantation area available for growing timber.
Before one can understand the impact of the forest road on the environment, it is essential to have a sound understanding of the hydrological cycle and geological erosion processes that naturally occur within the forested environment.

The hydrological cycle (Figure 1.4-1) depicts the movement of water through the forest ecosystem. Watersheds collect and funnel precipitation through a network of watercourses, which ultimately drain into perennial streams. Water then re-enters the atmosphere via evaporation and evapo-transpiration to continue the cycle indefinitely.

In the undisturbed forest, potential soil water infiltration rates generally exceed rainfall rates and overland flow is rare, even during abnormal rainfall events. Stream flow in undisturbed forest watersheds is primarily driven by water flowing through the soil, rather than over it.

Geological erosion and weathering, under natural conditions, are gradual processes, providing most of the sediment naturally occurring in forest streams.
The Managed Forest

Forest roads disrupt the hydrological cycle and alter the natural water movement processes. The following are effects associated with forest road construction:

- Soil is loosened and exposed;
- Infiltration is reduced;
- Subsurface flow is interrupted and converted to overland flow;
- Overland flow is concentrated and accelerated.

These effects become more pronounced as the terrain becomes steeper.

Impact on the Environment

The issues of resource sustainability and water quality have brought the impacts of erosion and sedimentation to the public’s attention in recent years.

Suspended sediment impacts biota by reducing light penetration, thereby limiting the amount of primary production in the food chain. Sedimentation can also lead to reductions in dissolved oxygen as microorganisms decompose the nutrients contained in the sediment. Additionally, suspended sediment can impact biota by increasing steam water temperatures.

Sedimentation can also result in the infilling or aggradations of water bodies and the choking of filtering biota. Aggradations within a watercourse can result in the infilling of lakes, dams, estuaries and harbours, reducing water storage capacity and affecting watercourse navigability. Aggradation also changes channel morphology, causing stream bank instability, bank undercutting and downstream sedimentation.

Excessive runoff and sedimentation could increase filtering costs of water, interfere with irrigation systems and increase the flood potential. The average annual sediments load released into streams of the southern and eastern Cape result in an average loss of 10% of reservoir capacity every decade.
Forest Roads and Erosion

Sedimentation is caused by erosion. The main factors governing the rate and severity of erosion are precipitation, soil properties, topography and vegetation.

- **Precipitation** in terms of intensity and duration affects the dispersion of soil particles and the amount and velocity of run-off.
- **Soil properties** that effect erosion are infiltration capacity and stability. Infiltration capacity determines the volume of water available for surface runoff. Soil stability is the resistance of the soil particles to detachment, transport and dispersion from the force of raindrops and flowing water.
- **Topography** in terms of the degree and length of slope are two features that determine runoff and erosion. The velocity and erosive power of surface runoff increases with the degree of slope.
- **Vegetation** cover diminishes the effect of rainfall and steepy topography on erosion. Vegetation reduces total rainfall, rainfall intensity, and raindrop impact through interception, and decreases runoff velocity and erosive power.

Commercial forestry in South Africa is best suited to the high rainfall regions in the upper reaches of drainage basins. The precipitation and topography of most afforested areas favour erosion. Exposing and modifying soil properties through road and landing construction, timber harvesting, and site preparation further increase the erosion potential.

Surface erosion may be caused by water flowing off cut or fill slopes, on the road surface, in side drains, or on undisturbed slope below roads. Excess soil water raises pore water pressures, reducing the strength of soil, which may result in mass erosion above road cuts and fills, underlying soils, and in soils below the road.

Road and Surface Erosion

The amount of surface erosion from forest roads is proportional to the road density. Surface erosion is greatest during the first year following construction and declines as exposed soils become revegetated. Soil losses from road surfaces are greatest during the rainy season and during peak harvesting traffic.

Cut and fill slopes and compacted roads carry surface runoff during storm events, and can be a source of sediment. Poorly designed or maintained drainage systems can compound this effect.

Research has shown that surfacing can greatly reduce sedimentation. Sediment yield was reduced by a factor of 4.3 for gravelled surfacing, 3.2 for dust oil and 28.7 for bituminous surfacing, relative to an unsurfaced forest road. Sediment yield from a gravelled road is only 23% of the yield generated from an unsurfaced road. Rutted unsurfaced roads produce twice the sediment as a smooth unsurfaced road. This effect results from the increase in water velocity associated with rutted surfaces.

Roads and Mass Soil Movement

Mass soil movement, also called landslides, is a general term that describes the rapid downslope movement of large volumes of soil and rock material. It is a common erosion form in mountainous terrain and part of the natural process that shapes topography. Gravity is the primary cause of movement, although water decreases soil strength and may add sufficient weight to cause failure.

Landslides in forested watersheds occur naturally, but may be triggered by improper road construction methods, poor road maintenance, or by road drainage. These factors, in combination with steep slopes (> 30%) contribute to the increased probability of landslides in forest areas. The largest and most dramatic slides usually originate on roads or landings where fill material has been side cast on steep slopes.
Minimising the Impact of Forest Roads

All forest roads disturb the natural environment. The impact can be minimised through proper management. There are essentially two means available to reduce erosion and sedimentation:

- Institute remedial action to reduce the potential of erosion
- Use appropriate planning to limit the need for remedial action.

Landslides and much surface erosion can be traced to poor planning, design and construction practices. Many potential erosion sources from forest roads can be avoided or minimised by proper planning and construction.

A properly planned road network that minimises road density also minimises the amount of exposed soils that generate erosion and sedimentation.

A drainage system should be designed to prevent water from concentrating on the road surface, or from travelling long distances in side drains. The road must have proper camber and side drainage in addition to properly sized, spaced, and maintained culverts. Water discharged from the road surface and culverts must be carefully controlled and dissipated.

Roads should be surfaced shortly after construction. If the road will not be surfaced, exposed soils should be stabilised to facilitate natural revegetation. Soil losses are minimised by stabilisation on surface cover, even during abnormal rain events.

Full-bench roads should be constructed on terrain with side slopes exceeding 50%. Fill material is difficult to manage and compact on steeper slopes and is prone to erosion or landslides.

Recommendations to Minimise Environmental Impacts

- The planning phase will identify different routes which will then be field investigated to ensure compliance with management objectives.
- Design standards should be the lowest necessary to provide the required level of service and minimise adverse environmental effects.
- Road surface area and drainage should be optimised.
- Exposed soils should be stabilised to facilitate natural revegetation.
- Roads should be surfaced when feasible. If roads are unsurfaced, sediment transport must be mitigated.
- Buffer strips and filter windrows should be constructed to intercept road-generated sediment.
- Consider suspending traffic during abnormally wet periods, not only to reduce sediment, but limit unnecessary damage to the road.

1.5 References and Further Reading

1. Forestry South Africa (FSA), *Environmental Guidelines*, FSA, Rivonia, South Africa. 2002
Chapter 2 - Road Planning

2.1 Planning Methodology and Strategies

A properly engineered, constructed, and managed road system is an essential component of a sustainably managed forest. A common challenge for the forest manager is determining the appropriate level of roading – how much, when and where.

Planning an optimised road network and harvest system can produce a lower road density when compared with harvesting operations without a comprehensive road plan. The appropriate road density for a particular area will depend upon the type of forest, cost of road construction and maintenance, extraction methods and other factors.

A plantation with a high road density requires a large investment. Such a network is typically associated with close road spacing and reduced primary transport costs. Conversely, a plantation with a low road density requires less investment, but typically requires longer primary transport distances and associated higher harvesting costs.

2.2 Planning Optimum Forest Road Spacing

There are many factors that influence the layout and spacing of forest roads. Some of these factors are:

- Terrain conditions;
- Stand density or volume to be removed per hectare;
- Primary transport cost;
- Secondary transport cost and demands;
- Road construction cost;
- Road maintenance cost;
- Forest area removed from production;
- Type of forest management practiced (exploitative versus intensive);
- Needs of other road and forest users;
- Environmental protection factors.

Roads should be spaced such that the minimum total cost is achieved. Many of the above factors are difficult to quantify. To simplify the problem, the optimum road spacing equation that will be developed only considers primary transport cost, road construction cost and volume removed per hectare, with the objective being the lowest total cost per m$^3$ of wood. Additional cost factors can be added to the total cost equation if desired (Figure 2.2-1).
Figure 2.2-1: Relationships between total cost ($C_t$), variable primary transport cost ($C_v$), fixed primary transport cost ($C_f$) and road cost ($C_r$) in harvesting and transport operations.

The controllable variable is road spacing ($S$), while the uncontrollable variables are:

- Road construction cost ($R_c$, R/km);
- Volume removed ($V$, m$^3$/ha);
- Off-road transport machine cost ($M_c$, R/min);
- Loaded off-road driving speed ($D_l$, m/min);
- Empty off-road driving speed ($D_e$, m/min);
- Average load ($L$, m$^3$);
- Fixed off-road transport time ($T_f$, min);
- Terrain factor ($p$, actual driving distance vs. straight-line distance).

Another expression linked to road spacing, is road density. Road density is an expression of the number of metres of road per hectare of forest and is reflected in the practical and relevant inverse road spacing expression.

Road density (m/ha) = 10 000/road spacing (m) and;
Road spacing (m) = 10 000/road density (m/ha).

Road density is theoretically determined by dividing the total road length by the total land area.

Figure 2.2-2: Road spacing, and maximum and average off-road transport distances with extraction from both sides of the road.
It must be noted that the optimum road spacing should only be used as a guide to assist in road planning, because most logging areas are not perfectly flat. As a general rule, if you must deviate from the optimum road spacing, it is best to increase the distance between roads rather than to decrease it.

The optimum road spacing equations are derived in Appendix 2.

Another road equation deals with the maximum distance ($D_{\text{max}}$) to the back of the felling area. Beyond $D_{\text{max}}$, the sum of primary transport and the building of a route into the felling area is cheaper than just primary transport out to the existing road (Figure 2.2-3).

**Figure 2.2-3: Using $D_{\text{max}}$ to determine whether additional routes should be built.**

This is applicable since there is a dead zone from which wood will be transported to the existing road, thus the full benefit of the potential additional route is not gained (Figure 2.2-4).

**Figure 2.2-4: Dead zone area.**

The optimum road spacing information is combined to simplify the equation:

If no spur roads are built the cost = $D/2*C$, where
- $D$ is the distance to the back of the block (m);
- $C$ is the marginal off-road transport cost (R/m³/m).
If spur roads are built the cost = \( \frac{S}{4}C + \frac{R}{V} \), where
- \( S \) is the optimum road spacing (m);
- \( C \) is the marginal off-road transport cost (\( \text{R/m}^3/\text{m} \));
- \( R \) is the road cost (\( \text{R/ha} \));
- \( V \) is the volume removed (\( \text{m}^3/\text{ha} \)).

The break-even point is when the two equations are equal:
- \( D_{\text{max}}/2*C = \frac{S}{4}C + \frac{R}{V} \);
- \( D_{\text{max}} = \frac{S}{2} + \frac{2R}{VC} \).

Because at this point the dead zone has not been accounted for, you will notice that \( D_{\text{max}} = S \), and thus \( \frac{2R}{VC} \) is equal to \( \frac{S}{2} \). From Figure 2.2-4 we see that the dead zone area equals \( S^2/4 \). The road cost component must be multiplied by a factor equal to the area serviced by the road divided by the reduced area due to the dead zone. This factor is equal to \( S^2/(S^2-S^2/4) \).

\[
D_{\text{max}} = \frac{S}{2} + \frac{S}{2} \left( \frac{\frac{S^2}{2}}{\frac{S^2}{2} - \frac{S^2}{4}} \right)
\]

If a decision is made to build spurs then they should be built at the optimum spacing (\( S \)) and they should end so the average extraction distance at the back of the block is equal to \( S/4 \).

### 2.3 Optimising the Road Network Layout

Determining appropriate road spacing is only the first step towards optimising a forest road network. The second step is to determine the most efficient road layout. Road efficiency is determined from an optimisation of harvesting and transport.

The layout of the road network is determined by topography, location of existing roads, environmental constraints, and construction methods. Gentle terrain allows for a greater choice of network patterns, which tend to be more symmetrical than road networks occurring in steep or variable terrain.

<table>
<thead>
<tr>
<th>Ground (%)</th>
<th>Road spacing Slope (m)</th>
<th>Road Density (m/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 15</td>
<td>800</td>
<td>27</td>
</tr>
<tr>
<td>15 to 30</td>
<td>600 to 800</td>
<td>37 to 27</td>
</tr>
<tr>
<td>30 to 60</td>
<td>300 to 400</td>
<td>73 to 55</td>
</tr>
<tr>
<td>&gt; 60</td>
<td>400 with uphill cable yarding</td>
<td>55</td>
</tr>
</tbody>
</table>

*Table 2.2-1: Optimum road spacing guidelines for varying terrain conditions.*
2.4 Road Junctions

A 90 degree junction between two forest roads is generally the most efficient, as it reduces the amount of double opening-up i.e., two roads serving the same area (Figure 2.4-1).

![90° Degree Junction vs. 30° Degree Junction](image)

*Figure 2.4-1: Diagram showing double opening-up resulting from road junction less than 90 degrees.*

Road junction configuration is often dictated by topography or haul direction. Where topography permits, a 90-degree junction is most efficient.

2.5 Network Patterns

The road network pattern or shape affects harvesting and transport efficiency.

Figure 2.5-1 displays various potential road network patterns as may be found in a compartment. Each square represents a 1km² area. As can be seen from Table 2.5-1, only road networks with parallel patterns (a and b) have a coefficient of 1. This type of pattern is however, impractical. Block patterns (c and h) are the least efficient and the fork pattern (i) the most efficient. Patterns d, e and f compare the effect of junction angles on the efficiency of the network. As the angle increases the efficiency of the network increases. Patterns d and g illustrate that a joining road within the plantation is more efficient than one on the boundary.

An “efficient” road network is one that maximises the amount of area served by each road segment. The amount of terrain that is served by more than one road is minimised, and junction angles are configured to allow for easy negotiation by transport vehicles.

![Network Patterns](image)

*Figure 2.5-1: Network patterns of roads in a compartment.*
Table 2.5-1: Efficiency of network patterns – A coefficient of 1 is good, less than 1 better and greater than 1 poor.

<table>
<thead>
<tr>
<th>Network pattern</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>j</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network density (m/ha)</td>
<td>10.0</td>
<td>30.0</td>
<td>20.0</td>
<td>37.1</td>
<td>40.3</td>
<td>44.6</td>
<td>37.1</td>
<td>60.1</td>
<td>29.5</td>
</tr>
<tr>
<td>Avg primary transport dist (m)</td>
<td>250</td>
<td>83.2</td>
<td>167</td>
<td>76.7</td>
<td>73.4</td>
<td>68.3</td>
<td>80.0</td>
<td>83.3</td>
<td>83.6</td>
</tr>
<tr>
<td>Opening up coefficient</td>
<td>1.00</td>
<td>1.00</td>
<td>1.34</td>
<td>1.14</td>
<td>1.18</td>
<td>1.22</td>
<td>1.20</td>
<td>2.00</td>
<td>0.98</td>
</tr>
</tbody>
</table>

2.6 Recommendations for the Layout of a Road Network

Variations in terrain and other factors prevent a standard solution for layout and spacing patterns. Experience has shown that certain techniques are appropriate for different scenarios. Each individual location must be analysed separately before being integrated into a network.

In mountainous terrain, differentiation is made between:

- Valley roads;
- Mid-slope roads;
- Ridge roads.

Valley roads are main roads that access a watershed and are typically constructed as Class A roads. The road should be routed along one bank, maintaining a suitable distance between the river and the road to minimise the risk of sediment reaching the stream. Stream crossings should be minimised to reduce costs and environmental impacts. Steep slopes exceeding the maximum gradient that may occur along the route can be overcome by constructing switchbacks or by travelling up a side drainage. Both options lengthen the road distance, allowing a lower grade to overcome the steep section.

Planning should be coordinated with neighbouring landowners to prevent duplication of road networks.

Ridgetops are the most desirable location for roads in mountainous terrain. Ridgetop locations are least affected by upslope drainage, resulting in reduced maintenance. Additionally, uphill cable yarding is preferred and ridgetop roads facilitate uphill yarding.

In mountainous terrain, switchback curve locations are critical control points. Switchback curves should be located on gentle terrain where possible and the grade through the curve should be kept to a minimum.

Existing roads should be considered for upgrading if their location and alignment meets management objectives.
2.7 Road Classes

A standard system of road classes has been developed to facilitate effective communication regarding forest roads.

A good forest road classification system should:
• Permit dialogue without confusion over terminology;
• Provide a basis for the design of any new road;
• Provide a basis for the evaluation of existing roads.

Roads will defined by the following classes:

**Class A** – Suitable for all vehicles in all weather conditions, with full signage.

**Class B** – Suitable for appropriate vehicles (Timber trucks, bakkies) with appropriate signage. Constructed to a higher standard than class C roads.

**Class C** – Suitable for appropriate vehicles (timber trucks, bakkies) with appropriate signage, includes all spur roads.

2.8 Forest Road Standards

A primary reason for classifying and categorising forest roads is to provide the road designer with the necessary information to design the forest road to meet the required level of service. Once the axle loads, travel speeds, traffic density and the service life of the road are known, the design standards can be specified. Standards define the geometry of the road alignment, road prism dimensions, and drainage requirements. Road standards balance the economic, operational, and environmental needs of the road for the planned use.

The optimum standard for a particular forest road will be dictated by the following considerations:
• Total volume to be accessed by the road;
• Timber value;
• Period over which the timber is to be harvested;
• Construction costs and techniques;
• Seasonal and climatic factors;
• Environmental constraints;
• Harvesting system;
• Public use of the road;
• Vehicle operating costs.

Engineering judgment must be used when determining the appropriate standard for a given road project.
2.9 Specifications

Construction specifications concern the “nuts and bolts” of road construction and maintenance and are the technical details and procedures that enable design standards to be carried through to construction. They include:

- Road surfacing specifications;
- Soil/pavement material testing procedures;
- Sub-grade/pavement compaction criteria;
- Road maintenance considerations;
- Culvert installation procedures;
- Earthwork considerations;
- Erosion protection measures.

Specifications are independent of the standards chosen. Changing the width of a road will have no effect on the quality of material used or the procedure used to compact it. Similarly the culvert installation procedure is fixed and independent of the standard of road chosen.

The specifications for a given road project should be based on sound engineering procedures, economic analysis, environmental concerns, and management objectives. This handbook provides all of the information needed to determine appropriate specifications for any unsealed forest road project.

2.10 References and Further Reading


Chapter 3 - Road Design

Section 3.1 - Forest Road Design

3.1.1 Introduction

Forest roads should be designed to meet management objectives and optimise harvest system and transportation efficiency while minimising environmental impacts. The forest road engineer can use specific design techniques to achieve these goals. This section will discuss state-of-the-art forest road design standards and methods that can be used by the South African forest engineer.

Road design methods optimise the horizontal and vertical alignments of a road to provide the appropriate geometry for the vehicle sizes and traffic that will traverse the road. Designs will vary for different road standards and classes, and are often based on a design speed or a critical vehicle.

Design speed is the speed determined for design and correlation of the physical features of a road or road segment that influences vehicle operation. The design speed is the maximum safe speed that a vehicle can traverse a section of the road, where the design features of the road limit the vehicle speed, rather than vehicle design characteristics. Road design speeds will often vary along a route depending on the terrain crossed.

A design vehicle is a vehicle that determines the minimum standard for a particular design element such as land width, minimum radius horizontal curve, shortest vertical curve, maximum grade, etc. The design vehicle on forest roads is typically a road-legal timber truck.

The critical vehicle is often the largest, heaviest vehicle that will traverse a given road. On forest roads, this is typically a lowbed trailer carrying harvesting or construction equipment or a large cable yarder. The road is designed such that it may be traversed by the specified vehicle. The factors that must be considered are wheel width, wheelbase, gross vehicle mass, axle loadings, and overhanging components.

A systematic design process should be carried out to ensure that:
- Due consideration is given to legislation and company policies;
- Roads are constructed that meet access needs;
- Roads are economical to construct and maintain;
- A scientific process is used to ensure that the road reaches the required destination at an acceptable gradient and alignment;
- Road costing is accurate for budgetary and planning purposes;
- Roads are constructed in a manner that minimises adverse environmental impacts, especially water quality;
- A minimum amount of area is removed from timber production;
- Horizontal and vertical geometry is coordinated to facilitate safety, visibility, traffic flow and desirable visual impact;
- Sensitive resources, such as unstable slopes, wet areas, threatened or endangered species, or indigenous forests are adequately protected;
- Roads form an integral part of the forestry landscape and compliment management by fulfilling additional functions such as cut offs between open areas and plantations, fire-breaks, buffers, etc.
Forest road design is a complex science. A correctly designed forest road optimises vehicle and harvest system productivity and ensures operator safety. A competent engineer should perform road design. If a competent engineer is not on staff, the process should be outsourced to a reputable and qualified consultant. Specialised road design software packages are available for forest road design. This software however, is only a tool to assist the designer and should only be used if the longhand method of road design is fully understood.

3.1.2 Forest Road Design Process

The forest road design process has several steps, as listed below.
- Establishment of management objectives;
- Preliminary or Paper plan of road routes and alternatives;
- Field verification and route optimisation;
- Preliminary Survey or Direct Location;
- Office Design (if needed);
- Construction Staking (if needed).

Figure 3.1-1: Road cross-section.
Geometric Design Considerations

The following factors need to be considered by the design engineer:
- Horizontal and vertical alignment;
- Road widths;
- Cut and fill slope angles;
- Soil types;
- Available construction plant;
- Intended use of the road;
- Intended season of use;
- Level of road use;
- Climate and precipitation regime;
- Permanent or temporary use;
- Environmental impacts of proposed location;
- Availability of disposal sites or borrow pits;
- Surfacing availability;
- Surface and sub-surface drainage requirements;
- Slash disposal methods;
- Presence of rock and available rock excavation methods;
- Right-of-Way clearing widths;
- Soil erosion mitigation measures;

3.1.2.1 Establishment of Management Objectives

The management objectives for the road project should be clearly identified prior to commencement of the project. The designer should have a complete knowledge of the following factors:
- Timber harvest plans for the area;
- Sensitive resources and management plans;
- Time of proposed operations;
- Equipment to be used and hauled over the road;
- All applicable legislation and company policies;
- Whether the road is permanent or temporary;
- Other access needed, including fire protection, management, and recreation.

3.1.2.2 Preliminary Route Projection

The road locator must have the following knowledge, skills, and abilities:
- Aerial photo and map interpretation;
- Forest road design and construction methods;
- Cost estimation;
- Engineering geology and soil mechanics;
- Logging and transportation planning;
- Surveying methods;
- Surface and subsurface drainage;
- Technical report writing.
The engineer will gather available data, including topographic maps, aerial photographs and timber inventory data to prepare preliminary route projections and alternatives. The forest engineer should have knowledge of the route selection process and apply these skills to determine optimum and alternative routes based on the following factors:

- Harvest systems to be used (cable yarding vs. ground skidding);
- Minimising total road length;
- Minimising construction costs;
- Minimising total excavation;
- Avoiding steep or sensitive slopes;
- Minimising stream crossings;
- Avoiding culturally sensitive areas.

The road designer should look for areas containing gentle side slopes, areas for switchback curves, good landing locations, and favourable stream crossing locations.

The first step is to identify known control points, including landings, junctions, property lines, switchback curves locations, or saddles. These locations are plotted on the topographic map. Additionally, any other pertinent information, such as property lines or sensitive areas is transferred to the topographic map. An appropriate grade is then stepped out between the control points using dividers or an engineering scale. The method of doing this is shown below.

If the beginning point is an intersection with an existing road and the end point is a landing, then it is preferable to work backwards from the landing, as the point of intersection is often not fixed. Set the dividers to a distance that will achieve the required grade between adjacent contours, using the following formula:

\[
D_d = \frac{D_c \times 100 000}{G \times X}
\]

where:
- \(D_d\) = Spacing that the divider is to be set (mm)
- \(D_c\) = Map contour interval (m)
- \(G\) = Average grade (determined above) (%)  
- \(X\) = Map scale (1:X)

![Diagram](image)

**Figure 3.1-2: Topographic map with road grade plotted.**
Grades should be flatter (draw roadline parallel to the contours) in the following instances:

- Stream crossings;
- Ridge crossings;
- Draw crossings;
- Switchback curves.

### 3.1.2.3 Field Verification and Route Optimisation

Upon completion of the preliminary route projection, the engineer takes the plan to the project area and walks the proposed routes. The first step is to verify the location of the control points. Any changes are recorded. Beginning at one control point, the proposed route is walked to the next control point. The route is then optimised, sometimes requiring multiple iterations. This process is continued for the length of the road until the engineer is satisfied that an optimum route has been determined. This will be the route that is then surveyed in the next step. Along the way, notes will be taken on soil types, presence of exposed rock, possible disposal site locations, environmentally sensitive areas, or any other areas of concern. These factors will help the engineer choose the optimum route.

The road locator will want to keep the gradeline as close to the actual road centreline as possible. This facilitates more accurate survey measurements and a more accurate design, and also makes it easier to make changes during the construction-staking portion of the process.

The process for running a grade line between control points is as follows:

Running a gradeline is done in the field by making marks at eye level on trees or bushes at approximately 20 m intervals. Fluorescent plastic flagging is preferred for this use. Gradelines can be set with an abney level or clinometer. Two people make up the marking team and use the following procedure:

- The instrument person (Person A) starts by hanging a flag at eye level at the beginning control point. The finished road grade will be at ground level here. The other person (Person B) is sent approximately 20 m ahead, along the proposed roadline (established from the map).

- Person B holds a marker (at the eye height of Person A) on a stake or tree that is likely to be marked. Person A directs Person B up or down the slope until he is on “grade”. When on grade, he hangs a flag at this elevation.

- The procedure is repeated until the start and finish points have been joined.

- If one person is doing the process by himself, he simply hangs a ribbon on grade and proceeds along the road, backsighting on the last ribbon and adjusting his location until he is on the desired grade. This location is marked and he proceeds along, following the same process.

- In areas of through cut or through fill, the road is located on centreline, and cut and fill depths are recorded and kept track of to maintain the appropriate road grade.

- In areas of full-bench construction, it is often easiest to locate the grade along the “grade-out” line. This is the point where the finished road grade intersects the hillslope and is often the outermost point of the road prism. From this point, the centreline can be located and cut or fill at centreline calculated. This information is useful when field-locating slope stakes.

Horizontal curves should be located as accurately as possible during this process. The road locator should be familiar with field-expedient methods of horizontal curve establishment and should use those techniques to ensure that curve radii do not go below the minimum specified. The easiest method is to use the deflection-angle method described in Appendix 1 of the *South African Forest Road Survey Handbook*.

Field location of switchback curves is often done by a trial-and-error method to fit the curve to the terrain. Ideally, switchback curves are located on flat areas, but they can be located on any terrain, provided that fill material will be supported or the curve is constructed with a full-bench profile. Reducing the grade before entering a switchback curve is preferred. Appropriate curve widening must be included in the road design at tight switchback curves.
3.1.2.4. Preliminary Survey or Direct Location

The preliminary survey gathers the information that will allow the road designer to properly engineer the proposed road to meet the desired management objectives. The engineer must determine the appropriate level of precision needed for each project or section of the project.

The level of precision needed is dependent upon two factors. The first factor is the risk to natural or human resources posed by the road. The greater the chance of serious environmental, physical, or economic impact, the greater the level of precision that is needed. The second factor is the physical location of the road. A road with steeper grades or more complicated alignments, or one that is located on steep or unstable terrain will require a higher level of precision.

The particular details of each level of precision and the appropriate survey methods are in the *South African Forest Road Survey Handbook*.

Direct Location

In situations where the proposed route does not traverse steep ground or sensitive locations, direct location techniques can be used. These correlate with a LEVEL 1 survey as defined in the *South African Forest Road Survey Handbook*. This is the simplest, and lowest cost survey method. It proceeds as follows:

Application: For surveys on stable terrain with low likelihood of instability. For roads on slopes generally less than 50%, where geometric road design, construction surveys, fills greater than 3 meters, or significant stream crossing structures will not be needed.

Equipment:
- Hand compass;
- Clinometer or abney level;
- Hip chain;
- Retractable tape measure.

Single readings are taken with the compass (to nearest 1°) and clinometer or abney level (to nearest 1%) and distance measured to nearest 1 metre. Stationing (accumulated horizontal distance) should be marked on plastic flagging hung along the route centreline and should be painted on trees outside the right-of-way for easy reference by the construction crew.

Another commonly used method for a LEVEL 1 survey does not record bearings and slopes, but only records accumulated distance of critical locations along the road route. Locations of culverts, junctions, substantial curves (including switchbacks), stream crossings, sensitive areas, or any other pertinent features are recorded in the field notes and referenced. Beginning and ending locations are tied and referenced and clearly marked in the field. Road stationing at critical locations should be clearly marked in the field with paint. Right-of-way clearing limits can be established, if so desired.

When the topography traversed by the road alignment contains steep slopes, unstable soils, or other sensitive resources, a higher level of survey precision should be chosen and carried out. See the *South African Forest Road Survey Handbook* for further information on this topic.

Upon completion of the field survey, the engineer proceeds to the office design process.

3.1.2.5. Office Design

Upon completion of the appropriate level of preliminary survey, the engineer performs the office design. Many engineers use computer software specifically designed for geometric design of forest roads. This should only be done if the designer has thorough knowledge of the manual road design process.
There are numerous forest road design methods, but only the most commonly used method will be discussed here.

The engineer uses his knowledge of horizontal and vertical alignment, construction procedures, and earthwork estimation to design a road that will best meet management objectives. Grades and alignments will be varied to minimise the amount of road that traverses sensitive areas such as steep slopes, streams, or indigenous forests.

The first step is to plot the plan view of the road traverse. This is often done to a 1:2000 scale. The latitudes and departures of each survey point should be calculated and plotted on grid paper. The survey route connecting the survey points should then be drawn. Include the plan view of the cross-sections, streams, draws, property lines, rocky areas, existing roads, or other improvements.

![Figure 3.1-3: Transverse Plot.](image)

The second step is to plot the profile of the survey route. This is usually plotted to a scale of 1:2000 horizontally and 1:200 vertically. The elevations of the survey points are calculated from the grade measurements in level 2 surveys or from the level survey taken during level 3 surveys. These points are then plotted on the profile. Plot any additional features that may affect the road elevation location.

![Figure 3.1-4: Profile Plot.](image)
The third step is to plot the cross-sections taken during the preliminary survey. These are plotted at a scale of 1:100 on grid paper. Be sure to include any additional information taken during the cross-section survey, including locations of creeks, wet areas, or rock outcroppings.

![Figure 3.1-5: Cross-Sections Here.](image)

The engineer then proceeds to plot horizontal and vertical curves and adjust the road templates on the cross-section until the optimum horizontal and vertical alignment that meets the specified management objectives is achieved. The detail of this process is beyond the scope of this manual, and it is assumed that the reader has basic knowledge of this process. If this is not the case, the reader is advised to seek the advice of a reputable consulting engineer.

The office design will produce plan, profile, and cross-section diagrams, in addition to slope-stake notes for later use in the field. The information required on these diagrams is listed below:

**Plan View:**
- North arrow with magnetic declination;
- P-Line traverse with stationing;
- Reference points with ties illustrated;
- Existing structures and improvements;
- Terrain features such as rocks, swamps, etc.;
- Designed L-Line with curves;
- Curve radius and other curve information;
- Existing roads;
- Disposal sites;
- Stream crossing locations;
- Title block including project name, map scale, legal location, and date of survey;
- Legal boundaries and monuments;
- Culvert locations and dimensions.
Profile View:
- Chainage and elevation equations;
- Terrain features;
- Soil depths where known;
- Grade lines with labels;
- Grade breaks where greater than 2%;
- Vertical curves where grade break is greater than 4%;
- Culvert locations and dimensions;
- Mass Haul diagram with accumulated excavation and embankment;
- Horizontal and Vertical scales;
- Existing road grade at junctions;
- Balance points and direction of material movement;
- Bridge lengths;
- K-values if used for vertical curves.

3.1.2.5.1 Road Cross-Section

Typical road cross-sections are illustrated in Figure 3.1-6. The crowned road section is the most commonly used, and is suitable for the widest variety of locations. Outsloped and insloped roads are useful for temporary roads, and only in areas where grades are less than 10%. Grades steeper than 10% require the vehicle to negotiate the centreline grade and the cross fall grade. Unsurfaced outsloped roads can be hazardous in wet conditions. Sufficient camber of between 4 and 6% should be provided to allow easy run-off of surface water, which will prevent potholes from developing. Long, heavy vehicles can often only tolerate small cross-falls on steep gradients and a compromise is often necessary between that required for drainage and that suitable for the vehicles using the road.

Figure 3.1-6: Road cross sections.
3.1.2.5.2 Horizontal Alignment

A consistent horizontal alignment, with no “surprises” is important for the safety of the road user and outweighs an absolute design speed standard. Horizontal and vertical alignment should be coordinated.

Table 3.1-1: Minimum curve radius for a given vehicle speed.

Minimum curve radius can be found below:

<table>
<thead>
<tr>
<th>Vehicle Speed (km/hr)</th>
<th>Curve Radius (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>65</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

As vehicle speed increases, it is necessary to widen the subgrade. Roads with design speeds exceeding 30 km/hr should have a minimum subgrade width of 6-7 m.

Superelevation is rarely seen on forest roads, as design speeds are usually low enough to preclude the need for it. Where superelevation is needed, use the equation given in Appendix 2.

3.1.2.5.3 Vertical Alignment

Truck speeds are influenced by gradient, generally being reduced when the gradient exceeds 3%. The design should attempt to minimise the effect of grade on travel time, while still constructing a road that meets management objectives. Suggested maximum gradients for different design speeds and horizontal radii are given in Table 3.1-2.

Table 3.1-2: Suggested Maximum Grades for given design speeds and curve radii.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flat</th>
<th>Maximum grade (%)</th>
<th>Mountainous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design speed (km/h)</td>
<td></td>
<td>Rolling</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>60</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>80</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Horizontal radius (m)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 25 m</td>
<td>10</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>26 - 40 m</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>41 - 60 m</td>
<td>11</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>&gt;60 m</td>
<td>12</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

To minimise excavation or avoid sensitive resources, grades can be up to 18% adverse and 20% favourable for short distances.

The design engineer is advised to ensure the road meets the guidelines for the following areas:

- Sight distance;
- Safe stopping distance;
- Curve widening to compensate for vehicle off-tracking.
3.1.2.5.4 Sight Distance and Safe Stopping Distance

Vehicles must have adequate stopping distance in an emergency. Stopping distance is a function of sight distance, among other factors. The time and distance taken to safely bring a moving vehicle to rest is dependent on reaction time, initial velocity and deceleration (i.e. braking efficiency, skid resistance, vehicle mass, slope). In some instances, modifications to the road alignment may be required to provide adequate sight distance. Sight distance is limited by either the vertical or horizontal alignment. Sight distances are calculated from both alignments and the shorter of the two distances is the limiting factor. The process involves calculating the sight distance on a crest vertical curve or a corner and then comparing these to the safe stopping distance required to avoid a collision. If the sight distance is less than the required stopping distance, then either the design must be altered, or other provisions must be made to prevent an accident (e.g. road signs).

Table 3.1-3: Stopping Distances on unsealed roads.

<table>
<thead>
<tr>
<th>Initial speed (km/h)</th>
<th>Stopping distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td>60</td>
<td>63</td>
</tr>
<tr>
<td>70</td>
<td>82</td>
</tr>
<tr>
<td>80</td>
<td>103</td>
</tr>
<tr>
<td>90</td>
<td>128</td>
</tr>
<tr>
<td>100</td>
<td>166</td>
</tr>
</tbody>
</table>

See Appendix 2 for equations to determine sight- and safe stopping distances.

For safety, the sight distance available needs to be greater than the stopping distance required. Stopping distance should also be:

- Doubled for two way traffic on one-lane roads;
- Increased for vehicles travelling downhill;
- Increased on smooth slippery surfaces;
- Increased in wet weather;
- Increased for laden vehicles.

If the sight distance is less than the stopping distances, then either the design needs to be changed, or other steps should be taken, for example:

- Re-design the curve, making the curve length/radius longer and/or reducing the grades;
- Widen the road to two lanes;
- Clear the edge of the road to increase sight distances;
- Use appropriate warning signs to reduce traffic speed.
3.1.2.5.5 Curve Widening

Horizontal curves need to be analysed to ensure that adequate lane width is provided to allow for vehicle off-tracking. Common vehicles that off-track include timber trucks, lowbed trailers, and large cable yarders. Off-tracking is especially critical on short tangents approaching bridges or culverts.

Vehicle off-tracking is a function of the vehicle’s geometry and a curve’s radius and deflection angle. The vehicle’s wheelbase, axle widths, steering cramp angle and vehicle overhang all affect vehicle off-tracking (Kramer, 1993).

The following table can be used as a guideline for determining curve widening needs:

**Table 3.1-4: Curve Widening Requirements.**

<table>
<thead>
<tr>
<th>Curve Radius (m)</th>
<th>Curve Widening (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-18</td>
<td>2.8</td>
</tr>
<tr>
<td>19-24</td>
<td>2.1</td>
</tr>
<tr>
<td>25-31</td>
<td>1.6</td>
</tr>
<tr>
<td>32-37</td>
<td>1.2</td>
</tr>
<tr>
<td>38-45</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Curve widening is added to the inside of the curve. Adding curve widening to the outside of the curve effectively changes the curve’s radius, requiring a re-calculation of needed curve widening.

15 m RADIUS CURVE
Requires 2.8 m of curve widening (Table 3.1-4)

*Figure 3.1-8: Curve Widening.*
3.1.2.5.6 Cut and Fill Slope Design

Mountainous terrain, common to many forested areas, may require substantial excavation to construct roads to the desired alignment. Slope failures on forest roads can generate significant environmental damage and cause travel delays. Areas prone to slope failure should be identified during reconnaissance, and avoided if possible.

Figure 3.1-9: Cut/fill slope.
General Guidelines for Cut and Fill Slopes:

The following guidelines can be used in many forest road designs. The cut slope ratio is given as the horizontal distance: vertical distance. For example, a 1:1 cutslope would raise traverse 1 m horizontally for every 1 m vertical raise. A ½ :1 cutslope would traverse ½ m horizontally for a 1 m vertical rise

**Common Material:**

Cut less than 2.5 m: ¾: 1 (Horizontal: Vertical)
Cut greater than 2.5 m: ½: 1
Fill slopes: 1½: 1

**Rock Excavation**

Cut Slopes: ½:1 to Vertical depending on structural integrity of material
Fill Slopes: 1¼: 1 to 1½: 1

These guidelines are suitable for most soils encountered in forested areas. Areas with sandy or cohesionless soils may require slopes to be constructed at a lesser angle, typically the natural angle of repose. Fills will require proper compaction techniques to be stable at the given slopes. See section 4.2.3.4.1 for compaction techniques.

In areas of significant cut or fill, banks may need to be steepened (within logical limits) to minimise total excavation or fill and to reduce the visual impact of the road location. Stabilisation measures such as retaining walls, rip-rap, buttresses, or enhanced drainage may be required. A geotechnical expert or qualified engineer should be consulted in this situation. Areas of steep cut or fill slopes may require additional maintenance. These areas should be specifically addressed in the road maintenance plan.

Cut slopes in sandy or silty soils may be difficult to stabilise and control erosion on. Revegetation or bio-engineering practices should be investigated for these situations.

3.1.2.6 Construction Surveys

Construction surveying is the process of surveying for excavation control (slope-staking), re-establishing centreline, marking culvert locations, and marking right-of-way boundaries. On sections of full-bench excavation, slope-staking is critical to ensure that the road is constructed to the proper grade and alignment, and that an adequate road width is maintained while preventing excess excavation.

*Figure 3.1-10: Slope-staking.*
When a road cut is started too high or too low on the slope, it can have adverse effects on the grade, alignment, or maintainability of the road. An example is shown here.

Figure 3.1-11: Example of road alignment with cut started incorrectly.

Figure 3.1-12: Road alignment with cut started at wrong location but centreline and grade maintained. Note resulting oversteepened cut slope

Computer-generated stake notes are often used for this process, though it can be done from staking tables (such as Calder’s Forest Road Engineering Tables) or from trial-and-error iterations. The appropriate level of precision must be applied to this process as well. The engineer must make this judgement.

Slope-staking is best completed with a 2-3-person crew. One person can be in charge of the notes and the calculations, while the other two perform the measurements and set the stakes.

The right-of-way widths can be included in the output from forest road design computer programs, generated from tables, or calculated in the field. On road projects that do not need slope staking, the equipment operator will often use the right-of-way boundary for excavation control and begin the cut or fill 3 m in from the boundary.

<table>
<thead>
<tr>
<th>Design speed (km/hr)</th>
<th>Cleared right-of-way width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>60</td>
<td>27</td>
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<tr>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>80</td>
<td>33</td>
</tr>
<tr>
<td>90</td>
<td>35</td>
</tr>
<tr>
<td>100</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 3.1-5: Recommended Right-of-way widths (P. de Wet).
The inlet and outlet of large culvert installations should be established, along with any other cut or fill staking that will ensure proper installation.

3.1.2.7 References and Further Reading


3.2 - Pavement Design

3.2.1 Introduction

The primary function of a forest road is to provide access to the plantation for timber transport, fire protection, and management access.

In order to facilitate this, access roads should:

• Be constructed with a durable surface that will provide an acceptable level of riding quality, safety and service during the intended periods of use (all-weather or dry-use roads);
• Distribute vehicle loads such that they are supported by the subgrade;
• Have sufficient inherent strength to minimise deterioration under traffic loads or the effects of moisture.

To ensure this functionality, a number of factors need to be considered during the pavement design process. These include:

• Detail design;
• Material investigation;
• Material improvement.

3.2.2 Pavement Types

There are three basic pavement types:

• Rigid (concrete);
• Flexible (bituminous chip seal);
• Unsealed.

Flexible and unsealed pavements deform under loading, with the load ideally being distributed through the pavement and into the subgrade material. The design of rigid and flexible pavements is a complex science and should only be undertaken by a competent engineer. The remainder of this section will concentrate on unsealed roads with minimal reference to sealed roads.

![Diagram](image)

**Figure 3.2-1: The effect of pavement on transferring vehicle load to the subgrade.**
3.2.3 Recommended Approach to Pavement Design

Pavement design will only be effective if a systematic approach is followed. The approach followed for new roads and regravelling or rehabilitation of existing roads is essentially the same, since regravelling provides an ideal opportunity to review the performance of the road to make improvements to the structure where required. Pavement design entails the following components:

- Detail design;
- Materials investigation;
- Material improvement (stabilisation).

3.2.3.1 Detail Design

A systematic approach that includes the following factors must be followed when designing forest road pavement structure:

- Design life of road (years);
- Design and overload vehicles (including axle loads and traffic frequencies);
- Subgrade and pavement material properties;
- Environmental and precipitation factors.

3.2.3.1.1 Subgrade Assessment

The subgrade must be analysed to determine the susceptibility to strength changes resulting from environmental effects such as precipitation and temperature. Weak subgrades will require thicker pavement layers. Subgrade strength is dependent on its physical and mineralogical characteristics and the density and moisture content both during compaction and while in service.

Subgrade strength is best determined with a Dynamic Cone Penetrometer (DCP). The test should be carried out at similar density and moisture conditions to those that are likely to occur in the subgrade during service. The pavement should be designed to accommodate 90% of conditions with restrictions on traffic movements during very wet conditions. This strategy prevents “over-designing” the pavement structure.

A testing pattern should be developed that ensures representative sampling of the subgrade conditions. On variable materials, a test should be carried out at least every 50 m in a staggered pattern (left outer wheel track, centreline and right outer wheel track). On homogenous materials, testing can be reduced to 100 m intervals.

A DCP penetration of more than about 32 mm per blow indicates that the CBR (California Bearing Ratio, see Appendix 6) is 5% or less, in which case subgrade reinforcement should be considered.

Subgrade reinforcement should be considered when the subgrade exhibits any of the following characteristics:

- CBR of 5% or less;
- High clay content. Check exposed soil properties by using the Uniform Soil Classification system. See Appendix 6;
- High water table, as indicated by standing water or plant indicators;
- History of poor subgrade durability in the area.

The methods of subgrade reinforcement typically found on forest roads include:

- Thicker pavement layer;
- Larger pavement material (>37.5 mm, often up to 150 mm for the base course);
- Geosynthetics (Geotextile fabric or geogrids). See Section 3.2.5.2 for geosynthetic information.
3.2.3.1.2 Pavement Thickness

The pavement structure of a forest road must be of sufficient depth to protect the subgrade and provide a trafficable surface. Determining the appropriate depth can be a complicated process. As this is a handbook for forest roads, the process will be simplified and some useful guidelines will be found in this section.

No defined failure criterion for unsealed roads has been standardised in South Africa, although a rut depth of 75 mm from a single pass of a heavy vehicle can be used as a rule of thumb. This depth may be considered excessive for forest roads where the ruts may trap water for lengthy periods. Although the rut may be removed during routine grader maintenance, a significant proportion of the rut may be in the form of subgrade deformation. This deformation could result in the loss of wearing course material into the subgrade.

Gravel loss that occurs with time and under traffic results in a dynamic situation, and the optimum wearing course thickness is effectively valid for only a limited period of time (i.e. 5-10 years). Based on this consideration, the following simple structural design procedure can be used to determine the design thickness of gravel wearing courses:

Use the following equation to determine pavement thickness:

\[ T = t + \left( 1 + \frac{C_t}{100} \right) \times (GL_p \times L_d) \]

Where:
- \( T \) = design thickness in mm
- \( t \) = minimum thickness required for subgrade protection (mm) Usually 150 mm
- \( C_t \) = traffic induced compaction (%) (See Section 3.2.3.1.3 for equation)
- \( GL_p \) = predicted annual gravel loss (mm) (See Appendix 2 for equation)
- \( L_d \) = design life of road or regravelling frequency (years)

Thickness should be rounded up to the nearest 50 mm.

Example:
- \( T = 150 \) mm
- \( C_t = 10\% \)
- \( GL_p = 10 \) mm/yr
- \( L_d = 10 \) years

\[ T = 150mm + \left( 1 + \frac{10\%}{100} \right) \times (10mm/yr \times 10\text{ yrs}) \]

\[ T = 260mm \]

\[ T = 300mm \]

On average, 250 mm is a suitable minimum pavement depth for all weather roads, used by highway trucks when geosynthetics are not used.

If the subgrade is suitably strong, geosynthetic underlayment can reduce the required pavement depth up to 30%.

3.2.3.1.3 Traffic-Induced Compaction (\( C_t \))

A wearing course that is not compacted to at least 95% Modified AASHTO specifications (e.g. as happens when compacted dry) can lose up to 30% of the constructed thickness within a short period due to traffic compaction. Surfacing materials must not be compacted dry, as loss of pavement depth will occur rapidly and the pavement structure will not be adequately strong to protect the subgrade.

Table 3.2-1: Estimates of Potential Traffic Compaction.

<table>
<thead>
<tr>
<th>Construction compaction</th>
<th>Construction moisture content</th>
<th>Potential loss of gravel thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 grid roller passes</td>
<td>About OMC</td>
<td>10%</td>
</tr>
<tr>
<td>3 grid roller passes</td>
<td>75% of OMC</td>
<td>20%</td>
</tr>
<tr>
<td>3 PTR(^1) passes</td>
<td>About OMC</td>
<td>5%</td>
</tr>
</tbody>
</table>

\(^1\) Pneumatic tyre roller
The compaction that occurs during normal construction should also not be neglected and between 30 and 45% more bulk material is required to allow for this and still produce the required thickness.

Example: Calculations indicate a need for $30000 \text{ m}^3$ of surfacing material for proper coverage on a road project. The actual amount of material required is between $39\,000 \text{ m}^3$ and $43\,500 \text{ m}^3$. This amount varies depending on the material selected. Local knowledge should be consulted to determine the actual value.

### 3.2.4 Materials Investigation

The performance of unsealed roads is highly dependent on the material properties, as well as on traffic and environmental conditions.

The most important material parameters for assessment are:

- Particle size distribution (gradation);
- Oversize material percentage;
- Plasticity;
- Strength;
- Aggregate hardness.

A laboratory test of surfacing material will provide the required information. Sampling the material as it is discharged from the crusher is the best method. Use two or three 20 L buckets of material for each test. If production will continue over a long period of time, it is recommended to sample and test the material at least once a week.

Please note: All testing methods described below can be found in Appendix 6.

#### 3.2.4.1 Particle Size Distribution

Particle size distribution is determined from a grading analysis (TMH1 Method A1), recalculated on a 37.5 mm maximum size.

A continuously graded material is preferable since this will result in higher densities and therefore higher strengths. However, many materials commonly used in unsealed roads have higher proportions of certain fractions, which influence the performance of those roads. Materials with a high percentage of fines (i.e. smaller than 0.425 mm in diameter) are more susceptible to dust in dry weather and to slipperiness in wet weather when used on unsealed roads.

#### 3.2.4.2 Oversize Material

Oversize material (>40 mm) is a common sight on many forest roads. This has significant implications during construction (poor compaction around stones), maintenance (difficult to blade) and use (poor riding quality and higher vehicle operating costs). Maximum size is usually specified in the project description. It is important, when collecting samples from roads or gravel sources, to include all material in the bag (define the size of the sample) and not to discard large rocks, as this will give an incorrect indication of the presence of oversize.

When surfacing is placed in two distinct courses (base course and surface course), oversize material is acceptable in the base course, as it can add significant strength to the pavement structure. The maximum size allowable in each course should be specified in the project description.
3.2.4.3 Plasticity

The plasticity of a material is determined from the Atterberg Limit and Bar Linear Shrinkage Tests (TMH1 Methods A2 and A3). Materials with low plasticity do not bind in dry conditions, resulting in corrugations and ravelling, while materials with high plasticity are prone to slipperiness in wet weather and dustiness when dry. The forester should analyse the weighted bar linear shrinkage (shrinkage product), rather than the plastic limit when analysing test results.

3.2.4.4 Strength

The strength of a material, determined by the California Bearing Ratio test (TMH1 Method A8) at a standard density and moisture content (TMH1 Method A7) is used to determine subgrade or pavement strength.

3.2.4.5 Hardness

Aggregate hardness provides a good indication of how a material will perform over time. Very hard material will not break down when compacted resulting in excessive oversize material that will eventually be exposed after vehicle use. Very soft material will break down under traffic, leaving a thick layer of loose material on the road surface and often unacceptably high dust levels. Hardness is measured with an aggregate impact test (e.g. Treton Impact Value, TMH1 Method B7).

3.2.4.6 Analysis of Results

Laboratory test results should be analysed in terms of specifications for unsealed roads. The most appropriate specification, based on the South African Department of Transport’s TRH20 and subsequent research is given in Table 3.2-2.

Table 3.2-2: Material specifications for unsealed roads.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum size (mm)</td>
<td>37.5</td>
</tr>
<tr>
<td>Oversize index (%)</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Grading coefficient(^1)</td>
<td>16 - 34</td>
</tr>
<tr>
<td>Shrinkage product(^2)</td>
<td>100 - 365(^3)</td>
</tr>
<tr>
<td>Strength(^4) (%)</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Hardness – TIV(^5)</td>
<td>20 - 65</td>
</tr>
</tbody>
</table>

\(^1\) \([(\%\text{passing 26} - \%\text{passing 2}) \times \%\text{passing 4.75}] / 100\)

\(^2\) Bar linear shrinkage \(\times\) %passing 0.425

\(^3\) Max 240 preferable to reduce dust levels

\(^4\) Soaked CBR at 95% Mod AASHTO

\(^5\) Treton Impact Value
• The maximum size, oversize index (quantity of oversize material permitted) and grading coefficient are determined from the grading analysis after correction for materials retained on the 37.5 mm sieve.

• The shrinkage product is calculated by multiplying the bar linear shrinkage and the corrected percentage passing the 0.425 mm sieve.

• Strength is the CBR of a specimen compacted to 95% Mod AASHTO.

• Hardness is the Treton Impact Value.

3.2.4.6.1 First Level Interpretation

First level interpretation entails assessing each parameter to see if it meets the required specification, and if not, determining what the implications are. If these implications cannot be addressed by modification, revised construction procedures or revised maintenance techniques and programmes, then the material should be rejected. Accepting the material could cause significant and costly problems associated with performance and maintenance.

3.2.4.6.2 Plasticity and Grading

A plot of the shrinkage product against the grading coefficient provides a good indication of how the road will perform under traffic (Figure 3.2-2).

![Figure 3.2-2: Plot of shrinkage product and grading coefficient.](image)

**Zone A** materials generally perform satisfactorily but are finely graded and particularly prone to erosion by water. They should not be used on steep grades, sections with steep cross-falls and super-elevations or areas with high rainfall. Most roads constructed from these materials perform satisfactorily but may require periodic labour-intensive maintenance over short lengths and have high gravel loss due to water erosion.

**Zone B** materials generally lack cohesion and are highly susceptible to the formation of loose material (ravelling) and corrugations. Regular maintenance is necessary if these materials are used and the roughness is to be restricted to reasonable levels.

**Zone C** materials are generally fine, gap-graded gravels lacking adequate cohesion, resulting in ravelling and the production of loose material.

**Zone D** materials tend to be slippery when wet and may be very dusty after prolonged dry periods.

**Zone E** materials perform well in general, provided the oversize material is restricted to the recommended limits.
3.2.4.6.3 Strength

In addition to the above, materials with a CBR at 95% Mod AASHTO of less than 15% are likely to become impassable to traffic during and after heavy rainfall.

3.2.4.6.4 Hardness

Materials with a Treton Impact Value of less than 20 are typically very hard and will not break down under normal compaction, resulting in a stony surface. Treton Impact Values higher than 65 indicate that the material is very soft and will continue to break down under traffic abrasion leading to the accumulation of loose material on the road surface and high dust levels.

First level analysis is summarised in Figure 3.2-4.

![Flowchart for First level analysis of laboratory test results](image-url)

**Figure 3.2-4: First level analysis of laboratory test results.**
3.2.4.7 Reporting of Testing Results

The following information should be captured during material testing, analysis and interpretation of the results:

- Project detail;
- Laboratory job number;
- Summary of results;
- Comparison with specification;
- Plot of shrinkage product and grading coefficient;
- Implications if material does not meet the specification;
- Recommendation for use.

Completed reports should be kept in an appropriate filing system, easily accessible for future projects, if required.

If the material meets the specification, it can be used as is. If not, maintenance/management programs can be developed to overcome the problems (e.g. more frequent blading or dragging to reduce the effect of corrugations, or temporary road closure to limit the effect of slipperiness). Alternatively, the material can be rejected or improved by mechanical or chemical means.

3.2.5 Mechanical Improvement

Particle size distribution and plasticity have the most influence on the general performance of an unsealed road. Oversize material in the surface course (i.e. >37.5 mm) has a significant influence on riding quality and on the maintainability of the road.

Unless other more suitable sources are readily available, large percentages of oversize material do not automatically disqualify the material as surfacing. To ensure optimal performance, the oversize material must be removed or broken down. Savings in maintenance costs, better overall performance of the road and reduced vehicle operating costs can offset the additional costs incurred in the removal of oversize material.

Removal of oversize can be achieved by:

- Stone removal at source (oversize index >10%);
- Stone removal on the road (oversize index <10%);
- Grid rolling (oversize index >10%, Treton Impact Value > 20);
- Crushing at source (oversize index >10%);
- Crushing on the road (oversize index >10%).

These methods are discussed in more detail in Section 4.5 (Surfacing Operations). Modification of the particle size distribution is also achieved with the last three options, while blending of the material can be used to alter both the particle size distribution and the plasticity.

3.2.5.1 Material Blending

If material with the characteristics prescribed in the previous section cannot be located, the blending of two or more materials should be considered. Blending involves the mixing of materials that have different properties (typically particle size distribution and/or plasticity) to form a material having improved characteristics given the limitations of the source materials. Improvements in strength, improved ride quality, and reduced dust levels can be achieved by proper blending.
A methodology, using a ternary diagram (Appendix 4), has been developed to determine the optimal particle size distribution. The Atterberg Limit tests are then used to check plasticity. The ternary diagram has a shaded area that indicates the desirable range for optimal performance. The blend is altered until the required grading and plasticity characteristics are met. Input parameters for the ternary diagram are the percentages silt and clay (<0.075 mm), sand (0.075 - 2.0 mm) and gravel (2.0 mm - 37.5 mm) of the material sources that will be used.

Figure 3.2-5: Flowchart for material blending.

3.2.5.2 Geosynthetics

Geosynthetics are used in forest road engineering applications for soil stabilisation, where the basic functions are reinforcement, separation, filtration, and drainage. Geosynthetic materials were originally used during construction of retaining walls and fill structures, and were soon chosen for subgrade reinforcement during surfacing operations. The most commonly used geosynthetics are geotextiles and geogrids.

Geosynthetics are rated by their manufacturers for durability, strength, and hydraulic factors. Durability tests refer to how the material will tolerate handling during the construction process. Strength tests define the grab, tear, puncture, and burst strengths, among others. Hydraulic tests define permittivity and porosity. This information is available from the manufacturer and should be consulted when determining the appropriate geosynthetic for use.
3.2.5.2.1 Geotextile fabric

A geotextile fabric ("geotextile") is a synthetic permeable textile material used with soil, rock, or any other geotechnical engineering related material. Geotextiles used during forest road surfacing separate the subgrade from the pavement structure. This separation can increase the load capacity of the pavement structure, reduce rutting, and extend the life of the road.

Geotextiles provide three basic functions to forest roads:
- Separation;
- Filtration;
- Reinforcement.

Separation is illustrated in Figures 3.2-6 and 3.2-7, and involves the separation of two dissimilar layers of material, most commonly native material composing the subgrade and crushed aggregate composing the pavement structure. This separation prevents the pavement materials from migrating into the subgrade.

![Figure 3.2-6: Geotextile fabric absorbing shear and tensile stresses from vehicle loading.](image)

![Figure 3.2-7: Geotextile material provides separation, which preserves the integrity and extends the life of the road surface layer.](image)
Insert 3.2-8: Geotextile protecting subgrade during rutting.

Filtration involves the transmission of water while retaining the soil particles adjacent to the geotextile. This action reduces sediment transport from the subgrade through water action.

Reinforcement involves the geotextile handling a sustained tensile load. Soil and aggregate materials are very strong during compression, but not in tension. The geotextile supports the tensile forces that would otherwise have an adverse effect on the subgrade or pavement structure.

3.2.5.2.2 Geogrids

Geogrids are a synthetic woven underlayment with relatively large openings forming a grid shape. Geogrids are constructed in two configurations, uniaxial and biaxial. Uniaxial geogrids endure stress in one direction, while biaxial can endure stress in two directions. Biaxial geogrids are most commonly used on forest roads.

Weak subgrades (CBR <3%) can be reinforced by installing geogrid under the pavement structure. The geogrid absorbs the tensile stresses that would otherwise be applied to the subgrade. For very weak soils (CBR<1%), a combination of geotextile fabric and geogrid should be used.

Figure 3.2-9: Close-up of geogrid material.
3.2.6 Chemical Improvement - Fines Retention

It is conservatively estimated that approximately 120 000 tonnes of dust (material <0.075 mm) are generated on South Africa’s unsealed forest road network each year (approximately 3.1 million tonnes are generated on South Africa’s total unsealed road network). The consequences of this are significant in terms of:

- Gravel loss (fines bind the aggregate together, preventing ravelling);
- Sedimentation of rivers and streams with subsequent impacts on aquatic organisms and water quality;
- Safety hazards for all road users;
- Health risks (sickness associated with respiratory systems);
- Discomfort for the road user;
- Air pollution;
- Vehicle operating costs.

Improved fines retention can be achieved by better selection of materials, mechanical stabilisation using two or more different materials to achieve a better particle size distribution and to increase or reduce the plasticity, or by applying a chemical dust palliative.

Dust palliatives have been divided into the following eight categories:

- Water and wetting agents;
- Hygroscopic materials;
- Natural polymers;
- Modified waxes;
- Petroleum resins;
- Synthetic polymer emulsions;
- Tars and bitumens;
- Waste oils and other products.

Water and wetting agents are only suitable for very short-term applications. Waste oils may not be used in South Africa for environmental reasons. Other products are mostly industrial wastes. These products are often regionally specific and only available in small quantities from processing plants and may have unacceptable environmental impacts. Guidance on their use should be sought from the Departments of Environment Affairs and Water Affairs and Forestry.

Products in the other six categories can effectively reduce the rate of fines loss provided that they are used under appropriate conditions and applied and maintained correctly. Varying degrees of research have been carried out and the quality and comprehensiveness of guideline documentation differs from product to product.

When considering chemical fines retention, the following issues need to be considered before selecting a particular product:

- Can the supplier provide a comprehensive guideline document covering materials, climatic considerations, construction and application, maintenance and rejuvenation, based on the monitoring of scientific experiments comparing the performance of treated and untreated roads? Resistance to traffic abrasion, water erosion, ultra violet degradation and chemical breakdown should all be addressed in the document.
- Will the road authority have sufficient information to be able to reliably predict the improved performance of a treated road compared with that of an untreated road in to evaluate the cost-effectiveness of the treatment?
- Does an analysis for the specific road indicate that application of a product is justified?
- Are the environmental impacts of the product acceptable?
• Is the product available in sufficient quantities at reasonable prices?
• Are the health and safety impacts of the product acceptable?

If insufficient information is available, the decision to use the product should only be made after satisfactory performance in terms of dust reduction and environmental impacts have been proven in a field experiment.

All listed methods of chemical improvement are described in detail in Appendix 4.

3.2.7 References and Further Reading


Section 3.3 - Drainage Design

3.3.1 Introduction

Properly designed forest road drainage maintains natural drainage patterns, minimises erosion, allows fish passage where needed, and maintains the stability of cut and fill slopes.

The four critical aspects of forest road drainage are:

- Water that falls onto the road surface must be quickly removed by the use of a crowned, insloped, or out-sloped road camber;
- Water collected alongside the road must be drained away from the road as soon as possible with side drains, cross drains, and mitre drains;
- Water flows approaching a road from the upslope area must be intercepted from flowing toward the road by catch drains and diverted into natural watercourses or taken across the road by suitable culverts;
- Stream crossing structures must be appropriately sized and engineered to maintain stability, protect wildlife habitat, and provide for peak flow and debris passage.

Drainage on unsealed roads is as important as drainage on more expensive sealed roads. Materials used in unsealed roads are often of lower quality than those used in sealed roads and are more susceptible to water damage. The absence of a seal and the combination of traffic and water can rapidly erode the pavement structure.

Unsealed roads are a potential source of erosion and sediment production as they interrupt the natural drainage pattern, concentrate flows and provide a source of sediment entering watercourses. The resulting reduction in water quality can adversely affect plant, animal and human life.

Drainage from unsealed roads can be classified into surface and subsurface drainage.

3.3.2 Surface Drainage

Surface drainage comprises those elements that collect and remove water from the surface of the road. It includes drainage systems designed to intercept, collect and dispose of surface water flowing towards and onto the road surface from adjacent areas.

3.3.2.1 Side Drains

Side drains run parallel to the road and drain water from the road surface and adjoining slopes. Side drains are required in cut sections, except where an out-sloped road prism is used. Side drains are normally unlined unless the potential of scouring exists. Side drains on the low side of the road run into mitre drains or turnouts. Those on the high side of the road usually run into cross drain culverts. In sidehill construction, side drains on one side of a road may be eliminated by either in-sloping (unstable slopes) or out-sloping (gentle road grades and stable slopes). These road prisms are shown in Figure 3.1-6. In-sloping or out-sloping should only be used in appropriate situations and must conform to safety requirements on curves and grades. In-sloping must be used in conjunction with correctly spaced cross-drains to prevent accumulation of fast-moving water.

It is preferable to transfer water flowing in the side drains to the lower side of the road (where it can be discharged) by the frequent use of cross-drains or culverts. This prevents scouring and overflow onto the road surface which generates sediment and washes away valuable surfacing material.
Side drains are generally flat bottomed, but can be V-shaped in drier areas or areas that experience low-intensity rainfall where scouring is not a problem. They should be vegetated with grass where possible and maintained by mowing. Scraping drains tends to promote sedimentation and contamination of the road surface.

The geometry of the drains should be compatible with the maintenance techniques used, and should be easily maintained by a motor grader. The inverts of the ditch should be rounded and side slopes should not be steeper than 1.5:1 to provide reasonable safety for vehicles that run off the road.

The longitudinal slope of the drain should be adequate to prevent silt build-up, but below the value at which scouring and erosion will occur. The recommended minimum grade is 0.5%. If steep side drains are unavoidable, measures should be taken to prevent erosion. These include check-walls or drop-walls used at intervals to step the drains and/or lining the side drain with rock to reduce water velocity and minimise erosion or down-cutting.

During the last 50m before a road crosses a significant watercourse, the drainage from the road should be diverted into the surrounding vegetation. Where necessary, a culvert should be installed to pass drainage from the topside of the road to the lower side and then diverted into the surrounding vegetation.

*Figure 3.3-1: Side drain and culvert prior to stream crossing (ODF Manual).*

This will ensure that sediment carried by the water is not discharged directly into a watercourse.

### 3.3.2.2 Mitre Drains

Mitre drains channel water away from side drains into the surrounding area. They should be constructed as often as the topography allows, permitting water to flow into a natural drainage course or over stable areas of the forest floor. The width of the mitre drain should be 1-1.5 m. This width allows maintenance by hand or with a TLB. In high flow areas, it may be necessary to provide obstructions (e.g. vegetation, rocks, logs, tyres) downstream of the discharge point to disperse energy and reduce the erosive power of the discharged water.
3.3.2.3 Cross Drains

The spacing of cross drains or culverts to transfer water from the high side of the road to the low side is a function of the slope of the side drain, soil erodibility and quantity of water flow. Figure 3.3-3 illustrates a design layout of a cross drain that ensures self-drainage with a slope across the road.

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Figure 3.3-2: Mitre drains.

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3.3.2.3 Cross Drains

The spacing of cross drains or culverts to transfer water from the high side of the road to the low side is a function of the slope of the side drain, soil erodibility and quantity of water flow. Figure 3.3-3 illustrates a design layout of a cross drain that ensures self-drainage with a slope across the road.

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Left – Figure 3.3-3: Cross drain culvert installation. Right – Figure 3.3-4: Cross drain culvert installations.

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Figure 3.3-5: Cross-drain culvert terminology.
Culverts can be constructed of the following materials:
- Galvanized corrugated metal;
- Aluminium;
- High Density Polyethylene Plastic (HDPE);
- Concrete.

Culvert locations can include, but are not limited to the following:
- At the top of a steep grade to prevent accelerated erosion by dispersing water before it has the opportunity to increase velocity;
- In areas of seepage;
- At low points in the road profile;
- Where bedrock in the side drain approaches the road surface;
- Immediately prior to areas of cutslope instability;
- At any other location determined during construction or maintenance operations to need drainage.

Culvert Spacing is a function of the following factors:
- Slope;
- Rainfall patterns;
- Soil erosion potential;
- Maintenance program;
- Upstream drainage area;
- Culvert size.

Because of the wide variety of variables, spacing tables should not be used exclusively. The engineer should use local knowledge and engineering judgment in determining the appropriate culvert location and spacing.

A minimum culvert size of 450mm is recommended. This size culvert is easy to clean with a spade and carries enough flow to do a sufficient job of self-scouring.

<table>
<thead>
<tr>
<th>Road grade (%)</th>
<th>Drain spacing (m)</th>
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<tr>
<td></td>
<td>Moderate erodibility</td>
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<tr>
<td>1 - 5</td>
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<td>11 - 15</td>
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<tr>
<td>16 - 20</td>
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3.3.2.4 Raised Berms

Raised berms are normally constructed on the fill slope side of the road and are used to control the water flow running off the road by directing it to a mitre drain. This prevents water from spilling uncontrollably over the fill slope, which can cause scouring and erosion. Berms should be built from compacted material and then vegetated.
3.3.2.5 Water Bars

Water bars are commonly used on temporary roads and provide an effective, inexpensive method of diverting water from the road surface. Waterbars divert surface runoff at regular intervals and remove water from the roadway and from side drains. The disadvantages of water bars include increased travel time, potential erosion and disturbance of the running surface, and the need for vigilant maintenance.

To promote effective drainage from the roadway with minimal erosion, water bars should be excavated into the subgrade and not just into the soft surface layer. Water bars should be positioned at a 30° angle to the road centreline, and the side draining and berm should be carefully extended to the cut bank in order to eliminate side drain water bypass. Correct maintenance is needed to ensure that the berm is not compressed by traffic.

An alternative method is to construct waterbars from a flexible, yet durable material, such as rubber conveyor belting and bury them in the road. They are easily driven over with minimum disturbance to the vehicle, yet effectively channel water from the road surface. Care must be taken when grading the road to prevent disturbance to the water bar.

**Figure 3.3-6: Water bar construction.**

**Figure 3.3-7: (above) and 3.3-8: (above rt.) – Flexible Rubber Water bar.**
3.3.2.6 Catch Drains

Catch drains are used to drain water flowing towards the road from the surrounding area. They are only installed at the top of deep cuts and if omitted from the drainage design, severe erosion can occur at cut slopes.

When designing catch drains, care should be taken to prevent erosion and scour. Typical shapes and dimensions are the same as those used for side drains. They should be as close as possible to the top of a cutting and channelled into culverts or natural watercourses wherever possible. If the natural soil is prone to scour, catch drains can be lined with imported material or gravel. The longitudinal slope of the catch drain should be greater than 1% to prevent ponding of water above cut slopes, which could lead to slope failure, but less than 5% to prevent scouring. Drains should be vegetated (preferably grass) and maintained accordingly.

3.3.3 Subsurface Drainage

Subsurface drainage protects the road against water that has entered through the road surface, and against subsurface water that enters from surrounding areas or the water table. Wherever possible, surface drainage should be improved to minimise the need for subsurface drains. This can include raising the road embankment over flat areas and ensuring that side drains are at least 600 mm below the wearing surface.

Subsurface drains may be constructed using pipe or rubble drains set into the subgrade or by using a sub base layer of material with free draining properties such as course gravel or sand. Subsurface drainage is expensive and usually only justified in localised areas where no other method of preventing water ingress is possible. Typical examples include:

- Roads that traverse swampy land prone to collection of stagnant water;
- Locations where subgrade soil is poor and seepage from the cut slope is likely to be severe;
- Excavation at the top of a hill that cuts into an impervious stratum immediately below the water table;
- A substitute for side drains on the inside of the road when road width is severely limited, such as areas of very heavy cut.

The precise layout of a subsurface drain depends on local conditions, but should be based on leading the subsurface water away by the shortest route. Typical depth of the subsurface drain from the top of the pipe is 300 mm below subgrade level. If a geotextile is used in the drain, soil compatibility tests should be carried out prior to installation.

![Figure 3.3-9: Subsurface drain adjacent to cut slope.](image)
3.3.4 Stream Crossing Design Elements

Stream crossing structures can constitute a large percentage of the costs associated with a road construction project. Stream crossings should be avoided or minimised in number. When required, structures must be correctly designed and constructed to minimise environmental impact, ensure safe vehicle passage and provide a long working life.

Engineering guidance should be sought for the location, design and construction of stream crossing structures. Bridges should only be designed by experienced registered professional engineers.

A number of factors will need to be considered when determining the type of crossing structure required. These include:

- Intended traffic and vehicle type;
- Environmental and regulatory requirements;
- Size of the stream;
- Topography and catchment characteristics;
- Streambed and bank material and erosion characteristics;
- Peak flows and design flow requirements;
- Geology;
- Water quality requirements.

The common types of stream crossing structures applicable to southern African forest plantations include:

- Culverts;
- Drifts;
- Bridges.

3.3.4.1 Culverts

Culverts are the most common stream crossing structures used on forest roads in southern Africa. Culverts are easily installed, relatively inexpensive and if designed, constructed, and maintained correctly, will last for many years. Culverts are best suited for situations where low to medium water volume flows are experienced, and where there is low to medium debris potential. Stream crossings, where culverts are used will typically not exceed 6 m in width.

3.3.4.1.1 Types of Culverts

- **Pipe culverts:** The most common types of pipe culverts used on forest roads are constructed from concrete, corrugated galvanized steel or aluminium, or High Density Polyethylene plastic (HDPE). Concrete pipes have good hydraulic characteristics, such as a low Manning’s N-value, resulting in low resistance to flow and are ideally suited where a high load bearing capacity is required. They are easily reused and last a long time without corroding or losing structural strength. Concrete pipes are heavy and difficult to handle and place in position. Corrugated galvanized metal or plastic culverts are made from pipe sections that are banded together to give a snug, watertight fit. Their lightweight construction allows assembly at the work site and requires only a small team for installation. Transportation and handling costs are lower than that for concrete pipes. Corrugated pipes typically have a lower discharge capacity (diameter for diameter) than smoothbore concrete or HDPE pipes. Most plastic pipes are constructed with a double-wall design and have a smooth bore. This design results in an increased flow capacity when compared to concrete or metal pipes of the same size.
Box culverts: The most common box culverts are U-shaped or inverted U-shaped. The main advantage of a box culvert is the ability to handle large flows where headroom is limited. For an equivalent waterway area, box culverts can accommodate significantly larger flows than corrugated alternatives. In areas of difficult excavation, or where stream banks are environmentally sensitive, box culverts may require less excavation and backfilling. Box culverts are designed to withstand heavy wheel loads and thus typically only require standard thickness wearing course layers to be placed. Installation is relatively simple.

Battery culverts: Battery culverts are well suited to situations requiring vehicle access during periods of normal flow, with occasional blockage during periods of high flow. The finished design height should be as low as possible to allow continued water flow and allow debris passage during high flows.
3.3.4.1.2 Culvert Design

There are three core methods used to estimate culvert size:

- Inspection of the existing culvert or other culverts in the same catchment and if deemed appropriate, using their size as a design template;
- Use of an empirical formula to directly determine the required size of the culvert opening;
- Use of a formula to determine the quantity of water reaching the culvert, then a second formula or graph to determine the culvert size required to carry that quantity of water.

When determining size by inspection, existing culverts must have been in place for a reasonable period of time (at least 8-10 years) and should not have required constant maintenance or have been damaged by overtopping or erosive action. The engineer must account for land management actions, such as clear felling on peak flows within the catchment.

Stream crossing culverts should be designed to pass a 50-year peak flow. This design standard will allow ample water and debris passage during most storm events.

Consideration should be given to flood events where the culvert will be overtopped. The fill should be reinforced with rip-rap and geotextile fabric. Additionally, a depression or "overflow chute" can be constructed into the fill.

Peak flow calculations are a function of the catchment size, the rainfall intensity, and the nature of the ground cover of the area. Various methods and formulae can be used to determine the optimum culvert size. However, most of these require good quality input data, which may or may not be available. Other simpler methods can also be used to give a good indication of the culvert size, which are adequate for unsealed forest roads (discussed in Section 3.3.5.1).

Many of the formulae that have been developed are often country- and even region-specific and should be used with care in other catchments. Runoff coefficients are input which may need to be derived from representative sites incorporating soil type, vegetation cover and slope. Consideration must also be given to the constantly changing nature of forested catchments – runoff could be significantly different before and after clearfelling operations and slash burning.

Culverts should be installed at a grade that prevents siltation or excessive velocities and scouring. Normally, the grade line of the culvert should coincide with the streambed, however, in
certain circumstances it may be desirable to deviate from it to be in the range of 1-3%. Examples are:

- Where sediment build-up is expected to occur, the culvert invert may be set several millimetres higher than the stream bed, but at the same slope. When this type of installation is performed, it is critical to ensure that the material below the culvert is impervious, preventing "through-wash" under the culvert.
- When the culvert is installed in a steep stream channel, it is not always necessary to place the culvert on the same steep grade. The culvert can be put on a critical slope and then a spillway provided at the outlet to prevent scouring. This keeps the culvert shorter and under shallower cover, and can help to reduce the fill height.

3.3.4.1.3 Culvert Installation (Also see Section 4.2.3.5)

Proper installation will ensure culvert function and longevity. Backfill material must be properly compacted to ensure proper load transfer from the culvert to the surrounding fill and to minimise settling and deformation under load.

When placed in a natural waterway, culverts should be placed along the general grade of the stream, unless otherwise designed. If the foundation is not firm enough to support both the culvert and the design load, then a trench should be excavated to at least 1/3 the diameter of the pipe and backfilled with compacted crushed stone to form a firm base. The fill on top of the culvert should meet the road material specification and should be thick enough (> ½ pipe diameter) to ensure that the vehicle load is distributed and shock loadings produced by passing traffic are minimised.

![Figure 3.3-13: Culvert Installation and Backfill Compaction.](image)

It should be noted that most culvert suppliers provide a printed installation procedure with their pipes. This procedure should be closely followed. All pipes should carry an SABS approval.

Culvert inlets should have a smooth entry without abrupt changes in direction or elevation. When unavoidable, it should be adequately protected by concrete, gabion mattresses or riprap. Geotextile material should be placed under gabions or rip-rap with a cut-off wall to prevent undermining. In areas of highly erodible soils or unstable streambanks, energy dissipation can be achieved with rock placements, gabions, logs, or other structures placed downstream of the culvert outlet.

Stream flow must be diverted during installation by the use of pumps, pipes, or other channels. Diverting the flow allows easier construction work and minimises sedimentation from construction operations. Upon completion, any other stream channels that were used to divert flow must be blocked and rehabilitated.
3.3.4.2 Drifts (Fords)

A drift is a dip in the road constructed to facilitate crossing a stream. A drift should be constructed in a manner that allows water, debris, and fish passage, while minimising erosion or the need for maintenance. Drifts are suitable in areas where the following conditions are met:

- Low or intermittent traffic levels;
- Low stream banks, gentle approaches not requiring substantial excavation;
- Remote areas where maintenance equipment is not readily available;
- Area may be subject to debris torrents;
- Vehicle passage not required during high flow periods.

Drifts should be designed and constructed to cause minimum interference to the natural stream flow and to minimise bank erosion. The drift should be built at right angles to the direction of water flow and level to the existing stream bottom. If the running surface is elevated, a weir effect can be created, increasing downstream flow velocity and causing erosion of the stream bottom or impeding fish passage.

The drift should have a clean, firm running surface. If the natural stream bed is soft or erosive, consider replacing it with crushed stone, river-run stone, or concrete to provide a firm base. Gabions can be used to provide a stronger road base. If feasible, concrete approach aprons can reduce sedimentation and protect against scour.

![Figure 3.3-15: Well-constructed drift with concrete crossing surface.](image-url)
3.3.4.3 Bridges

Permanent bridges are typically used on main routes carrying high traffic volumes or on other routes where it is essential that permanent access is maintained. Bridges are used where restrictions prevent the use of culverts or where the waterway span is too large for a culvert.

3.3.4.3.1 Bridge Engineering for Forest Engineers

Bridge engineering is a complex task, often beyond the scope of typical forest engineering knowledge. This section is designed to give the forest engineer some insight into common bridge designs and installation methods used in the forest industry.

Bridges are used where the following conditions are met:
- Waterway is too large for a culvert;
- Stream gradient prevents a logical culvert installation;
- High debris or sediment load is expected (including ice in cold-weather climates);
- Streambed conditions prevent the installation of an open-arch culvert;
- Sensitive downstream resources preclude the construction of a large fill.

Types of Bridges

There are many types of bridges, but only a few are commonly used in the forest. Nearly all forest road bridges are single span, and they usually fit into the following categories:
- Steel;
- Concrete;
- Wood;
- Railway wagon.

3.3.4.3.2 Steel Bridges

Most steel forest road bridges are prefabricated, then transported and installed in sections. Various fabrication firms throughout the world construct these types of bridges, which can be up to 35 m long, and as wide as 6 m. A typical width is 5 m, with the bridge constructed in two sections, each being the full length, and half the width of the finished bridge. The deck can be constructed of wood, metal, or pre-cast concrete panels.

The purchaser specifies the load rating and dimensions of the bridge and the manufacturer prepares a tender to match these specifications. The bridge is then constructed at the manufacturer’s facility and transported to the installation location, where it is installed with a crane, hydraulic excavator, or other suitable construction plant. A principal advantage of a modular steel bridge is that it can typically be installed using the construction plant already on the jobsite, precluding the need to mobilise a large crane.

Costs of these bridges are typically greater than for a comparable wood or concrete bridge, however, they may be the only choice in remote locations where logistical or supply difficulties exclude other bridge options.

Figure 3.3-16: Modular steel bridge on forest road.
3.3.4.3.3 Concrete Bridges

Concrete bridges are often the lowest price alternative for permanent bridge installations. Concrete bridges can be poured-in-place or pre-cast. Poured-in-place bridges are limited to areas within a reasonable distance of a concrete mix plant. If one wishes to install a poured-in-place bridge in a remote location, a mix plant must be constructed on site. Pre-cast bridges can be installed anywhere, as long as the sections can be transported to the job site.

A structural engineer, specialising in reinforced concrete design should be consulted to ensure that the bridge is capable of withstanding the planned design loading. A concrete bridge can be an excellent choice in locations that require complicated approaches or curves, as it can be poured-in-place to any shape needed.

![Figure 3.3-17: Poured-in-place concrete bridge.](image)

3.3.4.3.4 Wooden Bridges

Wooden bridges, while not commonly used in South Africa, have a place in the forest engineer’s repertoire. A wood bridge can be constructed of sawn timbers, glue-laminated beams, or logs. Sawn timber stringers require large, high-quality trees. Glue-laminated beams can be constructed from lower-quality, smaller trees. One disadvantage to glue-laminated beams is that the stringer must be deeper than a steel or concrete stringer of equivalent strength, reducing the cross-sectional area of the channel or requiring the bridge to be higher. Log stringer bridges require substantial, high-quality trees, but there are techniques to allow the use of smaller logs and still construct a serviceable structure.

![Figure 3.3-18: Log stringer bridge.](image)
3.3.4.3.5 Railway Wagon Bridges

Used railway flat cars make excellent temporary bridges in many situations. The typical wagon ranges from 10-20 m in length and is approximately 3.5 m wide. The existing deck is removed and replaced with a deck of wood or steel. The bridge is placed on pre-cast concrete abutments. It is imperative to verify that the wagon is a flat car rather than a boxcar with the sides removed. Flat cars have heavy steel beams for support, while a boxcar carries much of its strength in the sides and roof. Used railway wagons can often be locally sourced and are inexpensive relative to other bridge options.
3.3.4.3.6 Bridge Abutments

The abutments the bridge sits on are often as important as the bridge superstructure. The abutments must be stable and of an appropriate design, given the soil and streambank conditions found at the structure location. For areas of deep valley bottom fills or highly erodible streambanks, piles are driven, and a concrete or metal pile cap is constructed for the bridge to sit on. For temporary bridges, a log sill can be used. Other times, a pre-cast concrete pad placed on a well-compacted gravel base is suitable. An expert should be consulted for abutment design if the forest engineer has any concerns about the installation.

Bridge abutments should be protected with rip-rap, gabions, or other measures to prevent scour and undermining.

Figure 3.3-22: Bridge abutments.

3.3.5 Recommended Approach to Drainage Design

Prior to designing a stream crossing structure, the engineer should become familiar with the catchment. A large-scale topographic map should be studied to determine catchment boundaries and determine the drainage area. Aerial photographs should be studied to determine any areas with a history of debris flow. The positions of the road(s), all obvious stream channels and the boundaries of the catchment should be recorded on the map. Existing culverts and bridges should be examined to provide preliminary sizing guidelines. Properly performing systems can be used as basis for designing new systems on new roads. Any scouring or overtopping indications should be investigated. Additionally, the engineer should check to see what kind of debris transport has occurred during high flow periods. Other information required includes:

- Climate data (rainfall patterns, average annual rainfall, typical storm duration, peak one hour records);
- Geology: (base geology and local anomalies);
- Soil type: (classification, permeability and erodibility);
- Land use: (planted or natural, density of trees, groundcover);
- Friction coefficients for runoff.

A field visit should be made to compare the information recorded on the map with actual ground conditions. Attention should be given to slopes, terrain type and run-off patterns. Any
point where water could intercept the road should be checked. On existing roads, measure the general size, depth and friction properties of the side drains and note any scour. Record the positions, size slope and general condition of the cross drains. Note the position of each mitre drain and whether it is effective. Check the condition and adequacy of cut-off drains and identify areas where new cut-off drains would improve the drainage process. On new roads, determine the drainage requirements (drain type, position, size and depth) based on other existing roads. Use 1 in 50 year peak flow return periods for major culverts and bridges where overtopping will have serious consequences.

The next step is to size the culvert or bridge. Ideally, stream flow data for the area is available, however this is rare for forested catchments. When streamflow data is limited or non-existent, an empirical design approach is followed. Talbot’s formula, commonly used for drainage design on forestry roads in other countries, is provided as an example.

### 3.3.5.1 Talbot’s Formula Method

This method provides a convenient way of determining the cross-sectional area of waterways required for small catchment areas. As with any empirical method, the output provides a guide only and should be interpreted and implemented with engineering judgement, especially in high rainfall areas or areas where high intensity storms are common.

Talbot’s formula is an empirical relationship between the area of the waterway required, the catchment area and the runoff coefficient relating to the type of country being drained.

\[
A = 0.183 \times C \times \sqrt[3]{M^3} \quad \text{and} \quad D = 2 \sqrt[4]{A / \pi}
\]

where \( A \) = required culvert size in \( m^2 \)
\( M \) = catchment area in hectares
\( C \) = runoff coefficient
\( D \) = diameter of culvert pipe in m

The relationship was derived for a catchment area having an anticipated rainfall intensity of 100 mm in one hour. For areas having different rainfall intensities, the result should be divided by 100 and multiplied by the anticipated rainfall. Safety margins should be considered. Where accurate prediction of the maximum rainfall intensity of one hour is not known, then any of the following will give acceptable values:

- If the daily rainfall is known, assume 40% could fall in any one-hour period.
- If the average rainfall is known, use:
  - 8% of the value for areas having less than 2 500 mm of rain per year
  - 4% of the value for areas having more than 2 500 mm of rain per year

Selection of an appropriate value of the catchment coefficient is critical to the accuracy of the method. Coefficients derived for the particular area where the design is being carried out should be used.

The following are acceptable coefficients to use in most forested areas of South Africa:

- Steep slopes, heavy soils, moderate cover – \( C = 0.75 \);
- Moderate slopes and soils, dense cover – \( C = 0.55 \);
- Gentle slopes, agricultural soil and cover – \( C = 0.35 \).
Table 3.3-2: Talbot’s formula output relating drainage area to required culvert opening for rainfall intensity of 100 mm/hr.

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<th>Catchment Area (ha)</th>
<th>Steep Slopes Heavy Soils Moderate Cover C=0.75</th>
<th>Mod. Slopes Med. Soils Dense Cover C=0.55</th>
<th>Gentle Slopes Agricultural Soil and Cover C=0.35</th>
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<td>350</td>
<td>11.11</td>
<td>8.14</td>
<td>5.18</td>
</tr>
<tr>
<td>400</td>
<td>12.28</td>
<td>9.00</td>
<td>5.73</td>
</tr>
<tr>
<td>450</td>
<td>13.41</td>
<td>9.83</td>
<td>6.26</td>
</tr>
<tr>
<td>500</td>
<td>14.51</td>
<td>10.64</td>
<td>6.77</td>
</tr>
<tr>
<td>550</td>
<td>15.59</td>
<td>11.43</td>
<td>7.27</td>
</tr>
<tr>
<td>600</td>
<td>16.64</td>
<td>12.20</td>
<td>7.76</td>
</tr>
<tr>
<td>650</td>
<td>17.67</td>
<td>12.96</td>
<td>8.25</td>
</tr>
<tr>
<td>700</td>
<td>18.68</td>
<td>13.70</td>
<td>8.72</td>
</tr>
<tr>
<td>750</td>
<td>19.67</td>
<td>14.42</td>
<td>9.18</td>
</tr>
<tr>
<td>800</td>
<td>20.65</td>
<td>15.14</td>
<td>9.63</td>
</tr>
<tr>
<td>850</td>
<td>21.61</td>
<td>15.84</td>
<td>10.08</td>
</tr>
<tr>
<td>900</td>
<td>22.55</td>
<td>16.54</td>
<td>10.52</td>
</tr>
<tr>
<td>950</td>
<td>23.49</td>
<td>17.22</td>
<td>10.96</td>
</tr>
<tr>
<td>1000</td>
<td>24.41</td>
<td>17.90</td>
<td>11.39</td>
</tr>
</tbody>
</table>
Example

A suitable culvert size needs to be determined for a catchment area of 650 ha. The design rainfall is 100 mm in one hour and the catchment area is described as predominately moderate slopes and soils with heavy forest cover.

For a rainfall intensity of 100 mm, the runoff coefficient is estimated at 0.55. Reading off Table 3.3-2, a catchment area of 650 ha will require a waterway estimated at 12.96 m$^2$. This relates to a pipe with a diameter of 4.06 m, as calculated from the above equation or interpolated from Table 3.3-3.

Table 3.3-3 – Conversion of waterway area to culvert size.

<table>
<thead>
<tr>
<th>Area (m$^2$)</th>
<th>Diameter</th>
<th>Area (m$^2$)</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.36</td>
<td>6.0</td>
<td>2.76</td>
</tr>
<tr>
<td>0.2</td>
<td>0.50</td>
<td>7.0</td>
<td>2.99</td>
</tr>
<tr>
<td>0.3</td>
<td>0.62</td>
<td>8.0</td>
<td>3.19</td>
</tr>
<tr>
<td>0.4</td>
<td>0.71</td>
<td>9.0</td>
<td>3.39</td>
</tr>
<tr>
<td>0.5</td>
<td>0.80</td>
<td>10</td>
<td>3.57</td>
</tr>
<tr>
<td>0.6</td>
<td>0.87</td>
<td>20</td>
<td>5.05</td>
</tr>
<tr>
<td>0.7</td>
<td>0.94</td>
<td>30</td>
<td>6.18</td>
</tr>
<tr>
<td>0.8</td>
<td>1.01</td>
<td>40</td>
<td>7.14</td>
</tr>
<tr>
<td>0.9</td>
<td>1.07</td>
<td>50</td>
<td>7.98</td>
</tr>
<tr>
<td>1.0</td>
<td>1.13</td>
<td>60</td>
<td>8.74</td>
</tr>
<tr>
<td>2.0</td>
<td>1.60</td>
<td>70</td>
<td>9.44</td>
</tr>
<tr>
<td>3.0</td>
<td>1.95</td>
<td>80</td>
<td>10.09</td>
</tr>
<tr>
<td>4.0</td>
<td>2.26</td>
<td>90</td>
<td>10.70</td>
</tr>
<tr>
<td>5.0</td>
<td>2.52</td>
<td>100</td>
<td>11.28</td>
</tr>
</tbody>
</table>

3.3.6 References and Further Reading


Chapter 4 - Operating Elements

Section 4.1 - Gravel Source Development

4.1.1 Introduction

In order to construct, rehabilitate, upgrade and maintain a forest road network, large quantities of surfacing material are required. Material location is a science in itself and should follow a logical process, rather than random exploration. Construction materials are non-renewable resources and must be managed in a way that maximises their utilisation while protecting the environment. Gravel sources must be mapped and described accurately to facilitate important management decisions.

Material location may be difficult in forested areas because many indicators used to identify potential sources are obscured. A systematic procedure using maps, aerial photographs and various site indicators is described later in this chapter to find potential gravel sources in forested areas.

There are a number of legal requirements that must be adhered to before prospecting and excavation of a gravel source can commence.

4.1.2 Statutory Obligations

A permit from the Department of Minerals and Energy or Department of Water Affairs and Forestry may be required before a gravel source can be exploited. Typically, quarries used by the property owner for forest roads, and not in a commercial manner, do not require permitting. If the area is environmentally sensitive, a permit may be needed. The forester should consult with appropriate agencies to make this determination.

4.1.3 The Geology of South African Forestry Regions

South African forestry regions are situated in various geological regions. The forests of the Barberton Mountain Land area are located on some of the oldest rock formations on earth (around 3.5 billion years) while the forests in the Sodwana Bay area are located on some of the youngest (less than one million years old).

In order to simplify the classification of materials and to categorise their application in road construction in South Africa, a geological engineering classification system was devised in the early 1970s (Weinert’s classification). This system groups hundreds of geological material types into eight broad groups, each containing materials with similar weathering and performance behaviour. These groups are based on the mineralogy of the unweathered rock that, under any specified climatic regime, will produce an end product with common clay or secondary minerals. The presence and quantity of quartz (one of the most common and easily identified minerals) is a feature of this classification system.

Because forestry areas are often located in high rainfall regions, chemical decomposition of the constituent minerals in rocks will predominate and the materials will often alter to gravels and soils with higher plasticity than those in dry or arid areas.
The groups of materials relevant to construction materials in forestry areas are as follows:

- Basic crystalline rocks (dolerite, diabase, basalt);
- Acid crystalline rocks (granite);
- High silica rocks (chert);
- Arenaceous rocks (sandstone);
- Argillaceous rocks (shale, mudstone);
- Carbonate rocks (dolomite);
- Pedocretes (ferricrete, calcrete);
- Transported soils (sand).

Each of these groups can contain materials that are derived from different geological origins (i.e., igneous, sedimentary or metamorphic) but have the same primary mineral compositions and will alter under a constant environmental regime to the same end products.

Typical areas of the different material groups are shown in Table 4.1-1. This is very general but illustrates the major materials to be expected in these areas.

**Table 4.1-1: Rock groups and their areas of occurrence.**

<table>
<thead>
<tr>
<th>Rock group</th>
<th>Typical Areas of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic crystalline</td>
<td>Localised dolerite and diabase intrusions countrywide</td>
</tr>
<tr>
<td></td>
<td>Basalt in north eastern Cape</td>
</tr>
<tr>
<td>Acid crystalline</td>
<td>Northern province, eastern Escarpment</td>
</tr>
<tr>
<td>High silica</td>
<td>Sabie-Rosehaugh-Pilgrims Rest area</td>
</tr>
<tr>
<td>Arenaceous</td>
<td>Waterberg, southern Cape</td>
</tr>
<tr>
<td>Argillaceous</td>
<td>Eastern escarpment</td>
</tr>
<tr>
<td>Carbonate</td>
<td>Sabie-Rosehaugh-Pilgrims Rest area</td>
</tr>
<tr>
<td>Pedocretes</td>
<td>Eastern Highveld, Lembombo flats</td>
</tr>
<tr>
<td>Transported</td>
<td>Countrywide</td>
</tr>
</tbody>
</table>

### 4.1.4 Issues Specific to Road Construction Materials

#### 4.1.4.1 Material Type

The mineralogical components of the rock dictate how the rock will weather, what the end products will be, and how they will perform on the road. Weinert separated those rocks that decompose from those that disintegrate on the basis of mineralogy, primarily the dominance of quartz in the rock. On this basis, only the acid and basic crystalline (e.g. granite and basalt) materials were considered to be subject to decomposition and the remaining material groups would essentially disintegrate, dependent on climatic influences. However, feldspathic sandstones and mudrocks also decompose severely in moist areas.

In general, forest areas have Weinert N-values less than two. This characteristic indicates that decomposition of rock materials will be the dominant form of weathering. A high propensity for the formation of clay minerals exists, primarily montmorillonite (basic crystalline rock) or kaolinite (acid crystalline rock), though illite may predominate during certain stages of the weathering process.
4.1.4.2 Depth of Weathering

The depth of weathering is highly variable and is a function of the material type and structure, the erosion cycle by which it has been affected, availability of water, and topography. The depth of weathering varies from a few centimetres, where only a thin layer of gravel is found at the surface, to very deep clays, where granites beneath the African erosion surface (underlying laterite) can be weathered to a depth of 20 m or more. In general, the soil profile consists of an organic top soil (A horizon), overlying weathered in situ material (B horizon), grading into the C horizon of weathered rock which overlies the R horizon or in situ unweathered rock. The soil profile and residual material typically becomes deeper as the slope becomes flatter.

The natural gravel material suitable for road construction is typically obtained from the B (residual material without relict structure) and C horizon (residual material with original rock structure or saprolite).

4.1.4.3 Topography

Topography influences ground water profiles and the weathering process. The topography in an area is a function of cycles of erosion over millennia. Most forest areas are in an active erosion cycle with deep river valleys.

4.1.5 Road Construction Materials

Properties of road construction materials related to their generic groups are summarised in Table 4.1-2. Material within the soil profile varies with depth, requiring testing and sampling of materials throughout the profile. The plasticity of the material will typically decrease with depth towards the unweathered rock while material coarseness and gravel component will increase. Table 4.1-2 summarises the expected properties of the material within the B and C horizons. The data provided should be used as a guide only because of the potential variability resulting from aspects such as lithological and structural variations within the material.

Table 4.1-2: Typical properties of materials.

<table>
<thead>
<tr>
<th>Rock group</th>
<th>Typical material types</th>
<th>Material grading</th>
<th>Plasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic crystalline</td>
<td>Dolerite, diabase, gabbro, basalt, norite, greenschist, amphibolite</td>
<td>Clays to clayey gravels</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Acid crystalline</td>
<td>Granite, gneiss, felsite, rhyolite, syenite</td>
<td>Sandy gravel to sand</td>
<td>Low to medium</td>
</tr>
<tr>
<td>High silica</td>
<td>Chert, quartzite, hornfels</td>
<td>Gravelly sand</td>
<td>None to low</td>
</tr>
<tr>
<td>Arenaceous</td>
<td>Sandstone, arkose, conglomerate, mica schist</td>
<td>Clayey sands</td>
<td>None to medium</td>
</tr>
<tr>
<td>Argillaceous</td>
<td>Mudstone, shale, phyllite, slate</td>
<td>Gravelly clays</td>
<td>Low to high</td>
</tr>
<tr>
<td>Carbonate</td>
<td>Dolomite, marble, limestone</td>
<td>Gravelly silt</td>
<td>None to medium</td>
</tr>
<tr>
<td>Pedocretes</td>
<td>Laterite, ferricrete, calcrete</td>
<td>Variable</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Transported</td>
<td>Sands, gravels</td>
<td>Variable</td>
<td>None to medium</td>
</tr>
</tbody>
</table>
### 4.1.6 Methodology for Material Location

Material location should follow a logical process. This entails:
- Developing a basic understanding of the regional geology;
- Developing an understanding of gravel indicators;
- A desktop study of maps and aerial photographs;
- A reconnaissance survey;
- A detailed field survey.

The recommended procedure for material location is illustrated in flowchart form in Figure 4.1-1.

![Flowchart for Material Location](image-url)
4.1.7 Sources of Information

Prior to embarking on a costly material location exercise, existing sources of material should first be assessed. The following sources should be considered:

- Local existing sources and quarries;
- Experienced staff and local residents;
- Existing source records;
- Construction documentation.

If no suitable material can be identified within a reasonable distance of the project from the above sources, then a material location exercise must be considered.

4.1.7.1 Interviews with Experienced Staff and Local Residents

Staff members that have worked in a particular region for a period of time often have knowledge of existing and potential material sources. They also often have a good idea of how materials from various sources have performed and which materials are likely to perform best under given conditions. Local residents are often aware of existing and potential sites and may be willing to share this information, especially if the material is used on roads where they will benefit from improvements.

4.1.7.2 Records

The quality of information regarding existing and potential material sources in gravel source databases will differ from forest to forest. Existing records are worth checking for information on likely sources. Information typically assessed includes:

- The types of materials that were found;
- Availability of materials;
- The general engineering characteristics of materials in the region, such as their overall quality, volume per pit and the thickness of the overburden;
- Materials location techniques used and known indicators of material identified;
- Landforms in which the material was located.

4.1.7.3 Construction Documentation

Records of completed construction projects (not necessarily only road projects) usually have details of where material was sourced, as well as test results. Records for sealed road construction in the vicinity of the forest should also be studied, since materials that were used for those projects may be suitable for forest road purposes. Occasionally, materials that were rejected for sealed road projects may still be suitable for unsealed road construction.

4.1.8 Gravel Indicators

Three types of gravel indicators are typically used for material location:

- Landform;
- Botanical indicators (specialised plants);
- Animal indicators (traces left by animal activity).
4.1.8.1 Landform

Landform refers to the configuration of the ground surface in a distinctive shape. Landform is important in gravel location, as different types of gravel are associated with particular landforms. This association is due to the:

- Presence of material near the surface, giving rise directly to a particular type of landform. (e.g. a band of harder rock gives rise to a bump on a slope or a flat hill top, depending upon the rock’s position and orientation).
- Development of a particular type of gravel in relation to a geomorphological feature (e.g. a river terrace typically is made up of alluvial gravel).

4.1.8.1.1 Landforms of Rock Regions

Rock regions have the typical range of gravel landforms illustrated in Table 4.1-3. This table is the key to the landform names given in Table 4.1-4.

Table 4.1-3: Landforms of rock regions, associated with gravel deposits.

<table>
<thead>
<tr>
<th>Landform</th>
<th>Diagram (cross-section)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat hill top</td>
<td>Flat, level hill top (plateau) with sharp edges at margins</td>
</tr>
<tr>
<td>Sloping hill top</td>
<td>Inclined, flat hill top with sharp edge between (steep) scarp slope and (more gentle) dip slope</td>
</tr>
<tr>
<td>Conical hill</td>
<td>Hill with pointed top, more or less circular in plan. Sides may be irregular or smooth</td>
</tr>
<tr>
<td>Mound</td>
<td>Rounded hill top with convex slopes, or convex ‘bump’ on a plateau or hill top</td>
</tr>
<tr>
<td>Ridge</td>
<td>Long, straight, narrow ridge running across country. Usually formed by an igneous intrusion (dyke or sill) or a quartz vein</td>
</tr>
<tr>
<td>Trench</td>
<td>Long, straight, narrow depression running across country. Like the Ridge landform (above), usually formed by an igneous intrusion. However, in this case the surrounding rocks are more resistant than the intrusion. Sometimes the trench is formed by a pair of closely-spaced parallel ridges, formed by the surrounding rock being ‘baked’ hard by the heat of the intrusion</td>
</tr>
<tr>
<td>Footslope</td>
<td>Gentle slope at the foot of a steeper slope, formed (in this case) by the accumulation of pedogenic gravel (usually ferricrete) in the soil profile</td>
</tr>
<tr>
<td>Terrace</td>
<td>Raised platform situated at the edge of a valley, deposited by a river</td>
</tr>
<tr>
<td>Floodplain</td>
<td>Broad, flat valley floor with winding river. Sand and gravel accumulate on the inside of river bends</td>
</tr>
</tbody>
</table>
Table 4.1-4 takes typical parent materials occurring in forest regions and indicates the landforms that are commonly associated with each.

**Table 4.1-4: Types of gravel associated with rock regions.**

<table>
<thead>
<tr>
<th>Gravel type</th>
<th>Parent material</th>
<th>Landform</th>
<th>Possible engineering problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual gravels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weathered rock</td>
<td>Lava</td>
<td>Flat hill top, sloping hill top</td>
<td>Lava of basic composition may contain weatherable minerals</td>
</tr>
<tr>
<td></td>
<td>Igneous dyke</td>
<td>Ridge or trench</td>
<td>Lavas of basic composition may contain weatherable minerals.</td>
</tr>
<tr>
<td></td>
<td>Igneous sill</td>
<td>Ridge on side of hill</td>
<td>Lavas of basic composition may contain weatherable minerals. Sill may be difficult to exploit, owing to position on side of hill (- overburden)</td>
</tr>
<tr>
<td>Granite, gneiss</td>
<td>Mound, None</td>
<td></td>
<td>Gneisses may contain weatherable minerals</td>
</tr>
<tr>
<td>Quartzite</td>
<td>Ridge, sloping hill top, flat hill top, mound</td>
<td>Poor mechanical interlock of particles</td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td>Mound, flat hill top None</td>
<td></td>
<td>Particles may be rather soft</td>
</tr>
<tr>
<td>Conglomerate, breccia</td>
<td>Flat hill top, sloping hill top, mound None</td>
<td>Conglomerate particles are rounded. Properties of the coarse particles may be different from those of the matrix</td>
<td></td>
</tr>
<tr>
<td>Limestone, marble, dolomite</td>
<td>Flat hill top, sloping hill top, mound None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vein quartz</td>
<td>Granite, gneisses of all types</td>
<td>Ridge</td>
<td>Poor mechanical interlock of particles</td>
</tr>
<tr>
<td>Transported gravels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz stone line</td>
<td>Footslope None</td>
<td>Poor mechanical interlock of particles. May tend to contain too many fines.</td>
<td></td>
</tr>
<tr>
<td>Colluvium</td>
<td>Footslope</td>
<td>May contain too many fines</td>
<td></td>
</tr>
<tr>
<td>Alluvium</td>
<td>Terrace, Floodplain</td>
<td>Rounded particles, often sandy and lacking in fines</td>
<td></td>
</tr>
</tbody>
</table>

4.1.8.1.2 Landforms of Sand Regions

Landforms found in sand regions are given in Table 4.1-5, and the gravels associated with them are given in Table 4.1-6. It should be noted that the geology of the Zululand/Maputoland region is very young and the likelihood of finding sufficient quantities of suitable materials is small.
Table 4.1-5: Landforms of sand regions, associated with gravel deposits

<table>
<thead>
<tr>
<th>Landform</th>
<th>Diagram (cross-section)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pan with 'platform'</strong></td>
<td></td>
<td>Flat-floored pan with no or minimal vegetation. ‘Platform’ is a low bench situated on the edge of the pan but usually not extending all the way round. May be more than 500 m across, or less.</td>
</tr>
<tr>
<td><strong>Pan without 'platform'</strong></td>
<td></td>
<td>Flat-floored pan with no development of a low bench around the edge. May be more than 500 m across, or less. May be without vegetation, or contain grasses.</td>
</tr>
<tr>
<td><strong>Depression</strong></td>
<td></td>
<td>Concave hollow in the sand surface, containing grasses. The grass communities are often arranged in concentric zones around the depression.</td>
</tr>
<tr>
<td><strong>Inter-dune hollow</strong></td>
<td></td>
<td>Very long, straight concave channel in sand surface. One of many forming parallel linear rises with hollows between. Calcrites are developed at intervals along the line of the hollow.</td>
</tr>
<tr>
<td><strong>Valley (old river channel)</strong></td>
<td></td>
<td>A dry river valley, filled in with sand. Takes the form of a broad, gentle elongated depression that extends for many kilometres. In places, easily visible on the ground but in others, so wide and shallow as to be hardly detectable.</td>
</tr>
<tr>
<td><strong>Grey sand</strong></td>
<td></td>
<td>No topographic relief, only grey sand contrasting with surrounding reddish or brown sands.</td>
</tr>
</tbody>
</table>

Note: Platform is not usually as distinctive or obvious as shown here.

Table 4.1-6: Gravel types associated with sand regions

<table>
<thead>
<tr>
<th>Landform</th>
<th>Material</th>
<th>Characteristics and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pan with platform</strong></td>
<td>Calcite, possibly hardpan or nodular Silcrete</td>
<td>The best quality calcrete is found in the pan platform</td>
</tr>
<tr>
<td>Around rim</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pan without platform</strong></td>
<td>Calcite</td>
<td>Good calcrete may occur but is not usual. Quality is not predictable. Large pans may contain hard or boulder calcrete</td>
</tr>
<tr>
<td>Around rim</td>
<td>Silcrete</td>
<td></td>
</tr>
<tr>
<td><strong>Depression</strong></td>
<td>Calcite can be nodular. Often no occurrence, or calcareous sand</td>
<td>Usually poor quality calcrete. May occur on the side slopes</td>
</tr>
<tr>
<td><strong>Inter-dune hollow</strong></td>
<td>Calcite and silcrete hardpan or honeycomb or nodular hollow's length</td>
<td>Locally, good quality materials but generally none over most of the hollow's length. Some valleys contain extensive calcified sands</td>
</tr>
<tr>
<td><strong>Valley (old river channel)</strong></td>
<td>Calcite, possibly hardpan or nodular</td>
<td>Locally, good quality materials but generally none over most of the valley's length. Some valleys contain extensive calcified sands</td>
</tr>
<tr>
<td><strong>No landform</strong></td>
<td>Calcareous sand. Possibly some calcrete</td>
<td>Usually poor quality calcrete but may be better if sand is non-plastic. Blackish sands usually yield better quality material</td>
</tr>
<tr>
<td>- grey sand only,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>contrasting with surrounding red sand</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If gravel particles are present in the soil, the processes of weathering and erosion may tend to bring some particles to the surface. The accumulation of a layer of stones and gravel on the surface can give the false impression that the soil is composed of gravel, or that a gravel layer lays at depth. Before marking the area as a potential source of gravel it is important to check that a gravel layer is actually present, by finding an exposed profile.

4.1.8.2 Botanical Indicators

The presence of certain plant species and the nature of their growth can depend upon the mineralogical and physical properties of the soil in which they are growing. Botanical indicators can be a useful aid to materials location, although it is often restricted in forest areas where most areas are planted with exotic species. It should also be noted that plants are adaptable and the absence of an indicator species does not necessarily mean that the material is absent, while the presence of the indicator species does not always signify that the underlying material is suitable for engineering purposes. Distinct changes in the species type, dense thickets of a particular species or a change in the form (e.g. multi-stemmed instead of single stemmed, stunted, windblown, etc) of plants are easily observed and are useful ways of identifying a potential source. Plant indicators are particularly useful for locating pedocretes (e.g. ferricrete and calcrete) and dykes and intrusions that are not easily visible on the surface.

4.1.8.3 Animal Indicators

The activity of certain animals results in gravel particles, soil or stones being brought to the surface. Examples are termites, porcupines, suricates and squirrels. Examination of the material in termite mounds and anthills, and material excavated from burrows should be carried out.

4.1.9 The Desktop Study

The desktop study entails an assessment of maps (topographical, geological and agricultural) and aerial photographs to identify potential gravel sources, before more costly, unplanned field visits are made.

4.1.9.1 Interpretation of Maps and Photographs

4.1.9.1.1 Topographic Maps

Medium- or large-scale topographic maps can indicate the landforms associated with gravels. Topographic maps also contain other useful information such as roads, access, land-use, mines and quarries, development and water, which indicate potential sources of material and assist with appraisal of the area.

4.1.9.1.2 Geological Maps

Geological maps are probably the most important source of preliminary information available to a prospector. Geological maps indicate the parent materials in the area and details such as quarries, faults, rock outcrops and igneous intrusions. The types of weathering products can be inferred from this information. All geological maps are accompanied by a narrative memoir. Reference to these is recommended. The forester must keep the following in mind when using geologic maps:
• The map shows the rocks as they would appear if all the superficial deposits such as soil or unconsolidated materials (e.g. thin windblown sand and alluvium) were removed. However, very thick surface deposits such as the sands of the Zululand/Maputoland region are shown because they are the dominant material for all practical purposes.

• Geological maps rarely indicate the presence of gravel deposits. However, geological memoirs often contain information on the degree of weathering or fracturing of the rocks and therefore indicate the possibility of a suitable gravel source. Memoirs may also describe superficial deposits such as pedogenic and coarse alluvial materials. The map legend (the key to the rock types on the map) may identify features that are related to gravel deposits, such as quartz veins, dykes or alluvial materials.

4.1.9.1.3 Aerial Photographs

The resolution of aerial photographs is of high quality and every detail of the ground surface down to a few metres (depending on the scale of the photograph) in size is shown. Features such as minor rock outcrops can be seen clearly, often through a forest canopy. Aerial photographs can be viewed in three dimensions with the use of a stereoscope allowing slopes and relief to be seen. The vertical relief in aerial photographs is exaggerated, making slopes appear steeper than they really are. This exaggeration is an advantage because it enables very small changes of elevation, including those on the ground, are barely discernible, to be seen (e.g. low relief landforms such as depressions associated with pedogenic materials are easily recognised in aerial photographs). When carrying out an interpretation, the following general characteristics of the terrain should be noted before looking in detail for the landforms described above:

• Relief and landform: Hill areas, rolling or undulating land, terraces, floodplains and low-lying land. Look especially for relief features that are too small to be shown on maps.

• Drainage: Note areas where drainage pattern is consistent, and boundaries where one pattern changes to another (often signifies geological boundaries). Note areas where drainage is absent (indicating highly permeable soils), or consists of parallel streams or straight stream courses (rock is controlling the stream pattern and is therefore near the surface).

• Vegetation and land use: Although it is not possible at normal air photo scales to distinguish individual plant species such as gravel indicator plants, plant communities of a type that may contain indicator plants are often identifiable.

• Human features: Farm boundaries, fences, and buildings give indications of the extent of properties and where the owners may be contacted.

4.1.9.2 Desktop Study Methodology

The following procedure should be followed. This procedure is included in checklist form in Appendix 5.

1. Obtain two sets of 1:50 000 topographic maps covering the route corridor. One set will be used as base maps for collation of information coming from various sources during the desk study. The other is for general project use and navigation in the field.

2. Mark out the road or route corridor on the base maps.

3. Confirm the quality and quantity of material required for the project.

4. Establish land use and land ownership (if applicable) and potential environmental constraints within the route corridor.

5. Obtain relevant materials investigation reports from previous projects.

6. Discuss material types and existing and potential sources with relevant staff and other people with experience of the area. Establish whether there is sufficient gravel at existing and known sources. If not, continue with the study.
7. Obtain geological maps, agricultural soils maps, aerial photographs and, if necessary, satellite images, as well as any past records for this and other roads in the area.

8. Determine the coordinates of existing gravel sources and locate these on the base maps, photographs and images. Note the terrain features at these coordinates and then look for other similar features elsewhere along the proposed corridor. Transfer the information to the base map.

9. Examine the topographic maps, looking for the occurrence of any of the landforms discussed earlier.

10. Examine the geological maps and:

   - Draw the road corridor on the geological map or a copy, in order to determine the approximate locations where differing geological units cross the road alignment. A 1:250 000 geological map is recommended for this exercise.

   - Read the map legend and the accompanying geological report for any mention of rocks that are potential sources of gravel-sized weathering products. Note the geological units within which these are found.

   - Identify these geological units on the map, within the exploration corridor. Pay particular attention to ‘oddlities’ on the map such as minor igneous intrusions and unusually prominent hills (often named). These features often contain gravels when the surrounding country has none.

   - Identify possible sources of material.

   - Study the identified areas of geological interest in aerial photographs to pinpoint the locations most favourable for field investigation.

11. Study the aerial photographs (in stereoscopic mode) in conjunction with information from the topographic, geological and agricultural soil maps to identify landforms associated with gravel. Make notes of all features, no matter how small, and mark their location and extent on the base map.

12. Transfer all relevant information to the base map and identify the best potential sites, as well as the best location to begin field work and the route to follow.

13. Obtain the necessary permission or authorisation to prospect.

14. Contact the landowners and arrange access to properties during the reconnaissance visit if applicable.

15. Establish the most appropriate method for the field survey.

4.1.10 Reconnaissance Survey

The primary purpose of the reconnaissance survey is to familiarise the prospector with the area, mark the existing pits and potential sites identified during the desk study, and to note any other potential sites that may have been missed. The detailed study can then be planned to optimise resources. The purpose of the reconnaissance survey as opposed to the detailed investigation is clarified in Table 4.1-7.

Table 4.1-7: Differences between reconnaissance surveys and detailed surveys.

<table>
<thead>
<tr>
<th>Reconnaissance survey</th>
<th>Detailed survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose is to obtain an overview of the types and distribution of materials within the whole route corridor, and possibly outside (i.e. to identify sites).</td>
<td>Purpose is to make detailed records of the most appropriate sources of material for the project in hand, (i.e. to investigate sites identified in reconnaissance survey).</td>
</tr>
<tr>
<td>Large distances are covered quickly, to obtain an overview of potential sites. Route is varied as necessary to visit as many sites as possible within the area of search.</td>
<td>The sites are covered methodically, therefore in much more detail. Route is planned to progress from one site to the next.</td>
</tr>
<tr>
<td>No samples are taken.</td>
<td>Samples are taken as necessary, appropriate for the specification of the material in the context of the project.</td>
</tr>
</tbody>
</table>
The most successful field survey procedure is to systematically traverse the route relating the information on the map prepared during the desk study to the prospecting corridor. The following procedure is recommended for the reconnaissance survey:

4.1.10.1 Reconnaissance Survey Procedure

1. Begin the traverse of the project area well before the actual start (there may be very good material at the beginning of the project). Continually refer to the base map and aerial photographs.

2. The first traverse should confirm the conclusions drawn during the desk study. Visit existing gravel sources and potential sites identified. Use GPS to record their locations. Estimate the spatial extent and available quantities without excavation. This can be done with simple techniques such as a calcrete probe or a DCP (Dynamic Cone Penetrometer).

3. Identify any significant geomorphological, soil or vegetation characteristics at existing gravel sources that can be used to indicate similar sources elsewhere along the route. Identify these characteristics on the maps and aerial photographs and look for similar features elsewhere on the images.

4. Study the geomorphology and decide which areas are likely to have a high potential for material (e.g. scree slopes and drainage channels). Study the vegetation and note any significant changes, such as species groupings or changes in plant characteristics (e.g. shape, height, form).

5. Note accessibility to each site and record GPS coordinates and observations.

6. Plot new sites on the sketch map. Review the pattern of sites on the map to see if they lie in clusters or straight lines, which would help in showing where to look for additional material.

7. Record other important information including thickness of overburden and ease of access.

8. Update the base map accordingly.

9. Draw up a plan for the detailed study, prioritising the most suitable sites according to the required material qualities and quantities. Identify a second set of sites in case the first selection proves to be unsuccessful.

Figure 4.1-2: Flow chart of reconnaissance survey
4.1.11 Detailed Field Survey

The process of searching for suitable gravel sources culminates with the evaluation and proving of the potential construction material source. The objective of this part of the investigation is to establish:

- The spatial extent of a potential gravel source;
- The thickness and quantity of the identified deposit;
- The characteristics of the identified deposit;
- The type and properties of the overlying material;
- The thickness and volume of the overburden.

4.1.11.1 Survey Procedure

For each potential source identified, the following procedure should be followed:

1. Demarcate the approximate spatial extent of the site with stakes. This can be determined with a calcrete probe or DCP. In sandy areas, the calcrete probe should also be used to determine the thickness of the overburden.

2. Identify the source with a unique location number, its chainage and direction from the start of the route and the offset from the centreline.

3. Lay out a 50 m staggered grid. The grid pattern may be reduced to a 25 m spacing in one or both directions if the material within the potential source changes over a short distance. The grid can be aligned in any direction convenient to cover the shape of the deposit. Setting out of the trial pits should be carefully planned taking the characteristics of the site, such as vegetation and rock exposure, into consideration. Trial pitting should also incorporate as much of the potential gravel source as is necessary to establish the deposit’s extent and variability.

4. Record the grid pattern with holes running in one direction left to right being labelled A, B, C, D, etc and holes running perpendicular to this (i.e. top to bottom) being numbered 1, 2, 3, 4, etc. Trial pits should be selected statistically (preferably on a stratified systematic herring bone pattern) and would then be numbered A.1, A.2…B.1, B.2……D.1, D.2 etc. The use of a grid system ensures a well co-ordinated study and simplifies the location of each trial pit. The system also facilitates selective stockpiling if different areas of the gravel source are recommended for different pavement layers or for blending.

5. Excavate a pit to the bottom of the suitable material. This can be done either manually or by machine depending on the circumstances of the project. The width of the pit will vary depending on the excavation method. Ensure that the necessary safety precautions are taken during excavation and examination of the pit.

6. Describe the soil profile in detail using the standard Jennings, Brink and Williams (1973) method. The overburden and the ratio of overburden thickness to gravel thickness should be recorded. During profiling, identify the horizons that are potentially suitable for meeting the material requirements of the road design.

7. Collect sufficiently large samples of material for the intended tests. Place the sampled material in bags (it is suggested that high quality sewn canvas bags are used for sampling) and carefully label each bag ensuring that the label is permanent. Label tags should be placed in a transparent waterproof plastic bag before being placed inside the sample bag to avoid moisture damage.

Information on the label must include the following:

- Project name;
- Date;
- Source location number;
- Trial pit number;
- Depth;
- Name of person sampling.
Backfill the pits with high quality material from within the staked area.

Remember that this material may be used in the road and therefore unsuitable material from outside the staked area should not be used for backfill. If the pits have to be left open for more than one day, they should be clearly identified with hazard tape or covered with wood to prevent people or animals from falling into them.

Estimate the volume of gravel in the source by determining the mean thickness of the gravel and multiplying it by the spatial extent of the source.

Draw a detailed sketch map of the area and include the following:

- Distance from the road;
- Potential access routes;
- GPS co-ordinates if available;
- Trial pit grid and location of pits that were sampled. Also include any additional information gathered from calcrete probe or DCP penetrations;
- Pertinent features such as outcrops, anthills, large trees (which may need to be protected), streams, etc;
- North direction marker;
- List any potential problems that may affect exploitation of the pit such as boulders, presence of water, etc on the sketch map;
- List any environmental, (SMZ's), archaeological or historical factors of concern in the area;
- Where necessary, list the names of landowners (e.g. if the potential gravel source is in a field or farm, or affects other land users);
- Mark the position of each potential gravel source on the 1:50 000 topographic map which serves as the working map.

Repeat this process for each identified source. When each source has been evaluated, add the estimated total volume from each and compare this figure with the project requirements. Remember to make sufficient allowances for compaction or bulking and wastage (e.g. oversize).

### 4.1.12 Estimating Material Quantity

There are various methods of estimating the volume of material in a potential source. The main objective, however, is to establish the thickness over a portion of the entire area. A simple, yet adequate method is outlined below:

Divide the gravel source into segments with simple ‘shapes’ - squares, rectangles and triangles (Figure 4.1-3).

![Figure 4.1-3: Subdividing a gravel source.](image)

Segment 1: Square with area 50x50 = 2500 m²
Segment 2: Rectangle with an area 100x150 = 15000 m², less outcrop of 20x10 = 14800 m²
Segment 3: Triangle with an area 100/2 = 2500 m², Total: 19800 m²
Determine the total area of each segment and make adjustments for obstacles such as large trees or sensitive vegetation that should be preserved, rock outcrops, areas of unsuitable materials etc, to determine a ‘useable’ area.

Within each segment, determine the average thickness of the material strata of interest (overburden or gravel) from trial pit profiles or as estimated with DCP, calcrete probe or auger.

Determine the approximate volume of the material that the strata can yield per segment by multiplying the average thickness by the area of each segment.

Add the volume of material from all segments.

To account for compaction or bulking factor, waste during stockpiling, transportation and construction, reduce the estimated quantities according to the appropriate factor of the \textit{in situ} gravel in comparison with the expected densities after compaction. An average factor would be 30-45%

Consider whether all materials from the pit would be used. In particular, note oversize materials that are not likely to break down during construction. However, the total volume of the material from the source (including oversize) must be reported for estimating transport costs unless such oversize can be removed at the source.

Carefully study the trial pit logs and determine whether the thicknesses reported in the logs are based on refusal (i.e. whether the pit was sampled to its full depth) or no refusal and whether the trial pits were excavated by machine or hand labour.

For pits not sampled to full depth the volume calculated could be conservative while pits sampled to refusal could imply that no additional material will be excavated, especially if a machine, such as a tractor/loader/backhoe (TLB), was used for trial pitting.

While preparing for digging, make a location plan of the site in relation to roads and compartment boundaries.

Indicate where overburden to be stored for future rehabilitation

\section*{4.1.13 Laboratory Testing}

Routine indicator and classification testing must be carried out before submission of the prospecting report. This is covered in 3.2 Pavement Design.

\section*{4.1.14 Field Testing of Gravel Materials}

The Unified Rock Classification System, as developed by D.A. Williamson is very useful for field testing rock to determine suitability for pavement surfacing. It is a very simple process and can be conducting using a geologist’s hammer and a magnifying loupe. It is as follows:

- First, strike the rock in question several times with the flat end of the geologist’s hammer.
- Second, view the resulting impact with the loupe and classify according to the following categories.

**“RQ” – Rebound Quality**

- No sign of impact
- Best used for asphalt
- Rock will produce “arrowheads” during crushing, resulting in potential tire damage

**“PQ” – Pit Quality**

- Rough pits from impact
- Excellent for crushed rock surfacing
“DQ” – Dent Quality
• Depressions from impact (no shearing)
• Acceptable “marginal” aggregate quality

“CQ” – Crater Quality
• Shearing and up-thrusting from impact
• Unsuitable for crushed aggregate surfacing

This process allows the forester to make a rapid assessment of potential rock quality prior to conducting a thorough investigation.

4.1.15 Site Investigation Report

A brief site investigation report should be prepared to record the material location survey and to provide a reference for future materials location exercises. Reports should be filed together for easy future access. The report should comprise two parts, namely:
• The factual or descriptive record;
• The engineering interpretation and recommendation.

The factual report should concisely and accurately describe the site, the work carried out and the results obtained. The interpretation of results should detail the analysis of field and laboratory results together with recommendations for use. The report must contain the essential information that is needed to exploit the gravel or to tender for its exploitation. The data should also be captured in a materials database.
4.1.16 References and Further Reading


Section 4.2 - Road Construction and Rehabilitation

4.2.1 Introduction

The performance of an unsealed road is directly dependent on the quality of construction. The best road materials will perform poorly if incorrect construction practices are followed. In the past, minimal attention has been given to unsealed road construction quality compared with that of sealed roads, where quality of construction is strictly controlled.

4.2.2 Approach to Construction

Historically, construction of forest roads in South Africa has not always been well controlled, resulting in rapid deterioration of the road, premature costly repairs, and unacceptable environmental impacts. Construction control of a forest road is no different than that of any other road and specifications should be strictly adhered to. The South African COLTO (Committee of Land Transport Officials) Standard Specifications for Road and Bridge Works (1998) document is recommended for this purpose.

4.2.3 Forest Road Construction Process

Forest road construction typically follows the chain of events detailed below and in the following subsections. Surfacing is listed here, but discussed in Section 4.5 (Surfacing Operations).

1. Engineering and Surveying
2. Right-of-Way Felling and Cross-Cutting
3. Clearing and Grubbing
4. Subgrade Construction
5. Culvert Installation
6. Ditch Construction
7. Surface Preparation
8. Surfacing

4.2.3.1 Engineering and Surveying

Engineering and surveying operations are discussed in Section 3.1 (Forest Road Design) and in the South African Forest Road Surveying Handbook.

1. Office Route Location
2. Field Route Location
3. Forest Road Survey
4. Construction Staking (if needed)
5. Plat and Contract Preparation
4.2.3.2 Right-of-Way Felling and Cross-Cutting

1. Right-of-way should be marked in field or specifications should be clearly communicated to felling crew.

2. Timber is typically hand felled with chain saws.

3. Logs should be cross-cut to lengths specified in contract.

4. Logs should be debranched as best as possible.

5. Dead trees outside of the right-of-way, but within reach of the work area must be felled for safety concerns.

6. Right-of-way should generally extend a minimum of 3 m beyond top of cut and toe of fill.

7. Felling should be conducted in a manner that minimises tree breakage and allows easy piece handling. Keep in mind that road right-of-ways tend to be narrow and present challenges in skidding, loading, and stacking.

4.2.3.3 Clearing and Grubbing

Clearing and site preparation is required for new roads, and must be considered when rehabilitating or upgrading existing roads to ensure proper right-of-way widths. Additionally, consideration must be given to water pipes, telephone lines, power cables and other facilities or improvements. The environmental implications of clearing operations should also be considered and guidance sought when necessary from an environmental practitioner if working in sensitive areas. An EIA may be required for new roads with due consideration given to sensitive resources.

Clearing of the right-of-way includes removal of all vegetation and obstructions from the road prism and any additional area needed to facilitate equipment movement. In planted areas, clearing should be kept to a minimum to limit the loss of timber resources. When working close to waterways, it may be necessary to take precautions to prevent sediment from washing into streams, such as installation of silt traps or silt screens.

For new road construction, the subgrade should be cleared of bush, trees, organic soil and other obstructions over the full width of the road prism with a hydraulic excavator or bulldozer. Holes and localised depressions remaining after clearing should be backfilled.

4.2.3.3.1 Clearing and Grubbing Guidelines

1. This stage of construction includes the removal of merchantable timber, unmerchantable timber, dead trees, windfalls, brush, stumps, and any other vegetation required to be removed by the road construction contract.

2. Another definition is the preparation of a portion of the road right-of-way for subsequent construction activities.

3. Merchantable logs should be stacked along the right-of-way or extracted to a location that will facilitate easy loading and extraction. It is often preferable to extract right-of-way logs prior to pavement construction. This minimises damage to a fresh road surface from loaded log trucks or from tracked or wheeled loading equipment.

4. Unmerchantable organic debris, such as tops, stumps, or dead trees should be piled along the lower edge of the right-of-way in a position where they will not be buried by embankment material. Decomposition of organic material within a fill will result in voids being created within the fill allowing water passage and uneven settling.

5. Stumps within the road prism are removed at this point. Additionally, any stumps which will have their root system compromised by the cut-bank should be removed. The engineer or operator must determine if these stumps will eventually end up sliding into the road or side drain, creating a maintenance problem.
6. The small stumps generally found in South African forests are easily removed with the blade of the crawler tractor or the hydraulic excavator bucket. Stubborn stumps may be split with a large stump-splitting attachment or removed by blasting.

7. Pioneer roads constructed during the clearing and grubbing phase should be located at the top-of-cut on excavated sections and at the toe-of-fill on embankment sections.

8. The engineer or construction supervisor must ensure that all debris marked for removal is actually removed. Failure to do so will reduce the efficiency of the subgrade construction phase of the project.

4.2.3.4 Subgrade Construction

Subgrade construction comprises the majority of road construction costs.

![Figure 4.2-1: Road Cross-Section.](image)

Common material can be excavated and loaded with a hydraulic excavator, while harder materials should be loosened by scarifying or ripping; or if this is not possible, then by drilling and blasting. Material is then moved by dozer (short distances, < 100-150 m) or by truck.

Fill compaction can be measured numerous ways, but the most practical method is the Dynamic Cone Penetrometer, as discussed in Section 3.2 (Pavement Design). Because embankment materials are naturally variable, it is recommended that a number of quick tests be carried out and the average density considered.

A good rule-of-thumb is that a well-compacted subgrade should not allow any impression from a boot other than a light outline of the tread pattern and should be difficult to compress when struck forcefully with the boot heel.
4.2.3.4.1 Subgrade Construction Guidelines

The actual process used in constructing the subgrade will vary for each job based on site-specific conditions, equipment used, and operator experience. The following description is intended to be a general sequence of events.

1. The first step in subgrade construction is to start the excavation at the top-of-cut stake or at the appropriate distance from the edge of the right-of-way. If a full-bench road is constructed, slope staking is very important, ensuring that the road will be constructed to the specified dimensions and not generate excess excavated material or be constructed too narrow.

2. Material is excavated or filled until the road is at the specified width and grade.

3. Fill material must be placed in layers of between 150 (fine grained material) and 250 mm (sand and rock) depending on soil type, aggregate size and compaction equipment. Layer depths should be at least 2.5 times the nominal stone size. On steep terrain, the ground on which the embankment is to be placed should be benched or stepped to provide a stable location for fill material to be placed and to facilitate compaction.

   The embankment material should be spread and mixed, watered to about optimum moisture content (OMC) and then compacted to a density of at least 90% Mod AASHTO (about 95% Proctor) maximum dry density.

   If the material is not at or near optimum moisture, water must be added until optimum moisture is reached. If material is too wet, construction must cease until moisture is reduced to an acceptable level. Material that is too wet does not compact properly and poses unacceptable environmental risks.

4. If the road is to be constructed out of blasted rock, construction can continue even during wet weather, provided no adverse environmental impacts, such as sedimentation of streams, occurs.
4.2.3.5 Culvert Installation

Excavation for culvert installation can be performed with dozers, excavators, backhoes, trenchers or using labour. Shoring of excavations may be necessary and should be done as prescribed by applicable safety regulations. Excavation should be carried out such that a stable and uniform foundation is provided for the satisfactory performance of the culvert. Trench foundations should be checked for hard or soft spots, which should be removed and replaced with quality material. A bed should be prepared to level out irregularities and ensure uniform support along the barrel of each culvert section. Culvert installation, including backfilling, should take place rapidly after excavation to avoid potential problems with surface and ground water.

Adequate compaction around culverts and headwalls must be provided. If a battery culvert-type installation is used, sufficient distance should be provided between the pipes to allow adequate compaction of the separating material. This will limit water from seeping through the embankment and undermining its stability. Backfill should be compacted, usually with handheld equipment, to the same standard as any other embankment material. Porous backfill should be sealed off at the culvert inlets and outlets with drainage provided, if needed.

Pipes and box culverts can be handled with conventional lifting equipment. If an excavator or front-end loader is used, the equipment and method of handling must be approved. If eyebolt holes are not provided, appropriately designed slings must be used.

Figure 4.2-3: Workers preparing culvert installation.

4.2.3.5.1 Culvert Installation Guidelines

1. Culverts can be installed either as the subgrade is being constructed (in the cases of fill) or upon completion of the subgrade.

2. Culvert locations should be marked during the preliminary road survey and then verified during the construction process. Occasionally, locations which appeared ideal for culvert locations during the survey phase, turn out to be less-than-ideal, and vice-versa, upon subgrade construction.
3. Culvert spacing should be based on a combination of road grade, precipitation patterns, ditch and subgrade material, and local knowledge (see section 3.3 – Drainage Design).

4. Culverts should be located where discharge will not directly enter a stream, but rather have an opportunity to filter out over natural ground prior to entering a stream.

5. Culverts that discharge onto fill material or sensitive soils should have an energy-dissipating device installed. These can include downspouts, flumes, old tyres, or rip-rap.

Figure 4.2-4: Culvert with downspout installed.

4.2.3.6 Side Drain Construction Guidelines

1. Side drains are needed along roadways to intercept and carry non-stream flows to a location where the flow accumulation can be safely dispersed downslope, predominately by way of cross-drain culverts.

2. Side drains must be constructed in a manner that ensures all water will flow to a cross-drain culvert or mitre drain.

3. Side drains are typically constructed with a motor grader, or in the case of solid-rock excavation, by drilling and blasting.

4. Side drain shape should be easily maintained by a motor grader, and the back slope should match the cut slope as much as possible.

5. Drain gradient should be a minimum of 1%, if possible, to allow water to flow and not pond.

6. Side drains should be a minimum of 300 mm deep, except at culvert locations, where a “catch-basin” is constructed deeper.

7. Catch basins should be constructed at culvert inlets to allow for trapping of debris and sediment that, over time, may plug the culvert inlet. A suitable dimension is 1 m x 1 m x 0.5 m.

8. Side drains constructed through erosive or sensitive soils may need to be armoured with rip-rap, geotextile fabric, or vegetative material.
4.2.3.7 Surface Preparation

The subgrade should be prepared in a similar manner to that described for embankment construction. After clearing, the material should be spread and mixed, sprayed with water to about optimum moisture content (OMC) and then compacted to a density of at least 90% Mod AASHTO (about 95% Proctor) maximum dry density. Adequate compaction strengthens the subgrade, reduces the possibility of subgrade deformation and reduces permeability. After compaction, the subgrade should be smoothed and shaped with a suitable crossfall or crown (about 2-4%).

Material of at least subgrade quality (CBR >3) should be used to build up the formation to a height of not less than 300 mm above the natural ground level in flat terrain. In flat areas, the formation should be high enough to allow the placement of drainage structures (usually culverts) at adequate depths beneath the wearing course. The material used for the formation should have some plasticity (a minimum plasticity index of about four) in order to provide a stable platform for construction of the pavement structure. Material for fill can usually be obtained during construction of the ditchline side and mitre drains. These drains should be deep and wide enough to remove all expected surface water from the road and adjacent areas during wet periods without ponding or excessive erosion.

Existing roads should not require extensive attention to the subgrade. However, if the assessment has revealed areas of severe deformation or transverse erosion, or the road has worn away to below the natural ground level, then corrective action must be taken.

If the road has worn away to below natural ground level, then the procedure detailed above should be followed. If isolated areas of deformation or erosion are noted, then spot improvements can be made. This would normally entail:

- Removal of unsuitable material and replacement with higher quality material;
- Incorporation of additional drainage measures;
- Raising the subgrade formation to promote drainage.
4.2.3.7.1 Surface Preparation Guidelines

1. Upon completion of subgrade and ditches to specifications set forth in the road contract, the subgrade is prepared for surfacing application.
2. A motor grader is used to smooth the subgrade and construct a crown, outslope, or inslope.
3. The surface is watered and a vibratory roller compacts the subgrade to a smooth, hard finish.
4. If necessary, the cut and fill slopes can also be smoothed with a motor grader.
5. The subgrade is then ready for surfacing application.

Surfacing operations are covered in Section 4.5

4.2.4 Slope Stabilisation

Slope stabilisation is an important aspect of road design and construction. Failure to stabilise slopes and inappropriate stabilisation practices can result in road closures and unnecessary expenses to rectify problems. Cut and fill slopes, riverbanks and bridge abutments can be inherently unstable and prone to erosion.

See Section 3.1.2.5.7 – Cut and Fill Slope Design for more details on slope design.

4.2.4.1 Water Control

Fill slopes are easily eroded by water. Erosion can be reduced by limiting the amount of water that flows over the slope or by protecting the fill. This can be achieved by providing adequate culverts and scour-protected flows that ensure that the water runoff is discharged onto solid ground or into waterways.

Cut and fill slopes should be adequately drained to relieve pore pressures within the slope, reducing the risk of slope failure. Drainage is essential where supporting walls (e.g. gabion baskets or blockwork) have been constructed. Without drainage, water build-up behind the wall will be forced outward or under the road. Drainage of slopes can be accommodated in catch drains and side drains that allow water to flow out of the slope and away from the road and away from cut and fill slopes. Holes can also be drilled into slopes to facilitate drainage. A porous geotextile should be placed behind the supporting structure to allow water passage, but retain soil material and sediment.

4.2.4.2 Geosynthetics

Various geosynthetics are commercially available for slope stabilisation. They are made of synthetic fibres or plastic formed into a mesh with differing hole sizes, depending on the problem that needs to be overcome. Geogrids hold soil particles within the grid, binding the material and allowing efficient load transfer from the soil to the grid.

Geogrids use two primary mechanisms to support slopes and retaining walls. For cut and fill slopes, grids are pinned to the surface of the slope to support the slope and to minimise local slumping and erosion. The grids will also promote re-vegetation by providing a mat type surface to support organic material and seeds. For retaining walls, the geogrid is used to "tie back" the wall to the soil behind it.

Additional discussion of geosynthetics can be found in Section 3.3 – Pavement design.

Information on where and how to use the grids should be obtained from the manufacturers or suppliers.
4.2.4.3 Gabions

Gabion structures can be used to support slopes and to provide erosion protection. Gabions are wire mesh baskets of varying sizes that are filled with stones and laced together to form a continuous structure. There are two types of gabion structures:

- Gabion baskets (typically 2 x 1 x 0.5 m) are designed to use their mass to support a toe of a slope, or to provide an effective retaining wall or bridge abutment. Retaining walls can be stepped, sloped or vertical depending on the situation.
- Gabion mattresses (6 x 2 x 0.24 m) are designed to overlay a riverbed or other surface to reduce the erosion effect of water flow. Stepped mattresses can be used for weir protection.

Gabions are flexible, owing to the combination of mesh and rock fill, which allows them to be used in variable conditions including soft or unstable ground where movement is expected, due to settlement. They are ideal for river and waterway erosion control, bridge abutments and approaches, and slope stabilisation. The high porosity of the mats generates free drainage through the structure, which reduces hydrostatic pressure build-up. Gabions can be used in combination with geogrids (tieback method) as reinforced earth retaining walls. Gabions can also be overlaid by concrete or vegetated.

Figure 4.2-7: Gabion Baskets and their use.
4.2.4.4 Slope Modification

Large cut slopes can become unstable due to the effect of gravity on the bank material. Since the toe of the slope must support all of the material above it, removing some of the cut bank material above the toe will relieve some of the downward pressure.

Reducing the angle of the cut or fill slope can reduce slope instability, reduce erosion and encourage re-vegetation. Soil material has a natural angle of repose and any slopes steeper than this angle will be inherently unstable. Reducing slope angle entails adding more fill, or removing more cut material to create a more stable angle.

In areas of heavy cut or deep fill, cut or fill slopes may be required to be steeper than normal. In these situations, a competent geotechnical professional should be consulted and a stabilisation plan developed. This often includes the use of geotextile fabrics and rip-rap to stabilise the slopes, and measures to reduce the pore water pressure found within the soil, such as weepholes or drainage pipes.

4.2.5 References and Further Reading

Section 4.3 - Landing Design and Construction

4.3.1 Introduction

A landing is defined as “any designated place where logs are laid after extraction and are awaiting subsequent handling, loading, and transport”. A landing is a location where the three disciplines of Forest Engineering, i.e. harvesting, road construction, and transport, meet. Landings are usually located at the origin of skid trails or cable systems, at suitable interfaces with the forest road network. Landings can be seen as the hub around which an efficient and productive harvesting and transport system rotates. A smooth flowing landing operation facilitates productivity in extraction and transport of timber.

A landing is a geographical location where a number of activities or a combination of activities may occur. The number of different activities on a landing and the way that these activities are organised influences landing size and shape. A landing may fulfill the following functions:

- To concentrate timber for subsequent loading and transport;
- A location where trees and logs are prepared (including delimming and cross-cutting) and sorted;
- A landing may facilitate subsequent forestry operation, such as acting as a helicopter landing zone for silviculture or firefighting operations.

4.3.2 Types of Landings

Landings are typically divided into two main types: centralised and continuous roadside landings. Both landing types are commonly used. The forester must know the inherent characteristics of each landing type, along with the relevant advantages and disadvantages so that an appropriate type of landing is used for a specific situation. Typical characteristics and advantages of both landing types are listed below:

4.3.2.1 Centralised Landings

A centralised landing can be defined as a centrally located area to which timber can be extracted from a spectrum of extraction routes. Figure 4.3-1 illustrates a centralised landing. Centralised landings are often constructed as part of the initial road construction project. Equipment used includes hydraulic excavators, dozers, and TLB’s.
Potential advantages of centralised landings:
- Landings can be well constructed;
- Landing activities impacts on a smaller area;
- Landing activities tends to interfere less with each other (i.e., loading trucks interfering with stacking or debranching);
- Landing activities cause less damage to the road;
- Transport moves to only one place where timber is concentrated;

Potential disadvantages of centralised landings:
- A certain amount of landing preparation or construction is needed before harvesting begins;
- Thorough planning is needed on landing location and layout;
- Less storage space is available for stockpiles of timber as compared to continuous landings.

4.3.2.2 Continuous Landings

Continuous landings can be defined as landing activities that occur continuously along the roadside. There is usually one landing per extraction route. After all timber has been extracted, the operation progresses further down the road to the next extraction route (Figure 4.3-2). Continuous landings are located on or next to the road. When they are situated on the road, little landing preparation is needed. Continuous landings are often constructed immediately prior to a harvesting operation. Typical construction equipment includes TLB's and small dozers.

![Continuous Landing](skidroads)

Figure 4.3-2: Continuous Landing.

Potential advantages of continuous landings:
- Less planning is needed;
- Little construction is needed;
- Cumulatively there is more stacking space available for stockpiles of timber;
- Continuous landings often reduce construction costs and soil erosion associated with large areas of cleared soil.

Potential disadvantages of continuous landings:
- Landing activities can damage large areas of the road and compartment;
- Timber is spread along the road, which increases loading times;
- Bigger areas are impacted if landing activities occur next to the road;
- Activities on the landing often interfere with each other because of restricted space.
4.3.3 Landing Location

Identifying landing locations is one of the initial steps in the harvest planning process. A harvest plan will often require both types of landings. For each specific landing location, the potential construction cost, environmental impacts, effect on extraction efficiency and safety aspects must be considered. The location of all landings must be shown on the harvest plan.

Landing location for Cable Yarding is described in detail in the *South African Cable Yarding Safety & Operating Handbook*. Landing location for ground based extraction should take into account the following factors:

- Truck transport distance;
- Vehicle access (Turn-around areas for trucks);
- Equipment capabilities and skidding distances;
- Topography (minimising uphill skidding);
- Log loading methods to be used;
- Environmental impact;
- Amount of decking and storage room needed;
- Number of log sorts;
- Drainage;
- Amount of machinery being used (i.e. multiple skidders, delimbers, loaders);
- Future harvest operations.

4.3.3.1 Terrain Considerations

The landing area should be relatively level to prevent timber from rolling downhill, while still allowing drainage. The soil type and its suitability as fill material for constructing the landing should be considered. Certain soils are difficult to compact, and may fail under loading, rendering the material unsuitable for fill construction.

The following criteria serve as guidelines when considering landing location:

- Landing should be located away from sensitive areas such as streams, wetlands and unstable soils (See Figure 4.3-3);
- Sites that facilitate the needed extraction direction;
- Dry areas on ridges or benches are preferred;
- Well-drained areas;
- Areas of moderate slope to reduce needed excavation.

![Figure 4.3-3: Landing location.](image)

Roadsides may be used if:

- Excavation is reduced;
- Landing areas and roads can be adequately drained;
- The resulting damage to the roadbed will not cause excess environmental damage or disruption to other forest management activities.
4.3.3.2 Landing Size

Landing size refers to the dimensions of the working surface of the landing. When considering the size of a landing there are no hard and fast rules.

In general, large and nearly-level landings are conducive to efficient landing activities. The following observations have been made:

- A reduction in landing size can only be achieved through an increase in harvesting cost.
- Small landings tend to reduce efficiency and increase safety risks.
- For steeper terrain, restricted landing size was found to cause a significant reduction in productivity.
- The larger the landing, the more economical the landing operations.

The above factors can be in conflict with environmental considerations. The experienced forester will take the following factors into account when considering size:

- The better the landing activities are planned, the smaller the landing can be.
- Size will depend on topography, volume to be extracted, number of activities to be performed, equipment used, stacking space needed and truck turning and loading.
- Landing size should be as small as possible, without effecting the efficiency and safety of the operation.
- Landings tend to grow over the course of the harvesting operation. The boundaries must be clearly marked on the ground to ensure that everyone knows where the boundaries are and to prevent growth of the landing.
- Utilising equipment such as excavator-based loaders will reduce soil compaction and disturbance on a landing.
- A buffer strip must be left between a landing and any stream, conservation area, or regularly travelled public road.

4.3.4 Landing Rehabilitation

Rehabilitation occurs when the landing is at the end of its useful life and will no longer be used. Rehabilitation minimises erosion and sedimentation and reduces the environmental and visual impacts that the landing may have caused. The extent of required landing rehabilitation will depend on the extent of the landing’s impact.

Erosion and runoff control is the minimum rehabilitation that should occur. Erosion control is achieved by slowing and dispersing the flow of water. Water should be redirected to flow over stable slopes and through established vegetation. Vegetative cover can act as a stabiliser by shielding the exposed soil from erosion. Figure 5.4 shows an example of a landing that has been rehabilitated by vegetative cover.

Figure 4.3-4: Example of rehabilitated roadside landing.
Cross-drains on the extraction routes discharge surface water into surrounding vegetation or slash to minimise concentration of water and reduce velocity. Deep ruts should be filled and drainage directed away from them. Slash piles should be piled and burned or broken down and spread on top of the landing. These actions facilitate future silvicultural operations and help to protect the landing against erosion.

When the harvesting team is finished using a landing, it is important to close the landing down from operation. Close-down activities include:

- Cleaning the site of non-biodegradable material and all solid waste, including oil/fuel drums and wire rope.
- Dispersal of any bark and landing residue evenly across the landing to assist in stabilisation.
- Grading the site so that it drains and is reasonably smooth.
- Seeding the bare areas or facilitating natural re-vegetation.

4.3.5 References and Further Reading


Section 4.4 - Road Maintenance

4.4.1 Introduction

Traffic and weather have a detrimental effect on unsealed roads, including loss of ride quality, accelerated loss of surfacing, and erosion-related sedimentation.

Timely maintenance is needed to ensure that a good riding surface, safe driving conditions and minimal environmental impact are maintained.

Maintenance operations range from routine preventative maintenance to on-demand corrective maintenance, as may occur after abnormal rainfall events.

The following issues are to be understood when planning for forest road maintenance operations:

- Understanding unsealed road defects;
- Roadside maintenance;
- Drainage maintenance;
- Surface maintenance;
- Regravelling.

4.4.2 Maintenance Procedures

The recommended procedure for unsealed forest road maintenance is illustrated in flowchart form in Figure 4.4-1.

The flowchart details the maintenance process from planning to re-gravelling. The forester begins at the top rectangle and progresses downwards, following the arrows to each subsequent rectangle, which details a maintenance procedure.
Figure 4.4-1: Strategy for unsealed road maintenance.
4.4.3 Defects found on Unsealed Roads

This section details common defects found on forest roads. Personnel involved in the maintenance and management of unsealed roads should be familiar with these defects, the causes, and corrective measures.

4.4.3.1 Gravel Quantity/Layer Thickness

Most unsealed roads are constructed with a wearing course of 150-250 mm of compacted gravel. Under traffic and environmental influences, this gradually wears away and requires periodic replacement to prevent subgrade exposure.

The rate of gravel loss is a function of the material properties and traffic patterns. As the traffic level increases, or as material quality deteriorates, the annual loss increases.

Assessment

During the visual assessment, it is necessary to estimate whether sufficient gravel remains to provide adequate service until the next assessment period. Assessment requires taking measurements of the layer thickness, or judgement by the engineer, taking into account material quality, traffic levels, subgrade exposure, or other road conditions.

Gravel quantity can be rated on a five-point scale as described in Table 4.4-1, or physically measured on the road by excavating small holes in the wheel tracks. This should be done at a frequency sufficient to determine a representative average for the segment. Output from the assessment will be millimetres of material remaining.

Table 4.4-1: Visual assessment of gravel quantity.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
<th>Description</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plenty</td>
<td>Good shape, and no stone protrusion</td>
<td>&gt;125</td>
</tr>
<tr>
<td>2</td>
<td>Sufficient</td>
<td>No exposures of subgrade, but some stone protrusion</td>
<td>100 – 125</td>
</tr>
<tr>
<td>3</td>
<td>Isolated exposures</td>
<td>Less than 25% exposure of the subgrade</td>
<td>50 – 100</td>
</tr>
<tr>
<td>4</td>
<td>Extensive exposures</td>
<td>Up to 75% exposure of the subgrade 75 to 100% exposure*</td>
<td>25 – 50</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td></td>
<td>0 – 25</td>
</tr>
</tbody>
</table>

Exposure of pipe drains, culverts and bedrock indicates neglect of the road and inadequate gravel cover. These structures must have adequate cover to protect them from traffic loading. Exposure of large stones should also be noted. If it is assumed that the surface of the road was level after compaction, the height of large stones above the surrounding road surface will give an indication of the amount of gravel that has been lost.

When less than 25% of the imported gravel wearing course material remains, but the exposed subgrade material appears to be performing adequately, the gravel quantity should still be rated as “none” to ensure that the road is prioritised for regravelling in the maintenance plan.

Action Required

Spot or full regravelling
4.4.3.2 Gravel Quality

The performance of an unsealed road depends primarily on the quality of the gravel used to construct the wearing course. Pavement material qualities are discussed in Section 3.2 – Pavement Design. Ideally, samples of the gravel should be tested in a laboratory. This is usually not feasible during annual assessments and a more subjective evaluation will often suffice. Training and calibration before the assessment will minimise the subjectivity.

Assessment

Gravel quality is rated on a five-point scale, as described in Table 4.4-2.

Table 4.4-2 Visual Assessment of gravel quality

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very good</td>
<td>Evenly distributed range of particle sizes and sufficient plasticity that the material will leave a shiny streak when scratched with a pick. No significant cracking, ravelling and/or excessive oversize</td>
</tr>
<tr>
<td>2</td>
<td>Good</td>
<td>Minor ravelling or cracking and/or minimal</td>
</tr>
<tr>
<td>3</td>
<td>Average</td>
<td>Cracking, loose material or stones clearly visible,</td>
</tr>
<tr>
<td>4</td>
<td>Poor</td>
<td>Poor particle size distribution with excessive oversize. Plasticity high enough to cause slipperiness. Ravelling is sufficient to cause loss of traction.</td>
</tr>
<tr>
<td>5</td>
<td>Very poor</td>
<td>Poorly distributed range of particle sizes and/or zero or excessive plasticity. Cracking and/or quantity of loose material/ stones are significant and affect safety of road user. Excessive oversize</td>
</tr>
</tbody>
</table>

The factors influencing the rating must also be recorded. The following factors can be marked:
- Excessive clay and/or silt (i.e. plasticity too high);
- Excessive sand – loose with insufficient fines (i.e. plasticity too low);
- Excessive oversize stones and/or loose gravel.

If the gravel quantity has been rated as “extensive exposures” or “none”, it is still necessary to rate the related performance. This rating should be applied to the predominant surface material on the running surface, whether it is subgrade or the remaining wearing course. This assessment should be carried out in terms of the road users’ perception of the road and the ability to carry out effective maintenance.

Action Required

Mechanical or chemical stabilisation. Regravelling.

4.4.3.3 Road Cross-Section

The shape of the cross-section of a road has a substantial impact on road performance. Roads with a proper cross-section shed water efficiently, avoiding the development of potholes and potentially impassable conditions. Where the road cross-section is flat, water tends to pond in depressions resulting in softening of the wearing course and the development of potholes and other ruts. Rutts may become water paths resulting in erosion, sedimentation, accelerated gravel loss and significant deterioration in riding quality.
Assessment

The road cross-section is rated on a five-point scale where one is very good and the road surface will shed water easily, and five is very uneven resulting in ponding and/or surface rutting. These are defined in Table 4.4-3 and illustrated in Figure 4.4-2. The influence of the cross-section becomes greater as the road grade increases.

**Table 4.4-3: Visual assessment of gravel profile.**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very good shape</td>
<td>Well formed camber (about 3 - 4 per cent)</td>
</tr>
<tr>
<td>2</td>
<td>Good shape</td>
<td>Good camber (about 2 per cent)</td>
</tr>
<tr>
<td>3</td>
<td>Flat</td>
<td>Some unevenness with camber mostly less than 2 per cent</td>
</tr>
<tr>
<td>4</td>
<td>Uneven</td>
<td>Obvious development of irregularities that will impede drainage and form depressions</td>
</tr>
<tr>
<td>5</td>
<td>Very uneven</td>
<td>Development of severe irregularities impeding drainage and likely to cause extensive localised ponding. Water tends to flow to the centre of the road or individual lanes</td>
</tr>
</tbody>
</table>

**Figure 4.4-2: Gravel Profile Schematics.**

Action Required

Blade for rating of 3 or 4. Rip, shape and recompact for rating of 5.

### 4.4.3.3.1 Drainage from the Road

Road drainage and road cross-section are strongly related. The cross-section relates directly to the capacity of the road to shed water without causing erosion, while drainage from the road relates more closely to the impact of standing water on the surfacing and subgrade. Functioning side drains are crucial for proper road drainage. Effective drainage must remove water from areas adjacent to the road to reduce erosion.

Assessment

Drainage from the road is rated on a five-point scale. A rating of one indicates that the road is well above ground level and has effective side drains leading water away from the road formation, while a rating of five is classified as a canal where the road acts as the primary drainage path in the area. These are defined in Table 4.4-4 and illustrated in Figure 4.4-3. The descriptors are applicable to roads in gentle terrain. Steep terrain amplifies the effects of road drainage, and maintenance becomes much more critical to prevent severe damage.
Table 4.4-4: Visual assessment of drainage/road formation.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Well above ground level</td>
<td>Edges of road are at least 300 mm* above natural ground level with effective side drains.</td>
</tr>
<tr>
<td>2</td>
<td>Slightly above ground level</td>
<td>Road is between 50 and 300 mm above natural ground level. Side drains are present. Stormwater could cross in isolated places.</td>
</tr>
<tr>
<td>3</td>
<td>Level with ground</td>
<td>Road is generally at ground level with ineffective side drains. Stormwater could cross in most places.</td>
</tr>
<tr>
<td>4</td>
<td>Slightly beneath ground level</td>
<td>Isolated areas of the road are below natural ground level. No side drains are present and localised ponding of water will occur.</td>
</tr>
<tr>
<td>5</td>
<td>Canal</td>
<td>Road is the lowest point and serves to drain the entire area.</td>
</tr>
</tbody>
</table>

* If pipes are laid under the road for cross drainage, then the formation should be at least 500 mm above natural ground level.

Figure 4.4-3: Schematics of road drainage.

Figure 4.4-4: Erosion on forest road.

Additional information may be required on the presence, condition and effectiveness of culverts and mitre drains. This will entail written information on the structures with recommendations on maintenance or upgrading if required.

**Action Required**

Assess drainage design. Implement requirements. Repair damage once cause has been corrected.
4.4.3.4 **Ride Quality**

The riding quality of the road is a major performance parameter affecting driver and passenger comfort and safety. Riding quality has a significant impact on the overall vehicle operating costs associated with the road.

Road roughness is influenced primarily by maintenance frequency, skill of maintenance operators, material properties and traffic levels. Other factors such as rainfall and heavy seasonal traffic will also have an influence. Those defects influencing riding quality are:

- Corrugation;
- Loose material;
- Stoniness;
- Potholes;
- Ruts;
- Erosion.

More detail is given on these defects in later sections.

**Assessment**

Riding quality is rated as a function of the “estimated” comfortable and safe driving speed (neglecting the influence of geometric constraints or road width) which the road could be traversed in a bakkie. This is estimated while travelling at the speed recommended for the appropriate road design class and is interpreted as follows (Table 4.4-5):

<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very good</td>
<td>Road can be comfortably traversed at original design speed</td>
</tr>
<tr>
<td>2</td>
<td>Average</td>
<td>Road can be traversed at 50-70% of original design speed</td>
</tr>
<tr>
<td>3</td>
<td>Poor</td>
<td>Road cannot be traversed above 50% of original design speed without undue discomfort</td>
</tr>
</tbody>
</table>

Riding quality is measured in conjunction with an assessment of the parameters that influence it.

**Action Required**

Blade/drag, modify material or regrav el depending on problem, cause and severity.

4.4.3.5 **Dust**

**Definition and Cause**

Road dust is the dry solid matter consisting of clay and silt-sized particles that is carried by wind, the wind forces created by vehicles and the interaction of vehicle tyres with the road and which disperses and remains in suspension for a period 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.
**Problem**

Dust is undesirable for the following reasons:

- Safety (loss of visibility);
- Economic (accelerated gravel loss);
- Vehicle occupant comfort;
- Health (respiratory ailments);
- Vehicle wear (filters and exposed moving parts);
- Environmental (degradation of air and water quality).

Dust levels can be considered unacceptable when the dust-generating vehicle cannot be seen by a following vehicle.

**Measurement**

At network level, assessment of dust levels are necessary as input for prioritising a potential dust problem and determining the costs of applying a dust palliative. In assessing the dustiness of a road, the moisture condition at the time of assessment plays a major role. Dust generation is influenced by many factors and some subjectivity during assessment is required. The following procedure has been developed in an attempt to bring some uniformity to dust assessment.

For the purposes of strategic network level assessments, dust is usually rated as either acceptable or unacceptable with safety being the major factor taken into account. If the dust generated by a vehicle is perceived to be dangerous, it should be rated as unacceptable. Dustiness should be rated in the rear view mirror while travelling at 30-40 km/h. This may require that short distances within the segment be monitored at this higher speed. Wind speed and lighting conditions (position of the sun) can influence rating in this way and should be taken into consideration.

While specialised equipment is available, a visual evaluation as well as a subjective assessment of dust on vehicle occupant comfort will suffice in most instances. This is carried out either by the driver of the vehicle travelling at 40 km/h and using the rear-view mirror to assess the dust generated by the vehicle, or by an observer at roadside. Occupant discomfort is judged on the necessity to close windows and ventilation systems. Runs should be made in both directions to determine the effect of the sun, with an average degree recorded (rounded upwards where necessary). Trucks generate significantly more dust than cars and light duty vehicles and ratings will be unacceptable on most roads. Dust ratings on roads with a daily high percentage of heavy vehicles (e.g. > 30%) will often be rated unacceptable.

The description of degrees of dustiness is given in Table 4.4-6. The extent of dust is not normally estimated.

**Table 4.4-6: Degrees of dustiness.**

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No loss of visibility</td>
</tr>
<tr>
<td>3</td>
<td>Some loss of visibility – no discomfort</td>
</tr>
<tr>
<td>5</td>
<td>Dangerous loss of visibility – significant discomfort</td>
</tr>
</tbody>
</table>

**Action Required**

Chemical dust control. Erect warning signs.
4.4.3.6 Trafficability

Trafficability (or passability) is the capacity of a bakkie to negotiate the road without losing traction or without excessive use of low gears. The terms trafficability and passability are used interchangeably throughout this document (however, impassability should not be confused with the inability to overtake in dusty conditions). The mechanism affecting trafficability is the loss of traction between the tyres and the road resulting from low shear strength of the surface material. This results in churning of the material and settlement of the vehicle into the weak layer. Sandy materials are more prone to impassability when dry, while clayey materials are strong when dry, but often become impassable when wet. Impassable conditions may result from continued trafficking of slippery roads.

Problem

The primary objective of importing wearing course gravel during the construction of an unsealed road is to provide an all-weather surface. This objective is not met if the material becomes impassable in wet weather. This is often a particular problem with earth roads where in situ materials are used.

Assessment

Impassability is difficult to assess unless the observer actually experiences the condition at its worst. Evidence of earlier impassable conditions often remains after the event. This includes:
• Deep ruts and evidence of large potholes;
• Detouring on the shoulders and to avoid wet areas;
• Material used to fill depressions and to provide temporary traction (often including vegetation).

For assessment purposes, trafficability is rated as acceptable or unacceptable, the latter only being used when definite evidence is observed over a major portion of the segment.

Action Required

Erect warning signs and/or choose alternative routes for isolated instances. Mechanical stabilisation or regravel for longer stretches.

4.4.3.7 Potholes

Potholes are round or elongated depressions in the road surface and arise from the following:
• Poor road shape and drainage;
• Poor grader operation practice (e.g. plucking of oversize material and destruction of the crown);
• Compaction of material behind oversize stones under wheel loads;
• Poor compaction;
• Material and moisture variability;
• Enlargement of corrugation troughs;
• Deformation of weak subgrades and wearing courses;
• Subsidence or excavation of animal and insect burrows;
• Disintegration of highly cracked roads (i.e. excessive plasticity);
• Disintegration of soft oversize materials;
• Dispersive soils.
Problem

Potholes play a significant role in the development of roughness on unsealed roads and may cause substantial damage to vehicles if they are allowed to develop and increase in size. The effect of potholes on vehicles depends on both the depth and diameter of the pothole. Potholes that affect vehicles the most are those between 250 and 1 500 mm in diameter with a depth of more than 50 to 75 mm.

Once pothole formation has been initiated (irrespective of the cause), the drainage deteriorates, water ponds in the depressions and the potholes are enlarged by traffic. Enlargement occurs through compaction and remoulding of the weakened material (in the wet state) and removal of the material from the hole by the wheels and splashing. Materials with a low soaked strength are thus likely to develop larger and deeper potholes in shorter periods. The influence of drainage on pothole formation is clearly manifested by the general absence of potholes on grades. Potholes are usually worst at the bottom of vertical sag curves, on level road sections with poor shape, and near bridges. The influence of potholes on riding quality is a function of both the degree and extent of the potholing (i.e. many degree 3 potholes have a greater impact on riding quality than a few degree 5 potholes). The descriptions of degrees of potholing are given in Table 4.4-7.

![Figure 4.4-5: Potholing.](image)

**Table 4.4-7: Degrees of potholing.**

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Depressions just visible. Cannot be felt in the vehicle</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 20 mm deep</td>
</tr>
<tr>
<td>3</td>
<td>Larger potholes affecting safety – 20 – 50 mm deep</td>
</tr>
<tr>
<td>4</td>
<td>50 – 75 mm deep</td>
</tr>
<tr>
<td>5</td>
<td>Large, dangerous potholes requiring evasive action – &gt; 75 mm deep</td>
</tr>
</tbody>
</table>

**Action Required**

Identify cause and take corrective action to prevent recurrence when potholes are graded 3. Improve drainage and/or excavate and replace offending materials.
4.4.3.8 Rutting

Ruts are parallel depressions of the surface in the wheel tracks. Ruts form as a result of loss of gravel from the wearing course by traffic abrasion or by deformation of the subgrade and wearing course.

Problem

Ruts tend to retain and channel rainwater, negatively impacting road safety and softening the wearing course, leading to deformation under traffic. Routine blading of unsealed roads replaces gravel in the ruts and compensates for any subgrade deformation that may have occurred. The material graded into the ruts is generally compacted by traffic only when in a moist condition.

Assessment

Ruts are assessed in terms of their capacity to retain water using a visual estimate of their average depth. The descriptions of degrees of rutting are given in Table 4.4-8.

![Figure 4.4-6: Rutting on forest road causing sedimentation.](image)

Table 4.4-8: Degree of rutting.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rutting is just visible</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 20 mm deep</td>
</tr>
<tr>
<td>3</td>
<td>Rutting between 20 – 40 mm deep</td>
</tr>
<tr>
<td>4</td>
<td>40 – 60 mm deep</td>
</tr>
<tr>
<td>5</td>
<td>Rutting &gt; 60 mm deep affecting directional stability of a vehicle</td>
</tr>
</tbody>
</table>

Action Required

Blade if rating 4 or less. Rip and recompact if rating is 5.
4.4.3.9 Erosion

Erosion or scour is the loss of surfacing material caused by the flow of water over the road. The ability of a material to resist erosion depends on the shear strength (equal to the cohesion, as the normal stress is zero) under the conditions at which the water flow occurs. If the shear strength of the material is less than the tractive forces induced by the water flowing over the materials, grains will become detached and erosion will occur.

Problem

Erosion results in channelling and rutting, causing extreme roughness, dangerous driving conditions, and unacceptable environmental impacts. A significant loss of gravel may result. Much of this gravel is deposited in the drains and culverts necessitating extensive labour-intensive maintenance. Erosion of the wearing course also results in a change in the properties of the material as various fractions of the material are selectively removed.

Assessment

Transverse or diagonal erosion channels can be quantified by their depth and width. However, they are best assessed in terms of their effect on riding quality. Longitudinal erosion channels are assessed in a similar way to ruts by visual estimation. Assessments should only relate to the trafficked area and not to the side drains. The descriptions of degrees of transverse and longitudinal erosion are given in Tables 4.4-9 and 4.4-10, respectively.

Table 4.4-9: Degrees of transverse and diagonal erosion

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minor evidence of water damage</td>
</tr>
<tr>
<td>2</td>
<td>Seen, but not felt or heard (channels 10 mm deep x 50 mm wide)</td>
</tr>
<tr>
<td>3</td>
<td>Can be felt and heard – speed reduction necessary (30 mm x 75 mm)</td>
</tr>
<tr>
<td>4</td>
<td>Significant speed reduction necessary (50 mm x 150 mm)</td>
</tr>
<tr>
<td>5</td>
<td>Vehicles drive very slowly and attempt to avoid them (&gt;60 mm x 250 mm)</td>
</tr>
</tbody>
</table>

Table 4.4-10: Degrees of longitudinal erosion.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evidence of water damage</td>
</tr>
<tr>
<td>2</td>
<td>Channels &lt; 20 mm deep</td>
</tr>
<tr>
<td>3</td>
<td>Channels 20 – 40 mm deep</td>
</tr>
<tr>
<td>4</td>
<td>Channels 40 – 60 mm deep</td>
</tr>
<tr>
<td>5</td>
<td>Channels &gt; 60 mm deep</td>
</tr>
</tbody>
</table>
4.4.3.10 Corrugation

Corrugations can be either “loose” or “fixed”. Loose corrugations consist of parallel alternating crests of loose surface material and troughs of compacted material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted crests and troughs of hard, fine sandy-gravel material. Loose corrugations are easily removed by blading or dragging, whereas fixed corrugations need cutting or even tining with the grader before the material is re-spread.

Corrugations are caused by the initiation of wheel bounce by irregularity in the road (or possibly even worn suspension components such as shock absorbers) that results in kick-back of non-cohesive material, followed by compression and redistribution of the wearing course as the wheel regains contact with the road. Only low plasticity materials corrugate significantly, especially those with a high sand and fine-gravel fraction. However, many roads with gravels having plasticity indices of up to nine have produced corrugations. Many corrugations form when the material is continually spread from the sides of the road back onto the road during grader maintenance. This material is usually deficient in binder (most of it having been blown away with time as dust) and the material forming the corrugations is non-plastic.

Problem

Corrugations are one of the most disturbing defects of unsealed roads causing excessive roughness and poor vehicle directional stability. Corrugations seldom form to any significant
extent during the wet season, as the material effectively remains slightly "cohesive" in its wet state through capillary suction and is not adequately mobile to form corrugations. Corrugations are frequently associated with areas of steep grades, acceleration, deceleration and cornering.

**Assessment**

Corrugations should be scraped with a geological pick to determine whether they are loose or fixed – this will dictate the type of maintenance that will be required. The severity of corrugations is best assessed from within a moving vehicle at the average speed of the road. The descriptions of degrees of corrugation are given in Table 4.4-11.

**Table 4.4-11: Degrees of corrugation.**

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not felt or heard in a light vehicle</td>
</tr>
<tr>
<td>2</td>
<td>Can be felt and heard – no speed reduction necessary</td>
</tr>
<tr>
<td>3</td>
<td>Can be felt and heard – speed reduction necessary</td>
</tr>
<tr>
<td>4</td>
<td>Significant speed reduction necessary</td>
</tr>
<tr>
<td>5</td>
<td>Drivers select a different path and drive very slowly. Safety is affected</td>
</tr>
</tbody>
</table>

**Action Required**

Alter maintenance plan to drag or blade more frequently. Consider mechanical stabilisation with clay or regravelling if maintenance cannot be increased.

**4.4.3.11 Loose Material**

Loose material (material less than 26 mm in size) is formed by ravelling of the wearing course during traffic. Loose material may be distributed over the full width of the road but more frequently, it is concentrated in windrows between the wheel tracks, or alongside the travelled portion of the road. It is often caused by a deficiency of fine material (because of lack of cohesion), a poor particle size distribution (e.g. gap grading) in the wearing course gravel and/or inadequate compaction. Ravelling is generally worse in the dry season than in the wet season when capillary suction results in apparent cohesion.

**Problems**

The major problems with roads susceptible to ravelling are:

- The windrows are a safety hazard, affecting vehicle steering;
- Stones from the loose material may damage vehicles or windscreens;
- The rolling resistance of the vehicle is increased by loose material with resulting increases in fuel consumption and vehicle operating costs;
- Windrows of loose material adjacent to the trafficked portion of the road impede surface drainage.
**Assessment**

Loose material is assessed by estimating or measuring its thickness. This is achieved by scraping “paths” through the loose material to the hard surface with a geological pick and estimating the thickness or measuring it with a straightedge and wedge. The descriptions of degrees of loose material are given in Table 4.4-12.

**Table 4.4-12: Degrees of loose material**

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Just visible</td>
</tr>
<tr>
<td>2</td>
<td>Loose material &lt; 20 mm thick</td>
</tr>
<tr>
<td>3</td>
<td>Loose material 20 – 40 mm thick</td>
</tr>
<tr>
<td>4</td>
<td>Loose material 40 – 60 mm thick</td>
</tr>
<tr>
<td>5</td>
<td>Loose material &gt; 60 mm thick</td>
</tr>
</tbody>
</table>

**Action Required**

Alter maintenance plan to drag or blade more frequently. Consider mechanical stabilisation or regravelling if maintenance cannot be increased.

**4.4.3.12 Stoniness**

Stoniness is the relative percentage of material embedded in the road that is larger than a recommended maximum size (usually 37.5 mm). This is one of the few defects that can be controlled, but is usually not.

The blading process periodically leaves loose stones (larger than 37.5 mm sieve) lying on the surface.

**Problem**

Excessively stony roads result in the following problems:
- Unnecessarily rough roads;
- Difficulty with grader maintenance;
- Poor compaction of areas adjacent to stones (leading to potholes and ravelling);
- The development of corrugations;
- Thick, loose material is necessary to cover the stones;
- Loose stones left after blading are likely to cause vehicle damage and potentially unsafe conditions.

Many geological materials, particularly shale and hornfels, produce flaky or sharp stones when crushed or grid rolled. These can cause damage to tyres and affect the safety of road users.
Assessment

Stones can be measured to determine the percentage that the maximum size limit has been exceeded by. This is time-consuming and an estimate of their severity and extent is usually sufficient. It should be noted that the extent of stoniness is usually overestimated by a significant margin. The impact of stoniness on riding quality is best evaluated from a moving vehicle. This can be supplemented by assessing the impact of the stones on the ease of blading. The descriptions of degrees of stoniness are given in Tables 4.4-13 (embedded stones) and 4.4-14 (loose stones). Dedicated roughness measuring equipment can also be used to determine the road roughness if this level of detail is required.

Table 4.4-13: Degrees of embedded stoniness

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Seen, but not felt or heard in a light vehicle</td>
</tr>
<tr>
<td>2</td>
<td>Protruding stones can be felt and heard, but speed reduction not necessary. Blading is not affected.</td>
</tr>
<tr>
<td>3</td>
<td>Speed reduction necessary. Road is bladed with difficulty.</td>
</tr>
<tr>
<td>4</td>
<td>Protruding stones require evasive action</td>
</tr>
<tr>
<td>5</td>
<td>Vehicles avoid protruding stones or drive slowly. Road cannot be effectively bladed.</td>
</tr>
</tbody>
</table>

Table 4.4-14: Degrees of loose stoniness

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Few loose stones 25 – 40 mm. Driver can change lanes safely</td>
</tr>
<tr>
<td>3</td>
<td>Many loose stones 25 - 50 mm or few loose stones &gt; 50 mm. Stones influence drivers actions when changing lanes.</td>
</tr>
<tr>
<td>5</td>
<td>Windrows of loose stones 25 – 50 mm or many loose stones &gt;50 mm. Any lateral movement of the vehicle poses a significant safety hazard.</td>
</tr>
</tbody>
</table>

Action Required

Process oversize material with hammermill. Remix and compact.
4.4.3.13 Slipperiness and Skid Resistance

Slipperiness is the loss of traction caused by high plasticity wearing courses or an accumulation of excessively fine or plastic material on the surface in wet conditions. Skid resistance is affected by an excess of loose, fine gravel (between 2 and 7 mm in diameter) that accumulates on the road surface through ravelling under traffic or poor blading practices during dry conditions. This behaves like a layer of ball bearings and the skid resistance is reduced to practically zero. This is especially a problem on corners and at intersections.

Problem

The main problems with slipperiness and skid resistance are the safety implications for road users.

Assessment

Slipperiness is difficult to assess unless the observer experiences the condition. However, it can often be evaluated by observing tyre tread impressions formed during wet weather that are retained in the road after drying and other indicators. Slipperiness is rated as either acceptable or unacceptable. Skid resistance, also rated as either acceptable or unacceptable, should be evaluated in terms of the effect of loose material on vehicle stability and the general impression gained while driving and braking on the dry road. These ratings are summarised in Tables 4.4-15 and 4.4-16.

Table 4.4-15: Rating of slipperiness.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable</td>
<td>Exposed and protruding gravel on road surface. No significant cracking (£ Degree 3 (Table 4.4-17)). No evidence of tyre impressions remaining on the road surface.</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>Smooth clayey surface with few protruding gravel particles. Significant cracking (&gt; Degree 3 (Table 4.4-17)). Evidence of tyre impressions remaining on the road surface. Evidence of compaction and shearing under traffic. Loss of control when driving on a wet surface.</td>
</tr>
</tbody>
</table>

Note: The absence of evidence of slipperiness does not necessarily mean that the road will not be slippery. The evidence described above tends to be worn away under traffic within 6-8 weeks, or may be removed by blading.

Table 4.4-16: Rating of skid resistance.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable</td>
<td>No excessive fine gravel (2-7 mm) in the wheel tracks. Exposed and protruding gravel on road surface. Good directional control when braking.</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>Presence of layer of fine gravel (2-7 mm) in the wheel tracks. Loss of directional control when braking.</td>
</tr>
</tbody>
</table>

Action Required

Erect warning signs and/or choose alternative routes for isolated instances. Mechanical stabilisation or regravel for longer stretches.
4.4.3.14 Cracks

Cracks may be indicative of other problems within the subgrade or pavement structure. Cracking can be used to support other assessments (e.g. severe cracking is indicative of high plasticity gravels as well as the potential for unacceptable slipperiness). These data may also be useful for project level or research assessments.

Cracking of the wearing course (which usually occurs only during the dry season) is a result of the plasticity being too high or the material being very fine-grained. Cracks may also be indicative of an unstable subgrade fill.

Problem

Cracks as such are not a major problem on unsealed roads, but bad cracking may lead to the formation of potholes during the dry season. Materials that crack badly also tend to become slippery when wet. Roads with 100 to 150 mm diameter cracked blocks will often break up under traffic and form potholes.

Assessment

Cracks should be visually assessed on the basis of crack width, which may be measured if necessary as described in Table 4.4-17.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Faint – requires close scrutiny</td>
</tr>
<tr>
<td>2</td>
<td>Distinct – seen at walking pace</td>
</tr>
<tr>
<td>3</td>
<td>Distinct – seen from a moving vehicle</td>
</tr>
<tr>
<td>4</td>
<td>Open cracks - d&lt;5 mm wide</td>
</tr>
<tr>
<td>5</td>
<td>Open cracks - &gt; 5 mm wide</td>
</tr>
</tbody>
</table>

4.4.4 Roadside Maintenance

In forested areas, the roadside is defined as the space between the edge of the travelled roadway and the first row of trees. The roadside space can range from virtually nothing to a large firebreak. A space of 3 m is considered the ideal minimum for vehicle safety, road maintenance, and to allow the road to dry out under wet conditions.

4.4.4.1 Vegetation

The primary maintenance activity affecting the roadside is bush clearing and grass cutting. Brush clearing and mowing is primarily carried out for safety and fire protection reasons, but also to avoid damage to vehicles from vegetation overhanging the pavement edge. The frequency of these operations should be set by site-specific conditions. Areas with a high rainfall and short-radius horizontal and vertical curves (i.e. short sight distances) will require considerably more vegetation control than long straight roads in drier areas.
4.4.4.2 Cut and Fill Slopes

The repair and prevention of erosion affecting cut and fill slopes and side drains is an important maintenance activity that should not be neglected. A cost-effective method of preventing erosion is the establishment of vegetation. Cuts and fills should be constructed at suitable slopes (see Section 3.1) to allow the establishment of vegetation with cut-off drains or catchwater banks just behind the crest of the cut or fill. Should erosion occur, the erosion channels should be back-filled with rocks and grouted if possible. Erosion of side drains can be minimised with a rock lining and some form of obstacle (e.g. rock dams, vegetation) to retard the speed of the water flow. Vegetation must be managed, as siltation often results in vigorous vegetation growth and eventual filling of the drain.

Erosion of culvert inlets and outlets is a common problem and control structures (e.g. rock rip-rap or concrete wing-walls) may be considered at problem sites. With time, the erosion protection measures themselves may require significant maintenance.

4.4.5 Drainage Maintenance

Drainage problems affecting unsealed forest roads are significant, especially in the high rainfall mountainous areas. Many problems can be prevented by improved drainage maintenance. A drainage system, adequate at construction, will often become inadequate with time, due to drains becoming eroded and/or silted up.

Assessment

An assessment of the drainage system should be carried out at periodic intervals, usually soon after significant rainfall events. This is achieved by driving along the road and investigating any areas of ponding on or near the road as well as localised areas of slipperiness, impassability, potholing and erosion.

Defects listed above are indicative of insufficient or impeded drainage. Cross drains should also be inspected. Transverse erosion channels are often a good indicator of blocked or insufficient pipes, while longitudinal erosion is often a good indicator of poor road shape in that the water runs along the road instead of off being transferred to a side drain.

4.4.5.1 Need for New Drains

If additional side or mitre drains are required, the grader operator should be instructed on where to place them during the next routine maintenance visit to the road. In some cases, the drains may need to be constructed immediately, and cannot wait until the next routine maintenance operation. If additional pipes are required, these should be planned into the maintenance programme and funds budgeted accordingly.

4.4.5.2 Maintenance of the Camber

The surface of the road should be well maintained with an appropriate camber or cross-fall and without potholes, deep corrugations or ruts. A properly maintained road will remove rainwater from the road surface without causing surface erosion. Local experience has shown that a cross-fall of about four per cent is optimum, allowing adequate run-off without causing erosion. Longitudinal slopes and cross-falls steeper than about 5% are prone to erosion. Erosion is characteristic to steep areas, and a higher level of maintenance is required in these locations.
4.4.5.3 Maintenance of Side and Mitre Drains

Side and mitre drains should be designed and constructed with dimensions (widths and slopes) that allow easy maintenance with a motor grader during routine surface maintenance operations. The grader operators should ensure that all drains have an adequate fall with no low spots where water may pond. Routine blading of the road surface must not leave windrows blocking the entrance to mitre drains.

Deep V-shaped side drains are difficult to maintain (even manually), are not always effective and are often unsafe, even for lightly travelled roads.

Manual clearing of drains of silt and excessive vegetation is often cost-effective. Drain maintenance should retain the grass cover (cut instead of bladed), which reduces the erosion potential. Extra care is needed during manual clearing around culverts and drains.

Excessive silting of drains is indicative of inadequate water flow velocities, while erosion is indicative of excessive velocities.

4.4.5.4 Culverts

Regular culvert maintenance is needed to prevent blockage and the resulting erosion and damage of the road. Material removed during culvert maintenance must not be used on the road surface and should be deposited in a location where it will not erode and cause sedimentation. Culvert outlets must be cleaned to ensure free-flowing conditions. Additionally, any downspouts, energy dissipation devices, or sediment traps at the culvert outlet should be inspected and maintained if needed.

4.4.6 Surface Maintenance

Surface maintenance contributes a substantial portion of any maintenance budget, therefore, it must be conducted properly to effect the most return on investment. The scheduling for blading will vary, depending on the climate, traffic, required level of serviceability and available funding. Regravelling is necessary at intervals of between five and ten years (typically for traffic volumes of between 200 and 500 vehicles per day) depending on the traffic and maintenance programme. Poor or inadequate maintenance will invariably lead to accelerated gravel loss, increased maintenance costs, and increased vehicle operation costs.

4.4.6.1 Grader Blading

The standard procedure for surface maintenance is grader blading. A grader is run across the surface of the road with the blade set to smooth and shape the surface. After grading, no potholes, corrugations, excessive loose material, large boulders, ruts or erosion channels should be present. Straight portions of the road should have a definite crown and cross-fall, while curves should have an adequate super-elevation for safety, if warranted by vehicle speeds.

Blading can be classified as either light or heavy.

4.4.6.1.1 Light Blading

During the wet season, blading should be carried out when the road is moist but not wet as the material is most easily cut, moved and compacted in this condition. Blading should entail a light trimming of the road surface on a routine basis, with loose material bladed towards the centre of the road. Windrows should not be left on the side of the road where they will impede the flow of water and all mitre drains should be opened.
During the dry season, the hard upper crust that often forms on unsealed roads should not be cut, as this will reduce the riding quality instead of improving it. Instead, the loose surface material should be lightly spread over the surface of the road with any excess moved towards the side of the road. The drainage system should, however, be kept functional in case of unexpected rain.

4.4.6.1.2 Heavy Blading

Heavy blading should be carried out when inspection reports indicate excessive defects. The road surface is scarified and cut to a depth equal to the bottom of the deformations and reshaped. This should only be done when the road is moist and more than 75 mm of surfacing aggregate remains. Heavy grading is often necessary when “fixed corrugations” have formed. These corrugations may need initial ripping or deeper cutting to break them up before being graded and recompacted.

4.4.6.1.3 General Grading Guidelines

Loose material is a significant problem on unsealed roads. Many single vehicle accidents on unsealed roads are caused by windrows of loose material on the roads. These windrows interfere with the directional stability of vehicles, which may eventually overturn - the higher the vehicle speed, the greater the interference. It is important to ensure that these windrows do not become higher than 50 mm. In addition to the vehicle handling aspect, high windrows often conceal large stones, which can cause severe damage to tyres and undercarriages of vehicles.

A common problem caused by poor grading practices is ponding of water on the road by windrows left at the edge of the road. Often the material deposited at the end of the grader blade during the last run forms a bank that retains water. This should not be permitted and should either be removed by the grader, or manually after grading.

Surface grading should not result in the level of the road being below the adjacent shoulders. Heavy grading and reshaping should be carried out in this case to avoid canalisation of the water along the road surface.

The development of ruts should be controlled during blading operations. Grading should be carried out before ruts have become deeper than about 25 mm, with the ruts being filled with loose material. Prolonged rut development results in channelling of run-off and subsequent erosion and loss of shape of the road. Particular care should be taken to restore and maintain the crown during blading.

Instances have been observed where permanent corrugations with 2.5 to 3.0 m wavelength occur in the road. These have been caused by bouncing of the grader during blading (grader travelling too fast) and once formed cannot be removed by the same grader without
ripping, as their wavelength is the same as the distance between the front wheels of the grader and the blade. A grader with a different wheel/blade configuration can be used to cut them; other techniques include rotating the grader blade through 90° or extending the blade from the side of the grader and keeping the grader on the shoulder or on an uncorrugated portion of the road. Alternatively, the road can be ripped and recompacted.

4.4.6.2 Dragging

The lowest level of surface maintenance is dragging. Dragging is typically done with branches, trees, steel bars, tyre drags or mats. This process is generally only suitable for sandy materials on roads carrying less than about 50 vehicles per day. Tyre drags are the best form of drag (five truck tyres in a three-two combination attached by chain to separate points on the tow vehicle, see Figure 4.4-4). The other types of drag tend to damage the road shape (trees and branches score the surface, while steel bars tend to bounce and cut) and flatten the camber.

![Figure 4.4-10: Tyre drag configuration.](image)

4.4.6.3 Sand Cushioning

Sand cushioning involves spreading a thin layer of sand onto a road surface to reduce gravel loss, smooth the road surface for traffic, and to limit base deterioration. The process is best suited to areas where an abundance of sandy material exists adjacent to the road (i.e. Zululand/Maputoland).

The process entails:

- **Preparation of the road surface** – the road surface should be bladed and, if necessary, compacted to a suitable density. Potholes, erosion channels and ruts should be repaired and large loose stones should be removed. Sufficient camber should be incorporated to ensure adequate drainage. The sand cushion should be placed as soon as the necessary maintenance has been undertaken, to ensure that the road surface does not deteriorate under traffic prior to sand cushioning. If the road condition is in such a state that routine maintenance will not improve riding quality to an acceptable standard, the road should be ripped and recompacted prior to application of the sand cushion.

- **Application of the sand** – sand (preferably 100% passing 2.0 mm, but some larger particles acceptable) should be available in sufficient quantities (0.04 m$^3$/m$^2$) adjacent to the road to be treated. If sand has to be transported, a cost benefit analysis should be undertaken to justify the additional expenditure. Vegetation adjacent to the road should be cleared and large stones removed. Roadside improvements and drainage structures
should be demarcated to prevent damage. Sand is then graded onto the prepared road surface to a thickness not exceeding 40 mm. Stones larger than 37.5 mm should be removed either with the grader blade or manually. No further preparation is necessary and the road can be opened to traffic immediately.

- **Maintenance** – the frequency of maintenance depends on traffic and on the characteristics of the sand particles. If the sand particles are predominantly sub-angular or angular in shape and if the traffic volume does not exceed 50 vehicles per day, the sand cushion will require maintenance approximately every 10 days, while roads with a traffic volume of 100 vehicles per day will require maintenance approximately every seven days to prevent exposure of the base and corrugation of the sand. As sub-rounded sand particles and/or higher traffic volumes will require more frequent dragging, cost benefit studies should be undertaken to determine the feasibility of upgrading the road to a higher standard. Maintenance entails the road being dragged with a drag made up of five truck tyres in a three-two configuration (see Figure 4.4-4). A tractor-drawn grader in combination with the tyre drag is very effective for maintaining the required thickness of sand. The drag, or grader/drag combination should be driven along one side of the road at a speed of less than 10 km/h and then returning in the opposite direction on the other side of the road. The grader evenly distributes the sand that has accumulated on the edge of the road, thus maintaining a sand thickness of between 25 and 40 mm. The blade will also remove any large stones. **The blade should not touch the base material.** The tyre drag removes any corrugations and provides a smooth riding surface.

- **Maintenance planning** – the roads to which sand cushions have been applied can be divided into sections to enhance productivity. The length of each section will differ according to traffic and the maintenance equipment used, but should be such that the maintenance unit can be driven to the end of the section on one side of the road in one or two days, and then return to the base camp in the other direction. If circumstances allow, the base camp can be positioned to allow a maintenance crew to service a number of roads in a particular area.

### 4.4.6.4 Spot Regravelling

Spot regravelling is carried out to replace the gravel in small areas where the surfacing has become excessively thin or worn through, and for filling potholes, ruts, erosion channels and corrugations.

Spot regravelling is predominantly a manual operation. The same material as the wearing course should be used. Potholes should be cleaned out, the loose material removed from the sides, moistened with water, and then backfilled with moist gravel in 50 to 100 mm layers. Each layer should be compacted (a hand rammer is adequate) until the hole is filled to about 10 mm above the surrounding road.

### 4.4.7 Regravelling

Regravelling is often the most expensive maintenance procedure for unsealed roads. Regravelling is needed when the existing surfacing no longer allows the road to achieve management objectives. Regravelling should take place before the subgrade is exposed in order to avoid:

- Deformation that will necessitate reconstruction;
- Loss of the strength that has been built up in the subgrade by traffic moulding over time;
- Contamination of residual surfacing material, preventing it from being re-used.

Improvements to any drainage deficiencies should be made prior to regravelling. The quality of the gravel should comply with the required specifications (see Section 3.2 – Pavement Design).

The regravelling process should follow the same procedure as gravelling during the construction process (see Section 4.5 – Surfacing Operations).
4.4.7.1 Reworking and Compaction

It is sometimes necessary to rework the existing gravel by breaking down or removing over- size material, adding fines for improved cohesion, adding moisture and, recompacting. This is especially necessary when an adequate thickness of gravel exists on a road, but the roughness becomes excessive under increased traffic.

4.4.8 Road Closure

Forest road densities in South Africa are considered to be excessive by many experts. Closing roads that are no longer needed or that have excessive environmental impact is the focus of this section. Road closure reduces the risk to resources such as landslides, degradation of wildlife habitat, and sediment transport, and allows additional afforestation.

4.4.8.1 Prioritisation of Road Closure

The forester must determine which roads are candidates for closure. First priority should be given to roads that are no longer needed for harvesting or management activities that generate excessive environmental impact. Second priority should be given to un-needed roads that are not environmentally damaging.

The long-term harvesting schedule should be consulted, and roads prioritised for closure. The forester should identify closure candidate roads on the map, then proceed to field verify their status.

A long-term strategy for eliminating unneeded roads should be developed and the annual budget should contain adequate funds to achieve this goal.

4.4.8.2 Road Closure Methods

Road closure techniques range from simply gating or blocking a road to total obliteration and return to a natural ground profile.

Road closure activities have three main components:
1. Stabilisation of the road prism and cleared areas;
2. Restoration and maintenance of natural surface and subsurface drainage patterns;
3. Minimisation of sediment transport and associated effects on water quality.

The intent of permanent closure is to place the road in a self-maintaining state that will indefinitely protect adjacent resources at risk.

Permanent closure is done with the expectation that the road will no longer be used or needed by the landowner or the public. The road will receive no further inspections or maintenance. Permanent closure of mainline and primary branch roads is seldom carried out since these higher-standard roads provide access for future harvesting and other needs. Permanent closure is thus usually limited to in-compartment roads and spur roads, and to roads that provide duplicate access to areas.

Permanent closure will normally result in the elimination of motor vehicle access along road segments where unstable road fill is pulled back and where stream culverts and bridges are removed.

Stream crossing culverts should be removed and the channel reconstructed where culvert maintenance is impractical or impossible. The objective is to remove an existing culvert, while creating the least amount of sedimentation possible and leaving a cross-ditch. This should be done by re-establishing the natural width and gradient of the stream, as well as armouring the stream banks (sides of the cross-ditch) and the base of the channel.
The size, depth, and shape of the re-established stream crossing depend on the hillslope and creek/gully contours and expected flows.

At challenging sites, explore the range of practical options with experienced staff or fisheries agencies, to reduce the potential sedimentation to acceptable levels.

The purpose of full road fill pullback is to retrieve all potentially unstable sidecast material and place it securely against the cutbank, thereby reducing the landslide hazard to the greatest extent possible. Usually no access or only limited access for foot or ATV traffic is possible after full road fill pullback.

Decompacon of the subgrade may be needed. Decompacon involves breaking up road fill materials to a depth equal to, or greater than, the depth of the side drain, and removing this material to create an outsloped camber before pullback material is placed overtop. This action may promote water flow across the road under the pullback material, to provide for the greater downslope reach of the excavator during pullback, and to allow the operator to determine the width of the natural bench for machine positioning.

If it is not feasible or desirable to decompact the road fill, then drainage collected from the filled-in side drain can be discharged in a controlled manner by subdrains or open cross-ditches. Where very long and deep road fills are present, benching and/or ramping may be necessary to retrieve all the sidecast fill material.

**Figure 4.4-11: Pull-back of fill materials during road closure.**

To protect resources at risk, road closure work is site specific and may include some of the following techniques:

- Removing all or some stream culverts and restoring channel and bank stability, or backing up culverts with cross-ditches as necessary;
- Replacing all or some cross-drain culverts with cross-ditches or adding cross-ditches or other drainage systems as necessary;
- Installing cross-ditches or waterbars where there are:
  - Steep grades
  - Heavy ground water seepages
  - Switchbacks or road junctions
  - Side drains prone to plugging
  - Places where ponding may occur
  - Other potential drainage problem areas
- Protecting road users during the period of deactivation by removing, repairing, or replacing those bridges that may place users at risk;
- Removing or breaching windrows on the road surface;
• Outsloping or insloping the road camber or constructing waterbars as appropriate to optimize drainage;
• Carrying out measures to remove organic material (stumps, roots, embedded logs, topsoil) that may reasonably be expected to fail and de-stabilise the road fill;
• Pulling back potentially unstable sidecast fill.

Bridge superstructures should be removed. The bridge or log substructures must also be removed if a failure of the substructure could be expected to adversely affect downstream values.

Stream culverts will usually be removed to ensure there is no potential adverse impact on the stream. Where there is a low risk of damage to fish passage or water quality, pipe culverts at stream crossings may be left in place.

Cross-drain culverts should be removed and replaced with cross-ditches to re-establish drainage patterns, especially on steep road grades and sidehills. If the likelihood of failure is minimal or the consequences of a failure are low, consideration may be given to leaving the cross-drain culvert intact, provided it is backed up with a cross-ditch or armoured swale as necessary.

4.4.9 References and Further Reading

Section 4.5 - Surfacing Operations

4.5.1 Introduction

Surfacing of forest roads may be needed to protect the subgrade from vehicle loading or the erosive effects of water or wind, or to provide a driveable surface. Surfacing operations comprise a significant portion of any forest road construction budget. Diligence must be provided during the planning and execution of surfacing operations to ensure compliance with vehicle operation, economic, and environmental objectives.

Surface preparation and drainage system construction must be complete before any surfacing material is placed. On existing roads, the surface can be lightly ripped to assist bonding between the layers and to prevent surface laminations.

Surface preparation is detailed in Section 4.2.3.7.

4.5.2 Surfacing Process

1. Surfacing is applied when the native material is unacceptable for use as the road surface. Surfacing is usually needed when the road will be used for wet-weather haul.

2. Surfacing selection and design is detailed in Section 3.2 – Pavement Design. Surfacing material should be chosen that is durable and will meet the management objectives for the road.

3. A suitable depth of surfacing is determined, and material is brought in via dump truck and spread on the road.

4. The spread material is then watered, spread using a motor grader or, in the case of pit-run, a small crawler tractor, and compacted using a vibratory or grid roller.

5. The material should be compacted in lifts not exceeding 150 mm.

6. If proper surfacing material has been selected, the road should then have a hard, smooth finish, with a “seal”.

4.5.3 Loading

Loading of gravel is typically performed with a front-end loader. The following points should be observed to maximise efficiency and safety:

- The capacity of the trucks and the loader should be balanced to minimise downtime;
- The working area should be kept clear of stones and debris to prevent tyre damage;
- Operators of trucks and loaders should develop a communication system;
- Position equipment such that wind blows dust away from the loader operator;
- Position trucks such that loader turning and travel is reduced to a minimum;
- Position trucks alternately on each side of the loader so that one truck can manoeuvre into position while the other is being loaded;
- Avoid sharp turns with a loaded bucket. The bucket should be carried low when travelling and raised only when approaching the truck.
4.5.4 Surfacing Transport

The surfacing project should begin at the farthest end from the gravel source to prevent loaded trucks from traversing the newly-placed gravel.

A suitable number of dump trucks should be used to ensure that all pieces of construction plant are working at a near-optimum level. There should not be delays at the loading point, nor should loading or grading equipment be sitting idle for extended periods.

4.5.5 Spreading and Thickness

Surfacing level, shape, thickness, and camber are best controlled with guide stakes or wire flags set along the edges of the formation. Temporary staking along the centreline can assist in locating the crown in the correct position. Levels on the control line pegs can be transferred to the pavement by means of a surveyor’s level or by using string lines.

It is important that the material be dumped on the road at the correct spacing to provide the expected thickness of gravel after spreading and compaction. If the constructed thickness is insufficient, additional gravelling may be needed to adequately protect the subgrade and provide trafficability. A pavement structure that is overly thick requires extra material and incurs unnecessary expense.

Dump spacing should be calculated and marked with pegs next to the road. Spacing will depend on the thickness of the layer, width of the road and capacity of the truck. An example is provided below:

- Compacted layer thickness: 150 mm (bulking factor of 30%)
- Road width: 6.0 m
- Truck capacity: 6.0 m³

\[
\text{Quantity of material/km: } 0.15 \times 6 \times 1000 \times 1.3 = 1170 \text{ m}^3
\]

\[
\text{Number of truck loads/km: } 1170/6 = 195
\]

\[
\text{Dump spacing: } 1000/(1170/195) = 5.1 \text{ m}
\]

When spreading by grader, the first stage of the operation consists of blading the dumped material into a uniform windrow parallel to the centreline of the road. If the material is not windrowed in this manner, it is more difficult to obtain a uniform thickness of spread material. Windrowing also facilitates remixing any material segregated during handling. Where stony windrows have developed on existing roads it is preferable to blade these to waste rather than to try to incorporate them into the newly treated layer.

The grader then spreads the material over part-width of the road by cutting into the edge of the windrow with the blade raised 50 to 60 mm. As the grader moves along the windrow, the material cut from it moves along the blade and drops under it.

The flow of material along and under the blade is controlled by:

- The pitch of the blade (top set slightly forward of vertical);
- The angle of the blade to the centreline of the road;
- The width of cut into the windrow.

Care should be taken to avoid segregation in this operation. A slower grader speed and squarer blade will assist in this regard.

The additional water required for compaction is added after the material has been spread. A water tanker equipped with a spray-bar follows the grader through and uniformly applies water to the thin layer of spread material. On the return trip, the grader picks up the layer, turns it over, and deposits it in a windrow outside the edge of the blade. The process is
repeated until the materials have been thoroughly mixed and the required water uniformly incorporated.

When the material is thoroughly mixed, it is spread to the full pavement width and shape. The spreading should be carried out so that the course material does not segregate and "run" along the grader blade to the edge of the pavement. Compaction equipment is introduced at this stage to firm the material only enough to carry the weight of the grader. While the material is in this state, it is trimmed to its final shape. It is much easier to trim a pavement at this stage than when it is fully compacted. The damp, lightly compacted material can be easily cut by the grader blade, and the cut material, when used to raise low spots, will bond into the material below, thereby avoiding weakly bonded layers.

As the final trimming progresses, the pavement level and camber should be continually checked. The cross-section and shape of the road should ensure a definite crown, inslope, or outslope with a camber of about 4% (not more than 5%). Large stones (greater than 50 - 75 mm) that have not been removed previously, should be removed (manually if necessary) and discarded at a distance from the road to ensure that they are not bladed back onto the road during routine blading or drain clearing. The surface should be maintained in a damp state by sprinkling.

### 4.5.6 Pavement Compaction

Proper compaction produces tightly bound gravel with optimum particle interlock, minimum permeability and porosity and significantly increased strength. Poor compaction results in a low density, permeable material, which ravelS easily and is highly moisture sensitive. Deep rutting, compaction under traffic, potholing, corrugations and passability problems under soaked conditions are common problems associated with poorly compacted material. The initial traffic-induced compaction and increased gravel loss again interfere with the maintenance management strategy for the road.

Compaction is achieved with vibrating steel drum or pneumatic tyred rollers. Where a grid or pad-foot roller has been used to break down large material, it may also be used for initial compaction passes. Grid rollers are suitable for compacting pit-run or breaking down oversize material.

If the material contains large particles of soft aggregate, initial rolling should be carried out with a grid roller in order to break these down. Once adequately disintegrated, the material should be re-mixed with a grader before being compacted with a smooth vibrating roller of at least 12 tonnes mass. For clayey material a tamping or sheep's-foot roller is most effective.

The following rolling procedures are recommended in order to achieve satisfactory compaction uniformly across the pavement, while maintaining the shape and evenness of the surface:

The road should preferably be compacted to refusal density for the plant used, ensuring that a minimum of 95% Mod AASHTO is obtained, but that crushing of the material does not occur and that the crown and appropriate cambers are retained.

Care should be taken to ensure that any depressions are filled with moist, treated (where necessary) material to ensure that adequate compaction is achieved over the full area of the road.

It is recommended that proof rolling be carried out at each site where obvious changes in the material occur. During this process a short section of road (about 20 m) is rolled for a number of passes and a DCP test is done after each pass until no significant increase in strength (decrease in penetration rate) is obtained after additional passes. This defines the number of roller passes necessary to achieve the desired density.

Rolling should commence at the outer edge of the road. This will prevent the forcing of material to the outside of the road and consequent loss of shape.

A forward and reverse pass is made over the same section of pavement before moving to the adjacent section. It is important to check that this is done at the edges of the pavement.
When changing direction, the roller should be on the previously compacted section.

- Each pass of the roller should overlap the previous pass by up to 500 mm so as to ensure complete coverage.
- Where the outside edge of the pavement is unsupported and squeezes out excessively, rolling should commence 200 to 300 mm from the edge and the 200 - 300 mm strip rolled on completion of the section.
- Vibrating rollers should have the vibrator turned off when the machine is stopping or manoeuvring.
- All rollers should be slowly reversed without jolting. Sharp turns of the roller or sudden changes in direction should be avoided, as these actions will cause surface roughness.
- Static drum rollers should have the drive wheels leading on the initial pass so as to avoid pushing material ahead of the drum.
- When using vibrating rollers, a sequence consisting of a non-vibrating initial pass, followed by several high amplitude passes and finishing with low amplitude passes, has been found to achieve good compaction and surface finish. Most vibratory rollers have a range of amplitude and frequency settings.
- A minimum of 5 passes should be made.

### 4.5.7 Final Finish and Shape

The roughness of a road is one of the most important factors influencing vehicle operating cost, affecting travel time and vehicle wear and tear. Competent grader operators who can provide a smooth, well-finished riding surface should be used. A good surface after construction can be maintained to a much better standard than a poorly finished surface.

![Figure 4.5-1: Final finish cross section.](image)
4.5.8 Mechanical Improvement

4.5.8.1 Stone Removal at Source

The removal of large stones at the gravel source is the most effective method of managing oversize material. Removal at source has the following advantages:

- All material transported will be used on the road, thereby optimising transport expenditure.
- Discarded material will not have to be transported a second time.
- Labour used to remove stones on the road can be better utilised on other projects.

Stone removal at source is best achieved using a portable screen of the required aperture (i.e. 37 mm or the specified maximum size). Excavated material is passed through the screen before being stockpiled. Although production in the pit is slower, overall production will be quicker than removal of oversize on the road.

4.5.8.2 Stone Removal on the Road

Stone removal on the road by labour is only effective for removing small numbers of large oversize stones prior to compaction. The process entails labourers walking in a line down the road after the material has been spread and throwing any large stones to the side of the road. Good supervision is necessary to ensure that all oversize material is removed and to check that stones are removed and not pushed into the road. The process usually has to be repeated during mixing of the material when additional stones are exposed.

4.5.8.3 Grid Rolling

The use of a grid roller to break down oversize material is not always successful and depends on the percentage of oversize material and its hardness. The following issues need to be considered:

- The material should have a Treton Impact Value between 20 and 65. Materials with hardness greater than 20 will not be effectively broken down.
- The grid roller should be suitably ballasted.
- The tractor used to tow the grid roller should be powerful enough to maintain an appropriate speed (± 8 - 10 km/h).
- On completion of grid rolling, the surface should be ripped with the grader and then mixed to ensure that optimal particle size distribution is obtained. A large rock that has simply been cracked by the grid roller will still behave as oversize material.
- Once the material is suitably mixed, the road can be watered and compacted.

4.5.8.4 Stone Crushing at Source

If a significant proportion of the material is oversize (e.g. >25%), a portable crusher should be established in the pit to reduce this to the maximum size specified. Alternatively, oversize material can be windrowed in or close to the gravel source, reduced with a mobile hammermill (eg Rockbuster) and then screened to remove any large stones that were not crushed. This eliminates the transportation of material that is not broken down by the hammermill.
4.5.8.5 Stone Crushing on the Road

A hammermill can also be effectively used on a road, either to breakdown dumped material, or to process existing oversize material in the road. Dumped material should be windrowed to the height specified by the equipment manufacturer and then milled, before being spread, watered, mixed and compacted.

4.5.8.6 Blending

If blending is necessary to achieve the required shrinkage product or alter the particle size distribution of the gravel, this can be done at the gravel source if the sources are in close proximity, but is usually most effective on the road. When mixed on the road, the required quantities per 100 m should be spread to a uniform thickness, one on top of the other. The grader then mixes the two materials by cutting to the full-depth of the material, turning it over and spreading it across the balance of the road.

Careful supervision of the dumping and mixing of the material is necessary to ensure that the correct proportions are combined and mixing is complete. Control tests can be carried out on site with 26, 4.75 and 2.0 mm sieves to check the grading coefficient.

4.5.9 References and Further Reading


Section 4.6 - Construction Plant

4.6.1 Introduction

Construction plant is a very expensive component of any construction operation. Appropriate plant selection will have a direct influence on the cost of the project. The appropriate plant for the specific job is not always available and the project manager, when selecting the plant to be used should consider the following factors:

- Production, where highest production can be achieved with available plant;
- Characteristics and volumes of materials to be handled;
- Move-in distance;
- Weather at time of proposed operations;
- Trafficability of haul routes, both in terms of terrain and wearing course, where steep inclines will have a limiting effect on production and may influence the plant selection;
- Available Work space (such as narrow roads or small stockpile areas);
- Environmental limitations and conditions;
- Deliverability of plant to site (no point in choosing a piece of machinery that cannot be delivered to site);
- Operator qualifications;
- Age of available plant and available repair service or spare availability;
- Safety.

4.6.2 Safety

Forest road construction can be an inherently hazardous occupation. Construction planning must address the following safety considerations.

Identify Operational Hazards in terms of:

- Machine stability;
- Safe workspace, including stable cuts and fills;
- Restricted work space;
- Working alone;
- Falling debris;
- Adjacent operations such as tree felling or blasting;
- Other road users.

Ensure Personal safety:

- Are operators certified and qualified?
- Protective equipment on plant, i.e. ROPS (Roll Over Protective Structure) and FOPS (Falling Objective Protective Structure) must in place and functional.
- Effective personal protective equipment and knowledge of the use of PPE must be provided to all workers.
- Awareness and diligence when working around construction plant must be maintained
- A comprehensive safety plan, including training for all workers, shall be developed and implemented.
Identify *Health Hazards*:
- Work hours and breaks;
- Drug and alcohol use;
- Dust.

### 4.6.3 Types of Construction Plant used in Forest Road Construction

Please note: All time studies are done assuming 80% machine utilisation.

#### 4.6.3.1 Dozers

Dozers (crawler tractors equipped with a blade) are a basic and versatile piece of equipment widely used in forest road construction. Dozers are designed to provide high drawbar pull and traction effort. They are the standard equipment for land clearing, dozing, and assisting in scraper loading. They can be equipped with rear-mounted winches, rippers, or stump splitters. Crawler tractors exert low ground pressure, which adds to their versatility.

Dozers come in a large range of size in terms of weight, with very versatile small dozers (4 – 12 ton) with a high range of blade movement and tilting. Blade ability is particular useful in road formation, shaping and material spreading.

Heavy dozers (25 – 60 ton) are more appropriate for heavy cutting and breaking and pushing of hard rock.

**Applications**:
- Clearing, grubbing, and right-of-way timber removal;
- Sidecast excavation and embankment construction;
- Spreading surfacing material;
- Side drain cutting;
- Ripping, spreading, and stockpiling of quarry materials;
- Pulling or pushing of roller compactors, scrapers and assisting other plant on steep or difficult terrain.

*Figure 4.6-1: Dozer equipped with FOPS, ROPS, and U-blade.*
Work rate:

Bull dozers travel speeds (kmph)

<table>
<thead>
<tr>
<th>Gear</th>
<th>50 –59 kw</th>
<th>60 – 69 kw</th>
<th>70 –90 kw</th>
<th>90–120 kw</th>
<th>120 –160 kw</th>
<th>+160 kw</th>
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<td>4.5</td>
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<td>13.2</td>
<td>13.9</td>
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Combined average forward and reverse speeds (kmph) per dozer size based on a constant third gear reversing.

<table>
<thead>
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<th>Gear</th>
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<th>60 – 69 kw</th>
<th>70 –90 kw</th>
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Total linear distance advanced per hour allowing for both forward and reverse actions and an 80% machine effective utilisation.

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<th>60 – 69 kw</th>
<th>70 –90 kw</th>
<th>90–120 kw</th>
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<td>4600 m</td>
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Dozer production Lm$^3$/hr for straight blade dozers.*

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<td>190</td>
</tr>
<tr>
<td>250m</td>
<td>40</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>300m</td>
<td>35</td>
<td>75</td>
<td>125</td>
</tr>
</tbody>
</table>

* Based on figures from the Caterpillar Performance Handbook

4.6.3.2 Hydraulic Excavators

Hydraulic Excavators are widely used in forestry operations. Excavators are used for logging, timber loading, brush piling, road construction and road maintenance. Excavators can fit a large range of attachments to make them very versatile pieces of machinery. An excavator can excavate material, break rock, load material, shape the road, level material...
or compact embankment. As with dozers, excavators exert low ground-bearing pressure. An advantage of an excavator is the ability to excavate and place material below or above its work platform, which makes it the preferred machine to work in environmentally sensitive terrain.

Excavators come in a large range of size, ranging from (1.5 – 12 ton) for small excavators, (15 – 35 ton) for medium sized and up to 70 ton for heavy excavators.

Excavators can be fitted with longer booms to give increased reach. A large range of attachments, including buckets, rippers, jackhammers, and pneumatic drills can be fitted.

The buckets can changed to suit excavating in soft material, breaking of rock, loading of material and for shaping and formation of the road.

**Applications:**
- Clearing, grubbing, and right-of-way timber removal;
- Excavation and embankment construction;
- Full-bench road construction;
- Material placement during surfacing operations;
- Side drain construction;
- Excavating, stockpiling or loading of quarry materials;
- Culvert installation;
- Placing rip-rap;
- Clearing side and mitre drains;
- Repairing scour and washouts.

*Figure 4.6-2: Hydraulic excavator used in forest road construction.*
Work rate:

The excavator production depends on the size of the unit (bucket capacity) and the application of the unit. The table below outlines the hourly production guidelines for the excavator at an 80% machine effective utilisation.

As a guideline the following can be applied to the number of cycles per minute for various work functions for the excavators working under forestry conditions.

<table>
<thead>
<tr>
<th>Cycle / min</th>
<th>Min / cycle</th>
<th>Cycles / hour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.0 min</td>
<td>30</td>
<td>Excavator digging and loading in a quarry or road construction, difficult conditions</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 min</td>
<td>60</td>
<td>Excavator digging and loading in a quarry or road construction, medium conditions</td>
</tr>
<tr>
<td>1.5</td>
<td>36 sec</td>
<td>90</td>
<td>Excavator digging and loading in a quarry or road construction, light conditions</td>
</tr>
<tr>
<td>2.0</td>
<td>30 sec</td>
<td>120</td>
<td>Loading of course material to trucks</td>
</tr>
<tr>
<td>2.5</td>
<td>24 sec</td>
<td>150</td>
<td>Loading of loose material to trucks, light conditions</td>
</tr>
<tr>
<td>3.0+</td>
<td>20 sec</td>
<td>180</td>
<td>Loading of very fine material to trucks, very easy conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle / min</th>
<th>Min / cycle</th>
<th>Cycles / hour</th>
<th>Bucket capacity m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.0 min</td>
<td>30</td>
<td>2 5 10 14 19 24 29 34</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 min</td>
<td>60</td>
<td>5 10 19 29 38 48 58 67</td>
</tr>
<tr>
<td>1.5</td>
<td>36 sec</td>
<td>90</td>
<td>7 14 29 43 58 72 86 101</td>
</tr>
<tr>
<td>2.0</td>
<td>30 sec</td>
<td>120</td>
<td>10 19 38 58 77 96 115 134</td>
</tr>
<tr>
<td>2.5</td>
<td>24 sec</td>
<td>150</td>
<td>12 24 48 72 96 120 144 168</td>
</tr>
<tr>
<td>3.0</td>
<td>20 sec</td>
<td>180</td>
<td>14 29 58 86 115 144 173 202</td>
</tr>
<tr>
<td>3.5</td>
<td>17 sec</td>
<td>210</td>
<td>17 34 67 101 134 168 202 235</td>
</tr>
<tr>
<td>4.0</td>
<td>15 sec</td>
<td>240</td>
<td>19 38 77 115 154 192 230 269</td>
</tr>
</tbody>
</table>

Figure 4.6-3: Hydraulic excavator cycle.
4.6.3.3 TLB (Tractor Loader Backhoe)

A TLB is a combination of an excavator and a front-end loader mounted on a typical agricultural tractor. It is the most widely used forestry road maintenance piece of machinery in Southern Africa because of its ease of operation, mobility, versatility and low cost. TLB sizes range from 4 to 8 tonnes. The construction supervisor must ensure that TLB’s are used for appropriate activities and not used beyond their capacity, such as heavy excavation or sustained truck loading. These activities may be inefficient and can cause excessive wear and tear on the equipment.

TLB’s are available in a 4x2 or 4x4 drive configuration. 4x4 models are most suitable for use in forest road construction. 4x4 capability allows the TLB to traverse the uneven and often-low traction terrain encountered in the forest environment.

**Applications:**
- Loading of material;
- Spreading of surfacing material;
- Side drain cutting;
- Culvert installation;
- Culvert maintenance;
- Clearing side and mitre drains;
- Repairing scour and washouts.

![Figure 4.6-4: TLB.](image)

**Work rate: TLB - Backhoe**

The table below outlines the hourly production guidelines for the TLB front loader bucket operation at an 80% machine effective utilisation.

<table>
<thead>
<tr>
<th>Cycle / min</th>
<th>Min / cycle</th>
<th>Cycles / hour</th>
<th>Loader bucket capacity m³</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.0 min</td>
<td>30</td>
<td>18 24 30</td>
<td>Very difficult</td>
</tr>
<tr>
<td>0.75</td>
<td>1.3 min</td>
<td>45</td>
<td>27 36 45</td>
<td>Difficult</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 min</td>
<td>60</td>
<td>36 48 60</td>
<td>Medium</td>
</tr>
<tr>
<td>1.25</td>
<td>48 sec</td>
<td>75</td>
<td>45 60 75</td>
<td>Light</td>
</tr>
<tr>
<td>1.5</td>
<td>36 sec</td>
<td>90</td>
<td>54 72 90</td>
<td>Very easy</td>
</tr>
</tbody>
</table>
Example: A TLB used for cross-drain culvert installation would operate 50% of the time at a “difficult” or “very difficult” level when excavating the culvert bed, but would operate 50% of the time at “light” or “very easy” when backfilling the culvert.

The table below outlines the hourly production guidelines for the TLB backhoe operation at an 80% machine effective utilisation.

<table>
<thead>
<tr>
<th>Cycle / min</th>
<th>Min / cycle</th>
<th>Cycles / hour</th>
<th>Backhoe bucket capacity m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>0.5</td>
<td>2.0 min</td>
<td>30</td>
<td>1.2</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 min</td>
<td>60</td>
<td>2.4</td>
</tr>
<tr>
<td>1.5</td>
<td>36 sec</td>
<td>90</td>
<td>3.6</td>
</tr>
<tr>
<td>2.0</td>
<td>30 sec</td>
<td>120</td>
<td>4.8</td>
</tr>
<tr>
<td>2.5</td>
<td>24 sec</td>
<td>150</td>
<td>6.0</td>
</tr>
<tr>
<td>3.0</td>
<td>20 sec</td>
<td>180</td>
<td>7.2</td>
</tr>
<tr>
<td>3.5</td>
<td>17 sec</td>
<td>210</td>
<td>8.4</td>
</tr>
<tr>
<td>4.0</td>
<td>15 sec</td>
<td>240</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Work Rate: **TLB Front End Loader**

The table below outlines the hourly production guidelines for the TLB front loader bucket operation at an 80% machine effective utilisation.

<table>
<thead>
<tr>
<th>Cycle / min</th>
<th>Min / cycle</th>
<th>Cycles / hour</th>
<th>Loader bucket capacity m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.50</td>
</tr>
<tr>
<td>0.5</td>
<td>2.0 min</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>0.75</td>
<td>1.3 min</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0 min</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>1.25</td>
<td>48 sec</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>1.5</td>
<td>36 sec</td>
<td>90</td>
<td>108</td>
</tr>
</tbody>
</table>

### 4.6.3.4 Front End Loaders

Front End Loaders are specifically designed for loading of material onto trucks and stockpiles. A front end loader can also be used to cart material over short distances. Front end loaders used in forest road construction typically range from 8 to 16 tonnes. Front end loaders should be used on slopes of 10% or less to maximise production and minimise the risk of overturning when loaded.

Applications:

- Loading surfacing material into trucks;
- Constructing stockpiles at gravel sources.
Calculating cycle time
The cycle time can be broken into two categories:
Variable time: The distance and travelling speed;
Constant time: The loading and tipping cycle of the units.

From the observations completed on the tip trucks the average speeds achieved under forestry conditions where as follows

<table>
<thead>
<tr>
<th>One-Way Distance</th>
<th>Travel loaded</th>
<th>Travel empty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Min./metre</td>
<td>Speed</td>
</tr>
<tr>
<td>300 - 1 200 m</td>
<td>6.9 km/h</td>
<td>0.0087 m/m</td>
</tr>
<tr>
<td>1500 – 3 500 m</td>
<td>9.0 km/h</td>
<td>0.0067 m/m</td>
</tr>
<tr>
<td>+ 10 000 m</td>
<td>26.0 km/h</td>
<td>0.0023 m/m</td>
</tr>
</tbody>
</table>

Travel speeds conversion actors

<table>
<thead>
<tr>
<th>Speed</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min./metre</td>
<td>0.01</td>
<td>0.0075</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.0017</td>
<td>0.0015</td>
<td></td>
</tr>
</tbody>
</table>

Loading Times

<table>
<thead>
<tr>
<th>Loading Times</th>
<th>8 tonnes</th>
<th>16 tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavator 0.40 m³</td>
<td>= 10.0 min</td>
<td>= 20.0 min</td>
</tr>
<tr>
<td>Excavator 0.60 m³</td>
<td>= 7.50 min</td>
<td>= 15.0 min</td>
</tr>
<tr>
<td>Excavator 0.80 m³</td>
<td>= 5.00 min</td>
<td>= 10.0 min</td>
</tr>
<tr>
<td>TLB</td>
<td>= 10.0 min</td>
<td>= 20.0 min</td>
</tr>
<tr>
<td>Front end loader</td>
<td>= 6.0 min</td>
<td>= 12.0 min</td>
</tr>
</tbody>
</table>

Off loading Time

<table>
<thead>
<tr>
<th>Time</th>
<th>2.00 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipping</td>
<td></td>
</tr>
</tbody>
</table>
Example:

A pavement construction project requires a one-way haul of 4250 m from the quarry to the job site. The tip truck used carries 8 tonnes and travels at a speed of 10 km/hr loaded and 15 km/hr unloaded. The excavator loading gravel at the quarry has a bucket capacity of 0.40 m³.

Using the data found above, the cycle time is calculated in the table below.

<table>
<thead>
<tr>
<th>Calculation of cycle times</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable time</strong></td>
</tr>
<tr>
<td><strong>Distance</strong></td>
</tr>
<tr>
<td>Travel loaded</td>
</tr>
<tr>
<td>Travel empty</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
<tr>
<td><strong>Constant time</strong></td>
</tr>
<tr>
<td>Loading method</td>
</tr>
<tr>
<td>Off loading</td>
</tr>
<tr>
<td><strong>TOTAL CYCLE TIME</strong></td>
</tr>
</tbody>
</table>

### 4.6.3.5 Haulage or cartage plant

Haulage or cartage plant includes tip trucks, articulated dump trucks (ADT’s), tractor-pulled scoops, and scrapers. The type to be used is influenced by availability, terrain, lead distance and available workspace.

Tip trucks are cost effective for long haul of material and do not have statutory restrictions on using public roads. Dump trucks are productive for short haul distances and can negotiate more robust and adverse conditions. Scrapers and tractor pulled scoops are productive on short hauls where adequate workspace exists for safe vehicle manoeuvring.

In areas of heavy excavation, off-highway dump trucks may be a suitable option, provided they are available and lawful for the location. The articulated off-highway truck can haul up to 20 m³ per load. They have the following advantages:

- Greater payload, reducing variable hauling costs;
- Compaction during haul is excellent;
- Increased agility and reduced turning radius;
- Lower bin on articulated trucks allows use of a smaller loader.

Applications:

- Transporting surfacing materials to the job site;
- Transporting excavated materials to locations of embankment or disposal sites in the case of full-bench excavation;
- Transporting stumps or other organic debris to disposal sites.

_Figure 4.6-6: Tip truck spreading pavement material._
Figure 4.6-7: Articulated dump truck.

Figure 4.6-8: Motor scraper.

Work rate: *Tip truck*

The daily production of the tip truck is dependent on the distance and terrain over which the unit must travel as well as the loading methods.

The average cycle times for the 8 tonne tip trucks recorded over various distances for forestry conditions periods is detailed below.

<table>
<thead>
<tr>
<th>One-way Distance</th>
<th>Total cycle time</th>
<th>Loads / shift (7 hrs)</th>
<th>Tonnes /shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 200 m</td>
<td>28 min</td>
<td>15 loads</td>
<td>120 tonnes</td>
</tr>
<tr>
<td>3 300 m</td>
<td>46 min</td>
<td>9 loads</td>
<td>72 tonnes</td>
</tr>
<tr>
<td>12 500 m</td>
<td>62 min</td>
<td>6.8 loads</td>
<td>54 tonnes</td>
</tr>
</tbody>
</table>
Work rate: *Articulated Dump truck*

The travel speeds for the ADT are dependent on the terrain and applicable working conditions.

The table below details the average expected travel speeds for various sized ADT’s.

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Tonnes</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt;</th>
<th>4&lt;sup&gt;th&lt;/sup&gt;</th>
<th>5&lt;sup&gt;th&lt;/sup&gt;</th>
<th>6&lt;sup&gt;th&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>170 – 190 kw</td>
<td>16 – 19 t</td>
<td>10 km/h</td>
<td>16 km/h</td>
<td>26 km/h</td>
<td>40 km/h</td>
<td>56 km/h</td>
<td>65 km/h</td>
</tr>
<tr>
<td>200 – 230 kw</td>
<td>20 – 27 t</td>
<td>7.5 km/h</td>
<td>13 km/h</td>
<td>21 km/h</td>
<td>31 km/h</td>
<td>43 km/h</td>
<td>52 km/h</td>
</tr>
<tr>
<td>240 – 280 kw</td>
<td>28 – 30 t</td>
<td>7.0 km/h</td>
<td>13 km/h</td>
<td>21 km/h</td>
<td>31 km/h</td>
<td>43 km/h</td>
<td>51 km/h</td>
</tr>
<tr>
<td>290 – 310 kw</td>
<td>31 – 36 t</td>
<td>8.0 km/h</td>
<td>14 km/h</td>
<td>23 km/h</td>
<td>33 km/h</td>
<td>44 km/h</td>
<td>54 km/h</td>
</tr>
<tr>
<td>+310 kw</td>
<td>+37 tonnes</td>
<td>7.5 km/h</td>
<td>13 km/h</td>
<td>22 km/h</td>
<td>33 km/h</td>
<td>43 km/h</td>
<td>53 km/h</td>
</tr>
</tbody>
</table>

**4.6.3.6 Motor Graders**

Motor graders are equipped with a blade that can tilt and move sideways under the machine, and with rippers either at the front or the rear of the machine. Graders are used during surface preparation and surfacing operations and are widely used during road maintenance. Grader operation requires a suitable level of skill, so only properly trained operators should be used. Graders should not be used for subgrade construction or excavation, as these activities are beyond the design parameters of the machine and may cause excess wear and tear.

Motor graders used in forestry range from 12 to 16 tonnes.

Applications:
- Spreading material during surfacing operations;
- Shape and trim the road layers to final formation;
- Blade and reshape the road surface, smoothing out irregularities and potholes;
- Rip and reworking of existing road surfacing;
- Cut and shape side drains;
- Re-shaping and clearing of side drains.

*Figure 4.6-9: Motor grader.*
Work rate: Graders

The work rate of the graders is dependent on the application of the grader. The travel speeds for various units and models are consistent to the application of the unit. The travel speeds of the units are detailed in the table below. Please note: Most graders are very powerful and road grade does not affect travel speed.

<table>
<thead>
<tr>
<th>Description</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy ripping and blading – 1st &amp; 2nd gear</td>
<td>3 km/h</td>
</tr>
<tr>
<td>Medium ripping and blading – 2nd &amp; 3rd</td>
<td>6 km/h</td>
</tr>
<tr>
<td>Light blading – 4th gear</td>
<td>9 km/h</td>
</tr>
</tbody>
</table>

The turning area for the grader will also impact on the operational performance of the unit. All references refer to 180° turns.

<table>
<thead>
<tr>
<th>Description</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy turning – 2 point turn</td>
<td>1.20 min / turn</td>
</tr>
<tr>
<td>Medium turning area – 3 point turn</td>
<td>1.75 min / turn</td>
</tr>
<tr>
<td>Difficult narrow turns - +4 points</td>
<td>2.75 min / turn</td>
</tr>
</tbody>
</table>

The table below outlines the hourly production guidelines for the Motor Graders operation at an 80% machine effective utilisation. Note the output is given in total distance (m) covered. If multiple passes are to be completed then divide the distances below by the number of passes for the actual output in linear metres.

<table>
<thead>
<tr>
<th>Easy turn</th>
<th>500 m between turns</th>
<th>1000 m between turns</th>
<th>1500m between turns</th>
<th>2000m between turns</th>
<th>2500m between turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2140 m</td>
<td>2260 m</td>
<td>2300m</td>
<td>2330m</td>
<td>2340m</td>
</tr>
<tr>
<td>2nd</td>
<td>3870 m</td>
<td>4290 m</td>
<td>4450m</td>
<td>4540m</td>
<td>4580m</td>
</tr>
<tr>
<td>3rd</td>
<td>5270 m</td>
<td>6070 m</td>
<td>6400m</td>
<td>6580m</td>
<td>6690m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medium turn</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td>3 550 m</td>
<td>4 090 m</td>
<td>4 300 m</td>
<td>4 420 m</td>
<td>4 490 m</td>
</tr>
<tr>
<td>3rd</td>
<td>4 700 m</td>
<td>5 680 m</td>
<td>6 100 m</td>
<td>6 340 m</td>
<td>6 490 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Difficult turn</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
<th>1st</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td>3 100 m</td>
<td>3 770 m</td>
<td>4 060 m</td>
<td>4 220 m</td>
<td>4 330 m</td>
</tr>
<tr>
<td>3rd</td>
<td>3 940 m</td>
<td>5 080 m</td>
<td>5 620 m</td>
<td>5 940 m</td>
<td>6 150 m</td>
</tr>
</tbody>
</table>

4.6.3.7 Rollers

Rollers are used to compact embankment or surfacing material. Various types of rollers are used in forest road construction and maintenance operations. These include grid, sheepsfoot, vibratory, and pneumatic-tyre rollers. The use of each will be discussed below. The appropriate type of roller should be selected for each construction project.

Rollers used in forestry operations typically range from 2 to 16 tonnes.

The following factors determine the appropriate type of roller for the compaction effort:

- Material type:
  - Sheepsfoot or padfoot rollers for cohesive material where a kneading effort is required
• Vibratory rollers for compaction gravel materials;
• Grid rollers for breaking down large material or for compacing non-cohesive material.
• Road grade can be a concern, as self propelled smooth drum rollers have difficulty in working up a hill, however production studies show grade does not influence production rates, as long as traction is maintained.

Applications:
• Sheepsfoot or padfoot rollers are used for compacting fill material;
• Grid rollers are used to break down oversized material, compact pit-run surfacing, and compact sandy or rocky soils;
• Vibratory and pneumatic-tyred rollers are used to compact subgrades and pavement structures.

Figure 4.6-10: Self-propelled padfoot roller.

Figure 4.6-11: Self-propelled vibratory roller.
Work Rate: Smooth-drum vibratory roller

The work rate of the graders is dependent on the application of the roller. The travel speeds of the units are detailed in the table below. Note some machines are limited to a maximum speed of 5 – 7km/h, most are not geared, but rather use a hydrostatic drive. The operator must be skilled and have knowledge of appropriate frequency and amplitude settings as they relate to travel speed. A higher amplitude requires a slower travel speed, and vice versa.

<table>
<thead>
<tr>
<th>Description</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy rough rolling – low rpm</td>
<td>4 km/h</td>
</tr>
<tr>
<td>Medium rolling – medium – high rpm</td>
<td>6 km/h</td>
</tr>
<tr>
<td>Light rolling – high rpm</td>
<td>10 km/h</td>
</tr>
</tbody>
</table>

When pulling a grid roller with a dozer, use the dozer data given earlier in the chapter with an approximate one gear speed reduction from travel without pulling a grid roller.

The turning area for the grader will also impact on the operational performance of the unit.

<table>
<thead>
<tr>
<th>Description</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large easy turning – 2 point turn</td>
<td>1.50 min / turn</td>
</tr>
<tr>
<td>Restricted turning area – 3 point turn</td>
<td>2.50 min / turn</td>
</tr>
<tr>
<td>Tight narrow turns - +4 points</td>
<td>4.00 min / turn</td>
</tr>
</tbody>
</table>

The table below outlines the hourly production guidelines for the Motor Rollers operation at an 80% machine effective utilisation. Note the output is given in total distance (m) covered. If multiple passes are to be completed then divide the distances below by the number of passes for the actual output in linear metres.
4.6.3.8 Water Trucks

Water trucks are used to supply water for mixing in with road building materials. Water trucks are equipped with a water spreader at the front or back and work in conjunction with the grader for applying water to the material. Other uses are to apply water to reduce dust and improve maintenance blading.

Forestry firefighting trucks are very useful for use as water trucks in road building operations.

Applications:
- Watering embankment or surfacing materials to assist compaction;
- Watering work areas to reduce dust generation;
- Firefighting applications.

Figure 4.6-13: Water truck.
Work Rate: **Water tankers**

On average the water tankers move at a speed of between 6 – 8.5 km/h from observations. The required travel speed will depend on the required water application per m$^2$ rate. In order to calculate the required speed or number of passes the following information is required.

1. The spray width of the unit (2.5 m)
2. The flow rate from the unit (500 l/min)
3. Tank volume (10 000 l)
4. Application 10 l/m$^2$

Area to be covered / tank = 10 000 l / (10 l/m$^2$) = 1 000 m$^2$
Distance covered per tank = 1 000 m$^2$ / 2.5 m width = 400 linear metre of road / tank
Time required to empty tank = 10 000 l / (500 l/min) = 20 min
Speed required = 1.2 km/hr

### 4.6.3.9 Pneumatic Rock Drills

Pneumatic rock drills are used in areas of solid rock excavation. Drills can be self-contained on a dedicated tracked carrier, have a tow-behind air compressor, or can be used as an attachment on a hydraulic excavator. Typical drills used in forest road construction have a diameter of 25-50 mm.

**Applications:**
- Drilling holes that are filled with explosives for blasting operations during subgrade or side drain construction;
- Drilling holes for blasting during gravel source development.

*Figure 4.6-14: Pneumatic rock drill.*
4.6.3.10 Specialised road construction and maintenance plant

Other specialised road construction plant is available and are sometimes used in forestry road building operations:

- Stabilisation plant which mixes in lime or cement with the material for stabilisation and increase in bearing strength
- Tow behind rock breakers which uses a rotating drum fitted with hammers that breaks rock as it is pulled over it (See Section 4.5 – Surfacing Operations).

4.6.4 References and Further Reading

1. Cat Performance Handbook
2. Komatsu Performance Handbook
Chapter 5 - Road Management

Section 5.1 - Road Administration

5.1.1 Introduction

Roads must be properly administrated to achieve maximum return on the substantial investment required. Road administration is comprised of all details that facilitate operation of a road network that meets management objectives.

Aspects that will be covered in this section include:

- Personnel;
- Road numbering;
- Road signage.

5.1.2 Personnel involved in Forest Road Administration

The personnel responsible for forest road administration should be appropriately qualified and knowledgeable in all aspects of forest road management.

A forest road manager should have knowledge of the following attributes:

- Forest road planning;
- Forest road design;
- Timber harvesting methods and requirements;
- Construction methods and techniques;
- Construction and maintenance plant;
- Surfacing materials, methods, and design;
- Environmental management;
- Contract management;
- Personnel management;
- Safety practices and regulations.

Forest road managers ideally come from a forest engineering or civil engineering background, however foresters can become effective road managers by undergoing proper training and gaining practical experience.

The forest road manager should oversee an area no larger than 30000 ha. If the forest estate is larger than 30000 ha, the management responsibilities should be shared by two competent individuals. These managers should have properly trained and qualified subordinates. Where certain skills are absent, consideration should be given to input from qualified consultants.

5.1.3 Road Numbering

A simple, widely-used forest road numbering system is detailed in the following paragraphs. A road numbering system should allow easy navigation for the average forest road user, who may or may not have a map.
A simple system such as used by the U.S. Forest Service and Weyerhaeuser Company is ideal. In this system, the main road that accesses a drainage or forest estate is named, such as "Kleinfontein Mainline" or "Bobbejaanspruit Mainline". The name should be based on the primary geographic feature in the area, such as a river or mountain. The first main road that leaves the mainline upon entering the forest estate is the 1000 road, the second the 2000 road, etc. The first road off the 1000 road is the 1100 road. The first road off the 1100 road is the 1110. This system continues throughout the road network.

A benefit to this system is that a road user who is attempting to find a compartment that is on the 2245 road knows to turn on the 2000 road, then the 2200, then the 2240, to the 2245.

Road users can easily locate roads such as the "Kleinfontein 3350" or the "Buffelskop 1200". The road user should also be able to note that roads with "simpler" numbers will be higher-standard roads. For example, the 5000 road will likely be a higher standard than the 4235 road.

**Figure 5.1-1: Forest road numbering.**

### 5.1.4 Road Signage and Route Marking

Forest roads should be appropriately signed to provide safety for road users and the routes marked to allow easy navigation of the road network. Where roads are open to the public, signage should meet with applicable regulations.

The following situations should be signed for safety reasons:

- Dangerous corners;
- Stop signs at intersections, where needed;
- Road design speed;
- Mass restrictions on bridges;
- One-lane bridges;
- Gates.
The following situations should be signed for navigational reasons:

- Road junctions;
- Property lines;
- Directions and distances to towns or major public roads;
- Route numbers.

Any method or type of route marking or markers can be used, and methods and types might differ from area to area, as long as its cost can be equated with effectiveness and durability.

Route markers should indicate the:

- The route number;
- The start and end of a route;
- Direction of the route;
- The continuation of a route at an intersection or junction of another route;
- Total length of the route and the distance from the start at any other intersection, or junction.

Route markers can also indicate:

- If the route is a cul de sac;
- One or two way route;
- Whether the road is used by public;
- Water hydrant or fill stand or any other information that might make in-field management easier.
Section 5.2 - Tenders and Contracts

5.2.1 Introduction

This chapter deals with the different contract types that are used in the civil engineering industry, when they should be used and what should be included in such a contract document.

It takes a practical look at the more popular contract type called measurement contracts, and gives the reader an understanding of how to set up this type of contract, what steps to follow and gives examples of what a Schedule of Rates and Quantities and a Payment Certificate looks like.

5.2.2 Definitions

Client – (also referred to as the Employer) is the individual or company requiring the work to be done.

Consulting Firm or Design Office – the company or individual appointed by the Client to design the work. The consulting firm can also be asked to oversee the completion of the work. For this function the consulting firm will appoint an Engineer.

Engineer – appointed by the Consulting Firm and in some cases directly by the Client. The Engineer fulfils a number of roles, namely:
- To ensure that the Contractor carries out the work in terms of the specifications laid out in the contract documents;
- To ensure quality control on the project;
- To ensure costs are kept to a minimum;
- To ensure that schedules are kept;
- Communication between the Client and the Contractor;
- Solving of unforeseen problems with regards to the work;
- Monthly payments to the contractor for work completed.

Contractor – is the individual or company that is awarded the contract. This is the company that does the work.

Contract/ Works – is the work that is to be done in a specified time as laid out in the contract documents which are drawn up by the Consulting Firm.

Tender Documents – are the documents and drawings drawn up by the Consulting Firm informing the Contractor of the specific work to be carried out, the specifications for the contract and the standards required.

5.2.3 The Construction Contract

The construction contract can be viewed as a form of letting and hiring of services requiring no formalities for its conclusion.

The tender process is one of balancing quantifiable risk against price. Various forms of contract allocate these risks in different ways. The basis of a successful contract is the preparation of concise, unambiguous conditions of contract that gives a clear picture of the division of responsibility between the parties. It is essential that the Employer (Client) devote sufficient time and resources to the determination of a contract strategy as any areas open to different
interpretation are likely to be exploited and will therefore create friction between the parties. This holds true if:

- The Client has failed to select the appropriate form of contract for the circumstances;
- The Contractor has under-priced the project;
- The Contractor has misunderstood and/or miscalculated the risk.

Construction contracts are generally classified by reference to the method of measurement and payment. Different types of contracts offer different degrees of flexibility, incentive and allocation of risk between the parties.

5.2.3.1 Contract Types

There are three types of contracts namely:

- Lump Sum;
- Measurement (most common);
- Cost Contracts.

5.2.3.1.1 Lump Sum Contracts

- Single lump sum price quoted for the completion of the specified work to the satisfaction of the Client.
- Implies that the design is complete and final.
- The Contractor may be responsible for both the design and construction under this contract.
- Likely that payment will be made to the Contractor after each stage of work is completed to the satisfaction of the Engineer.
- Work is pre-estimated and therefore must be calculated precisely.
- Unless by special provisions provided for, the price will not vary i.e. fluctuation clause, or that the work has been varied or changed on the orders from the Client.
- Any Bill of Quantities or document showing units of construction and price will have no legal effect other than being a guide for payment purposes.
- The Contractor bears all the risk and therefore tenders are normally high.

5.2.3.1.2 Measurement Contract

This is the more popular method as the risk is shared between the Client and the Contractor, thereby giving a more competitive tender.

A measurement contract consists of two parts namely:

- The Bill of Quantities;
- The Schedule of Rates.

5.2.3.1.3 Bill of Quantities

- The design team estimates the quantities for the contract before the work is started; the figures are entered onto the Bill of Quantities, the Contractor then tenders according to the Bill of Quantities.
• At the end of each month the completed work is measured and paid for.
• On the completion of the Contract a final measurement is made and payment is made to the Contractor based on the work actually done.
• The Bill of Quantities facilitates competitive tendering, but incorporates changes in work conditions and content.
• The Total Contract Sum is the Tender Sum given in respect to a fixed measure of work.

Bill of Quantities
• Used where nature and extent of the work is assessed.
• Client’s advisers must analyse drawings and specifications and break them down and approximate the quantities for each construction process.
• Tendering contractors required to price individual items in Bill of Quantities, then grossed up to produce Total Tender Sum.
• Bill of Quantities fulfils the following contractual functions:
  • Indicates to tendering contractors the nature and extent of the work.
  • Forms the basis for determining the new rates.
  • Provides a basis for assessing interim payments.
  • Details exact measurements of work undertaken, adjusted once work is complete and actual quantities are known.
  • Can indicate the structure of the tender for examination.
  • Bill of quantities reduces the cost of tendering and provides an accurate basis for company tenders and valuing variations and interim payments.

The Bill of Quantities must be thoroughly studied by the contractor, as any deviations from the General Conditions of Contract, could be financially damaging to the contractor.

There are two reasons why the final quantities can differ from the originals:
1. Precise quantities of some items cannot be calculated exactly before hand and needs physical measurement when in progress ie removal of soft unsuitable material and the substitution of imported filling.
2. Separate prices for the excavation of rock may be included, but the amount of rock to be excavated is unknown.

5.2.3.1.4 Schedule of Rates (or Dayworks)
• Used where there is additional work that was not originally budgeted for (unforeseen work).
• The Schedule excludes revisions of the rates except where the tender sum is exceeded by a certain percentage.
• Total Contract Sum is calculated only after completion of the contract.

Schedule of Rates
• Used where the nature and extent of work cannot be adequately defined.
• Protects the Client.
• Any Bill of Quantities included, amounts to no more than a Schedule of Rates, does not form part of the documents unless some construction process method or working condition differs from that tendered for.
• Contractor offers to supply labour, plant and material at the rates specified for the individual units, while full extent of work remains unqualified and contract price derived by applying rate specified to actual man hours, plant hours and quantity materials ultimately consumed.
• Should identify nature of item, rather than nature of contract.
5.5.5.5 Cost Reimbursable Contract

- Used when requirements of Client are vague or when it is desirable for design to proceed at the same time as the construction.
- When Client wishes to be directly involved.
- Or to reduce financial risk to contractor.

5.2.3.1.6 Cost Plus Contract

- The Contractor is reimbursed for all costs incurred, plus an agreed fee to cover overheads and profit.
- The fee is a percentage of the agreed actual cost or a fixed amount.
- No financial risk for the Contractor.
- Contractor therefore may slack off as a result of a lack of incentive.
- Client should therefore establish a joint planning team.

It is important to note that a Consultant does not have to be appointed should the Client have the necessary expertise to carry out this function. This provides the Client with a large savings and allows the Client to have more control over the Contract.

5.2.4 The Tender Process

Once the Client has decided what the requirements are and a consulting firm has been appointed, the tender process begins.

Tenders are used to ensure that all contractors have the opportunity to bid a price for the contract. It gives the Client the opportunity to get the best deal and the best price.

The consulting firm will send a design team to the site to carry out a site investigation which entails the excavation of test holes to test the in-situ materials and to determine the underground water level. An initial survey is carried out to help with the project design. It is important that the consulting firm decides from the beginning what type of contract to use, as this will reduce any chance of legal battles later.

5.2.4.1 Tender Documents

These documents are drawn up by the consulting firm and are used by the contractors to bid for the contract.

A construction document is divided into different sections and colour coded for ease of reference. The colour of the pages is listed next to each heading below. Yellow pages are the pages that need to be filled in by the contractor.

A typical tender document consists of the following sections:
- Cover Sheet;
- Tender Notice;
- Tender Rules;
- Special Conditions of Contract;
- Project Specifications – included are the drawings;
- Bill of Quantities;
• Schedule of Rates;
• Forms – Certificate of tenderers visit to the site, schedule of construction equipment and schedule of previous work carried out by tenderer;
• Form of Agreement/Insurances.

5.2.4.1.1 Cover Sheet (White)
Details the name of the Client and Consultants, the address of the Consultants, Contract number, date, a brief description of the Contract and a space for the Contractor to fill in their company name.

2.2.2.2.2 Tender Notice (White)
This is a notification placed in the local newspaper advertising the Contract. The notice must have the following mentioned in it:

**Heading:** Clients name, contract number and brief description of the work to be tendered for. These details are normally in uppercase and bold.

**Paragraph 1:** Invites the contractors to tender and gives more detail of the contract.

**Paragraph 2:** States where tender documents can be collected, when and the amount to be paid for the documents.

**Paragraph 3:** States when the site inspection is to take place and where the Contractors are to meet. A site inspection is normally compulsory if there is a lot of unknown work or if the work is complicated. It is rather safer to make the inspection compulsory, as this will prevent the contractor having the excuse that the price tendered does not cover all the work required, as the contractor did not attend the site inspection when it was stated.

**Paragraph 4:** State that all tenders are to be placed in an envelope, clearly marked with the above contract number and description. At what time and date the contracts are to be received and where. Inform the tenderers that the tenders will be opened and read out in public at the time stated above.

**Paragraph 5:** Clearly state that late tenders will not be accepted.

**Paragraph 6:** Inform the tenderers of the validity of their tenders, normally one month.

**Paragraph 7:** Remind the tenderers to take note of the tender rules.

**Paragraph 8:** Close off by giving a contact name and number should the tenderers have any queries. Also state that the client does not have to accept the lowest tender or any other tender.

*A typical example can be seen below:*

ABC FORESTRY

TENDER NO.

MAINTENANCE OF PLANTATION ROADS

Tenders are hereby invited for the maintenance of plantation roads on ABC Forestry property in the Garden Route.

The work will consist of the cleaning of storm water pipes, side and mitre drains, building of headwalls, grading of roads and patch gravel of 2500 km of road in the area stretching from Mossel Bay to Knysna for the 2002/3-year.

Only Civil Engineering contractors with the required work experience need tender.

Tender documents may be collected from ABC Forestry, 39 ABC Boulevard, George – Jack Smith (Tel. 044 – 123456) upon payment of a deposit of R200.00, which will be refunded upon
receipt of a bona fide tender or the return of the complete set of unmarked, undamaged
tender documents prior to the closing date. Cheques must be crossed and made payable to
ABC Forestry.

Tenderers are to meet at the Forestry offices at 12h00 on Monday 1 April 2002 for a site
inspection. The site inspection is compulsory.

Tenders are to be placed in the tender box at ABC Forestry offices, 39 ABC Boulevard,
George before 12h00 on Wednesday 12 April 2002. Tenders will be opened in public at the
ABC Forestry offices at 12h00 on the closing date. Late tenders or tenders by fax will not be
considered. Tenders must be placed in a sealed envelope clearly marked "ABC Forestry, Tender
No. , Maintenance of Plantation Roads in the Garden Route for the 2002/3 year".

ABC Forestry reserves the right not to accept the lowest or any tender and no reason for
the acceptance or rejection of any tender will be given.

5.2.4.1.3 Tender Rules (Pink)
The tender rules inform the tenderer of what is expected of them during the tender process.
The following points are normally mentioned:
• Form of Tender;
• Signing of tender;
• Tender all-inclusive;
• Alterations to tender;
• Tender qualifications;
• Alternative tenders;
• Confidential nature of documents;
• Cost incurred by tenderer;
• Attendance at site inspection;
• Tender acceptance;
• Tender withdrawal or modification prior to closing date;
• Tender withdrawal or modification after closing date;
• Cancellation of contract;
• Legal aspects;
• Submission of tenders;
• Additional information required;
• Amendments of tender by Client;
• Disqualification of tender;
• Delegation of authority by Client;
• Stamp duties;
• Tender rules are binding;
• Language of the contract.

5.2.4.1.4 Special Conditions of Contract (Pink)
In Civil Engineering the CSRA: General Condition of Contracts (GCC), 1986, issued by the
International Federation of Consulting Engineers is used for all contracts.
5.2.4.1.5 Project Specifications (Pink)

The project specifications forms an integral part of the contract documents and supplements the standard specifications.

The following items are discussed in this section of the tender document, but are not limited to the following:

- Description of the works (or contract);
  - Location of the site and access to the site,
  - Nature of the work,
  - Detailed description of the Project,
- Drawings;
- Construction in confined areas;
- Additional requirements for construction activities;
- Requirements in terms of the Governments Reconstruction and Development Programme;
- Standard Specifications;
- List of Contract Drawings.

The purpose of a project specification is:

- It details the work to be done, giving nature and quality of materials and workmanship;
- It specifies any special responsibilities of the contractor that is not in the General Condition of Contracts;
- Could contain clauses specifying the order in which work must be done, the method by which it should be done and special facilities that may be required for the successful completion of the contract;
- The specifications should complete (with drawings and bill of quantities) the information necessary to allow the contractor to tender and complete the work without any queries or contradictions.

The sources of information that are used in writing a specification are the following:

- Previous specifications – but must update the latest technique, also add or delete to suit particular job;
- The required code for the contract, SABS, codes of practise, etc;
- Contract drawings – the draft contract drawings are available before the write up of the specifications. Drawings show the character and extent of the work;
- Employers requirements – certain requirements can be stipulated that must be incorporated ie complete certain sections of the work first;
- Site investigation – information on soil conditions, groundwater level must be inserted into specifications;
- Trade catalogues – obtained from manufacturers i.e. pipe sizes and flows.

The main qualities required when writing up a specification:

- Phrasing should be clear, concise, free from ambiguity or contradiction;
- Written in technical terms;
• Should be in the form of an instruction;
• Should be in a logical order.
  i.e. General – relates to job as a whole
  Materials – nature and quantity
  Workmanship – standard and extent
• Clauses should be numbered for ease of reference and should have headings.
• It is better to specify results rather than methods i.e. use 30 MPa concrete as opposed to using a mix of 1:2:4.
• Standardised items should be used as it cuts down on discrimination. Rather refer to codes of practise, material description as compiled by SABS or bill of standards.

5.2.4.1.6 Bill of Quantities (Yellow)
As discussed above, see example below.

5.2.4.1.7 Schedule of Rates (Yellow)
As discussed above, see example below.

5.2.4.1.8 Certificate of Tenderer’s Visit to the Site Meeting (Inspection) (Yellow)
Ensure that the certificate is signed by the contractor and the Employers representative at the site meeting should the meeting be compulsory. Should this document not be signed by the correct representatives it will mean that the tender will not be accepted.

5.2.4.1.9 Schedule of Construction Equipment (Yellow)
This schedule is used to ensure that the equipment to be used on the contract is of a good condition and is owned by the contractor. You would not want a contractor to work with equipment that continuously breaks down or is not belonging to the contractor and is removed from the contract without your permission.

5.2.4.1.10 Schedule of Work Carried Out by Tenderer (Yellow)
This form is to check the contractors references so as to ensure that the contractor is able to carry out the work required and has the required experience.

5.2.4.1.11 Insurances (Yellow)
The insurance is to cover the Employer/Client for any losses, damages and/or expenses that may be suffered or incurred by the Employer as a result of non-performance of the contract by the contractor.

5.2.4.1.12 Form of Agreement (Yellow)
This form is an agreement by the contractor to complete the work according to the contract rules as stated in the tender. The tender sum and the validity of the tender must be clearly marked on this form. The contractor must sign form giving the company name, the position held and the date.
5.2.5 An example of a measurement contract.

The contract involves the routine maintenance of 2,500 km of gravel road.

The yellow areas are filled in by the contractor in the tender process.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>QTY</th>
<th>RATE</th>
<th>AMOUNT R</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG : MAINTENANCE GRADING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG 1</td>
<td>Maintenance grading heavy</td>
<td>Km</td>
<td>500</td>
<td>800.00</td>
<td>400,000.00</td>
</tr>
<tr>
<td>MG 2</td>
<td>Maintenance grading normal</td>
<td>Km</td>
<td>1700</td>
<td>600.00</td>
<td>1,020,000.00</td>
</tr>
<tr>
<td>MG 3</td>
<td>Mitre drain cleaning</td>
<td>m</td>
<td>40000</td>
<td>10.00</td>
<td>400,000.00</td>
</tr>
<tr>
<td>MG 4</td>
<td>Ripping of side drains</td>
<td>m</td>
<td>2000</td>
<td>20.00</td>
<td>40,000.00</td>
</tr>
</tbody>
</table>

**TOTAL CARRIED FORWARD TO SUMMARY**

1,860,000.00
<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>QTY</th>
<th>RATE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SP : SPOT GRAVEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP 1</td>
<td>a) Pot hole areas less than 20 m²</td>
<td>m²</td>
<td>10000</td>
<td>10.00</td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>i) Depth less than 150mm</td>
<td>m²</td>
<td>5000</td>
<td>15.00</td>
<td>75,000</td>
</tr>
<tr>
<td></td>
<td>ii) Depth greater than 150mm</td>
<td>m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP 2</td>
<td>b) Spot gravelling areas between 20m² and 100m²</td>
<td>m²</td>
<td>20000</td>
<td>9.00</td>
<td>180,000</td>
</tr>
<tr>
<td></td>
<td>i) Depth less than 150mm</td>
<td>m²</td>
<td>10000</td>
<td>12.00</td>
<td>120,000</td>
</tr>
<tr>
<td></td>
<td>ii) Depth greater than 150mm</td>
<td>m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP 3</td>
<td>c) Patch gravelling areas over 100m²</td>
<td>m²</td>
<td>100000</td>
<td>5.00</td>
<td>500,000</td>
</tr>
<tr>
<td></td>
<td>i) Depth less than 150mm</td>
<td>m²</td>
<td>30000</td>
<td>7.00</td>
<td>210,000</td>
</tr>
<tr>
<td></td>
<td>ii) Depth greater than 150mm</td>
<td>m³/km</td>
<td>20000</td>
<td>5.50</td>
<td>110,000</td>
</tr>
</tbody>
</table>

**TOTAL CARRIED TO SUMMARY** 1,120,000
<table>
<thead>
<tr>
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<th>DESCRIPTION</th>
<th>UNIT</th>
<th>QTY</th>
<th>RATE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH 1</td>
<td>PH : CLEAN CULVERTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Less than 50% full</td>
<td>no</td>
<td>2000</td>
<td>80</td>
<td>160,000</td>
</tr>
<tr>
<td></td>
<td>b) More than 50% full</td>
<td>No</td>
<td>2000</td>
<td>80</td>
<td>160,000</td>
</tr>
<tr>
<td></td>
<td>c) Pipe inlets &amp; outlets</td>
<td>No</td>
<td>1800</td>
<td>200</td>
<td>360,000</td>
</tr>
</tbody>
</table>

**TOTAL CARRIED FORWARD TO SUMMARY**

680,000 00
<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>QTY</th>
<th>RATE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SR : SCHEDULE OF RATES (DAYWORKS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR 1</td>
<td>Plant Hire Rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Diger Loader</td>
<td>Hr</td>
<td>20</td>
<td>165.00</td>
<td>3,300 00</td>
</tr>
<tr>
<td></td>
<td>(ii) 10 cube Tipper</td>
<td>Hr</td>
<td>50</td>
<td>300.00</td>
<td>15,000 00</td>
</tr>
<tr>
<td></td>
<td>(iii) 6 cube Tipper</td>
<td>Hr</td>
<td>10</td>
<td>180.00</td>
<td>1,800 00</td>
</tr>
<tr>
<td></td>
<td>(iv) 20 ton Excavator</td>
<td>Hr</td>
<td>30</td>
<td>260.00</td>
<td>7,800 00</td>
</tr>
<tr>
<td></td>
<td>(v) 6000L Water Truck</td>
<td>Day</td>
<td>5</td>
<td>1050.00</td>
<td>5,250 00</td>
</tr>
<tr>
<td>SR 2</td>
<td>Personnel Rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Artisan</td>
<td>Hr</td>
<td>12</td>
<td>22.00</td>
<td>264 00</td>
</tr>
<tr>
<td></td>
<td>(ii) Hand Labour</td>
<td>Hr</td>
<td>15</td>
<td>12.00</td>
<td>180 00</td>
</tr>
<tr>
<td></td>
<td>(iii) Supervisor</td>
<td>Hr</td>
<td>10</td>
<td>35.00</td>
<td>350 00</td>
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<tr>
<td></td>
<td>(iv) Foreman</td>
<td>Day</td>
<td>5</td>
<td>460.00</td>
<td>2,300 00</td>
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</table>

TOTAL CARRIED FORWARD TO SUMMARY 36,244 00
A5.2.6 An example of the summary of rates.

**SUMMARY OF RATES**

<table>
<thead>
<tr>
<th>SECTION</th>
<th>DESCRIPTION</th>
<th>COST</th>
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</thead>
<tbody>
<tr>
<td>MG</td>
<td>MAINTENANCE GRADING</td>
<td>1,860,000.00</td>
</tr>
<tr>
<td>SP</td>
<td>SPOT GRAVEL</td>
<td>1,120,000.00</td>
</tr>
<tr>
<td>PH</td>
<td>CLEAN CULVERTS</td>
<td>680,000.00</td>
</tr>
<tr>
<td>SR</td>
<td>DAYWORKS</td>
<td>36,244.00</td>
</tr>
<tr>
<td></td>
<td>SUB TOTAL</td>
<td>3,696,244.00</td>
</tr>
<tr>
<td></td>
<td>CONTINGENCIES 10%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>ESCALATION 5%</td>
<td>-</td>
</tr>
<tr>
<td>SUB TOTAL</td>
<td></td>
<td>3,696,244.00</td>
</tr>
<tr>
<td>VAT 14%</td>
<td></td>
<td>517,474.16</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>4,213,718.16</td>
</tr>
</tbody>
</table>

**Discussion:**

Each section must be clearly marked for ease of reference. Contingencies, normally 10% or R 10,000 – depending on size of contract, are normally allowed for. Contingencies is any item of work that has not been allowed for in the tender documents or any unforeseen work i.e. when grading the road one could find a patch of clay that when removed requires filling of say 500mm in depth, this has not been allowed for and therefore a rate would be negotiated and paid for from contingencies. Escalation is built into a contract of a year or more and would cover changes in fuel prices, materials, etc. These are unforeseen variances.

Below is a typical example of a Monthly Payment Certificate:

**CLIENT:** ABC FORESTRY

**CONSULTANT:** ABC CONSULTANTS

**CONTRACTOR:** THE TENDERER (PTY) LTD

**P. O. BOX ****, *******

**CONTRACT NO.:** ABC 1 / 2

**ROUTINE ROAD MAINTENANCE**

**CONTRACT SUM:** R4,213,718.16

**CERTIFICATE NO. 5**
VALUATION OF WORK COMPLETED

DAYWORKS

TOTAL VALUE OF WORK

LESS RETENTION 5% OF R4,213,718.16

TOTAL PAYABLE FOR WORK DONE

LESS PREVIOUS PAYMENTS

THIS CERTIFICATE TOTAL PAYABLE FOR WORK DONE

VAT @ 14%

TOTAL DUE

I HEREBY CERTIFY THAT THE QUANTITIES OF WORK DONE IN THIS CERTIFICATE ARE CORRECT

ENGINEER __ __ __ __ __ __ __ CONTRACTOR __ __ __ __ __ __ __

DATE __ __ __ __ __ __ __ __ DATE __ __ __ __ __ __ __ __

5.2.7 Discussion on Payment Certificate:

Normally issued monthly, work is measured up until the 25th of the month and the payment certificate is submitted to the Consulting Firm. On some contracts, normally large ones a retention amount of between 5 to 10% is retained by the Consulting Firm. This is done to ensure that the contractor completes the work and to the standards required. Most contracts have a maintenance or guarantee period of between 6 to 12 months this allows for any defects as a result of sub standard work to be repaired in the period by the contractor. Should the contractor fail to repair the work to the satisfaction of the Consulting Firm then the retention monies owed to the contractor is used to pay for the repairs. However, should the contractor repair all defects at his own costs or should there be no defects in this period, then the entire sum is paid over to the contractor at the end of the maintenance period.

FORM OF AGREEMENT

I/we hereby tender to supply all or any of the supplies and/or to render all or any of the services described in the attached documents to ABC Forestry on the terms and conditions and in accordance with the specifications stipulated in the tender documents at the prices and on the terms regarding time for delivery and/or execution therein.

We agree that the offer herein shall remain binding upon me/us and open for acceptance by ABC Forestry during the validity period indicated and calculated from the closing hour and date of tender.
I/we confirm that I/we are satisfied with the correctness and validity of the tender, that the price and rates quoted cover all the work/items specified in the tender documents and that the tender price quoted includes all obligations to complete the work required, I/we furthermore accept that any mistakes regarding price(s) and calculations will be at my/our own risk.

We hereby accept full responsibility for the proper execution and fulfilment of all obligations under this agreement.

I/We offer to construct and maintain the above works as set out in these tender documents for the sum of R ……, amount in words …………………………, or as may be amended in accordance with these documents.

Signed in the presence of the subscribing witnesses:

At ………………… for and on behalf of ……………… ………(Contractor) on this ……… day of ……………… 20 ………

Address ……………………………..

…………………………….. ……………………………

SIGNATURE

AS WITNESSES:

1. …………………………………….. 2. ……………………………….
Appendix 1 - Glossary

**ABNEY LEVEL**
Handheld level that measures angles of depression and elevation.

**ADVERSE GRADE**
Ascending or climbing grade for a loaded truck.

**ANGLE DOZER**
Blade mounted across the front of a crawler tractor. Can be raised or lowered and each end retracted or advanced. Can also be called a 6-way blade.

**AASHTO**
American Association of State Highway Transportation Officials. (Modified AASHTO refers to a standard level of compaction that meets AASHTO specifications).

**ABRASION**
The removal of material from the surface of a solid by a grinding or rubbing action.

**ABUTMENT**
The structure that supports the end of a bridge and retains the bank.

**ADHESION**
The molecular attraction between bodies in intimate contact. The property by means of which a fluid or plastic substance sticks to the surface of a solid body.

**AGGREGATE**
Crushed rock or gravel screened to sizes for use in concrete and road surfaces.

**ALIGNMENT**
The geometric form of the centre line of the roadway. The relationship between the horizontal and vertical positions of the road centreline.

**ANGLE OF REPOSE**
The angle from the horizontal, which the sloping face of a bank of loose material assumes. Fill material should not be placed at a steeper angle without reinforcement such as rip-rap.

**APRON**
A layer of concrete, stone, timber or other permanent material placed at the entrance or outlet of a structure (such as a culvert) to prevent scour by the water.

**ATTERBURY LIMIT**
Soil test measuring liquidity and plastic limits of material.
**BACKFILL**
Earth or other material used to replace material removed during construction, such as in sub drain trenches or behind culvert and bridge abutments. Or the process of doing the replacing.

**BACKSLOPE**
Slope of a cut bank, expressed as a ratio of the horizontal in metres to one metre of vertical height.

**BALANCE**
a. To equalize the quantities of embankment and excavation;
b. to adjust a survey traverse.

**BEARING STRENGTH**
The load carrying ability of a soil or subgrade.

**BANK**
a. An embankment or fill;
b. A fill in the line of a road;
c. The cut face near the edge of a road.

**BASE COURSE**
On sealed roads it is the primary load spreading aggregate course in the pavement other than the sub-base. On unsealed roads it is the principal aggregate course (or layer) immediately beneath running course.

**BATTER**
The uniform side slope of walls, banks, cutting, etc.
The degree of such slope, usually expressed as: horizontal to one vertical. Also called cut or fill slopes or banks. Also to form a uniform side slope to a wall, bank or cutting.

**BATTER BOARD**
A board inclined at the same angle as a proposed batter cut to assist operators in maintaining an even batter cut.

**BATTER PEGS**
A stake or board positioned at the proposed head of a cut or toe of fill, indicating the amount of cut or fill required at that point. Also called slope stakes.

**BATTER (STEPPED)**
A batter cut having benches to avoid a long batter slope.

**BEDROCK**
The solid rock underlying superficial formations. It may be un-weathered or partially weathered.

**BERM**
A formed profile of compacted material. Usually used to direct water run off.
**Bench**

A ledge cut or formed in the batter of a cutting or bank to provide greater security against slip material depositing on the roadway, or to provide visibility on a curve.

**Benkleman Beam**

A device used to measure road pavement deflection under vehicle wheels.

**Bench Mark**

Survey reference point. Usually used to mark the beginning or end point or a midpoint of significance.

**Boning**

The operation of setting out levels by sighting over boning rods.

**Boning Rods**

Tee squares or rods of uniform height used to furnish a line of sight whereby from two given points, other points at the same level or on the same gradient may be established.

**Borrow**

a. Fill Material obtained by excavating at some point other than the construction project, required for the construction of the road;
b. To obtain fill from some point other than the excavation required for the work.

**Borrow Pit**

An excavation outside the construction area for obtaining borrow material (same convention to be used throughout = gravel source).

**Boulder**

A rounded or sub angular stone or piece of rock of large size, usually larger than 150 mm.

**Box Culvert**

A drainage structure of rectangular cross section.

**Box Cutting**

That portion of the road where both sides are in cut. Also known as a through cut.

**Braking Distance**

The distance travelled by a vehicle in the period between the initial application of the brakes and coming to rest plus reaction time.

**Bulk Density**

Measure of weight per unit volume of a material. Usually refers to soil or wood.

**Camber**

a. The degree of cross fall on a road from centre line to side;
b. The act of installing a culvert with a positive kink to allow for settling of the fill.
CAPILLARY ACTION
When water is induced to rise above the free water table level by the fine nature of the material.

CAT SKINNER
The person who operates a dozer.

CATCH DRAIN
A surface channel constructed along the high side of a road embankment, outside the batter line to intercept surface water and divert it from the road cut batter face.

CATCH BASIN
A compartment installed on ditched sections of roads to collect and redirect surface water and screen out silt and debris.

CATCH POINT
The lowest point down from the road surface on a fill where compacted material meets the natural ground.

CATCHMENT AREA
That area determined by topographical or equivalent features upon any part of which rain falling will contribute to the discharge of the stream at the point under consideration.

CBR
California Bearing Ratio – a test carried out to determine the strength of a road surface, sub base or base course. In simple terms it gives an expected performance percentage when compared to a high-quality road aggregate.

CENTRE LINE
The basic line, at or near the centre or axis of a road or other work, from which measurements for setting out or constructing the work can conveniently be made.

The centre of a road as calculated from baseline points and from which all structures and stakes are located and grades referenced.

CHANGE POINT
Used in levelling. It is not necessarily a fixed point but indicates a temporary holding point for the levels when the level is moved to a new location. Also known as a “turning point”.

CLEARING AND GRUBBING
The removal of vegetation, debris, and stumps from the ground. Generally associated with the first stages of forest road construction.

CLINOMETER
An instrument for measuring angles of slope or other vertical angles.

COARSE AGGREGATE
A general term used to differentiate between various sizes of aggregate, usually material retained on a 4.75 mm sieve.
**COHESION**

The ability of a material to resist by means of internal forces the separation of its constituent particles.

**COLD DECK**

Logs piled for future transportation or processing.

**COMPACTION**

The process of increasing the density of a material by inducing the closer packing of its particles by rolling, tamping or other mechanical means.

**COMPACTED MEASURE**

Volume of soil or rock after it has been placed and compacted in a fill.

**COMPASS**

Magnetic direction finder.

**CONSOLIDATION**

The process by which earth or soil reduces in volume over a period of time usually involving loss of water.

**CONTROL POINT**

Points identified along a proposed road location which help define a permissible route. Examples include junctions, landings, end of road, saddles, switchback curves, stream crossings, benches, etc.

**CORRUGATION**

A surface deformation into marker wavelike shapes at approximately equal distances and transverse to the line of traffic.

**CREEP**

a. A slow natural movement of a material;

b. A slow plastic deformation of a material under stress.

**CROSSFALL**

The slope at right angles to the main alignment direction.

**CROSS SECTION**

The profile of the ground more or less at right angles to a traverse or main directional line.

**CROWN**

The elevation of a road centre above its shoulders.

**CULVERT**

One or more adjacent pipes or enclosed channels for conveying a watercourse or stream below formation level.
CURVE WIDENING
Widening the road on the inside of a sharp curve to allow the rear wheels of a long vehicle to remain on the road during offtracking.

DEGRADATION
The changes in the mineral fragments of a pavement caused by rubbing, or grinding against each of them within the mass. Can also be caused by chemical or weathering processes.

DESIGN SPEED
A speed fixed for the design and correlation of those geometric features of a carriageway that influence vehicle operation.

DRAGGING
Pulling an object or objects, such as a heavy grate, chains, or tires, behind a vehicle to smooth the running surface of a forest road.

DRY DENSITY
The weight of a dry unit volume of a substance.

EARTHWORK
The quantities of soil that must be moved for embankment and from excavation as computed from road cross-sections.

EMBANKMENT
An area built up to designed roadway gradient or shape by repositioning soil. Also “fill”.

EXCAVATION
The removal of soil, also “cut”.

FASCINE
A layer of timber placed across swampy ground to support fill material. Also called corduroy.

FAVOURABLE GRADE
Downhill grade for a loaded truck.

FILL
a. The depth from the finished road surface to the natural depth;
b. That portion of a road where the pavement surface is above the natural surface.

FINE AGGREGATE
A general term used to differentiate between various sizes of aggregate, usually material passing a 4.75 mm sieve.

FINE CRUSHED ROCK
A graded aggregate prepared by crushing stone for use as a gravel for pavement construction, normally 19.0 mm to 26.5 mm maximum size.
**FIXED COSTS**

Operation costs that will remain relatively constant for all levels of output.

**FOPS**

Falling Object Protective Structure which protects equipment operators from falling objects such as tree limbs and tops, or rocks.

**GABION**

A rectangular basket constructed of wire mesh packed with stones or boulders used for protection of riverbanks, etc.

**GRADE**

The longitudinal profile of the centre of the roadway, or its rate of rises or falls; to establish a profile by cuts and fills or earthwork.

**GRADE LINE**

A marked gradient line in the field for the road survey line to follow.

**GRADED**

a. The sorting of particles in a soil sample, by size. i.e. can be well graded or poorly graded;

b. Pertaining to the surface of an aggregate roadway.

**GRADIENT**

a. A length of carriageway sloping longitudinally;

b. The rate of longitudinal rise or fall of a carriageway with respect to the horizontal expressed as a ratio or as a percentage.

**GRADING ENVELOPE**

A specified minimum and maximum particle size for crushed aggregate used in surfacing projects.

**GRAVEL**

a. A mixture of mineral particles, which may or may not include fine material occurring natural deposits, passing a 75.0 mm sieve;

b. A loosely used term for aggregate.

**GRID ROLLER**

A roller constructed of heavy crossed mesh often used for compacting "pit-run" rock or sandy soils. Often towed behind a dozer.

**GRIT**

Fine sharp aggregate or coarse sand; fine screenings substantially free from dust, usually passing a 4.75 mm sieve.

**GROUSER**

The raised steel strip the length of a crawler pad to provide traction.
**GRUBBING**
The removal of stumps from the ground.

**HEAD WALL**
A retaining wall at the end of a culvert barrel. Also a steep, concave slope.

**HIGHWAY TRUCK**
A truck designed to haul a load not exceeding legal highway limits.

**HIP CHAIN**
A measuring device that relies on string being pulled out and turning a wheel to measure accumulated distance. Usually carried on a belt.

**HORIZONTAL CURVE**
A curve in the plan or horizontal alignment of a carriageway. Expressed as a radius in metres.

**INSLOPE**
A road surface graded to slope toward the cut bank to direct water off the running surface into the ditch.

**LANDING**
A place where logs are collected preparatory to further transportation.

**LINE OF SIGHT**
The direct line or uninterrupted view between a driver and an object of specified height and location.

**LOCATION LINE (L-LINE)**
The staked centreline of the road consisting of tangents and curves usually designed from the preliminary line (P-Line) survey.

**LONGITUDINAL SECTION**
A section, usually with an exaggerated vertical scale, showing the existing surface levels along a road centre line. It commonly shows also reconstructive levels, gradients, cut and fill.

**LOOSE MEASURE**
Volume of soil or rock after it has been loosened by digging or blasting.

**LOWBED**
A heavy equipment moving truck capable of transporting harvesting and earthmoving equipment distances greater than which they would move themselves.

**MACHINE RATE**
Cost per unit of time for owning and operating a logging machine or some other piece of logging equipment. In accordance with engineering practices, the rate is composed of fixed costs such as depreciation, interest, taxes, and license fee, and variable costs including fuel, lubricants, and repairs and replacement of components such as tires and wire rope.
MAGNIFYING LOUPE
A small magnifying glass used for the examination of geological materials.

MAINTENANCE
Work carried out on a construction to maintain its efficiency or quality to the design level but not changing its capacity.

MASS DIAGRAM
A continuous plot of the algebraic sums of excavation and embankment quantities along a roadway. Most often used to balance earthwork.

MAXIMUM DRY DENSITY
The maximum density of a soil that can be achieved by a specified amount of compaction. The moisture content at which this is achieved is called the optimum moisture content.

MITRE DRAIN
An excavated drain that channels water from a side drain to the surrounding forest floor.

MOISTURE CONTENT
The quantity of water, which can be removed from the soil by heating at 105°C usually expressed as a percentage of the dry weight.

MOULDBOARD
The blade of a grader or bulldozer so shaped as to roll cut material away from the path of the machine.

OFF-HIGHWAY TRUCK
A truck designed to handle loads exceeding legal highway size and weight restrictions.

OPTIMUM MOISTURE CONTENT
That moisture content of a soil at which a specified amount of compaction will produce the maximum dry density.

OPTIMUM ROAD SPACING
Distance between roads that will give the lowest combined cost of timber transport (primary and secondary) and road construction costs per unit of area.

OUTSLOPE
A road surface graded to slope away from the cutbank to direct water off the running surface over the fill side.

OVERBURDEN
Unusable soil or rock

OVERTOPPING
The flow of water over the top of a bridge or fill structure as a result of high flows.
**PAPER PLAN**
An initial forest road plan using available maps and aerial photographs to serve as the basis for field verification and adjustment.

**PAVEMENT**
Constructed layers of a road surface which reduce/disperse loads to levels, which are within the bearing capacity of the sub grade.

**PERMEABILITY**
The property of a soil which permits the passage of water through open pore spaces.

**PENETROMETER**
A test instrument measuring penetration versus standard weight drop. Tests soil strength.

**PIONEER**
To initially work over rough or uncleared areas or to make a pioneer road.

**PIONEER ROAD**
A primitive tractor-trail type of access for moving equipment, workers, and material.

**PIT-RUN**
Stone, which when removed from the gravel pit, does not need to be crushed and can be placed directly on the road surface. Often compacted with a grid roller.

**PONDING**
Standing water, normally in ruts or side drains. Ponded water infiltrates the subgrade and reduces bearing strength by increasing pore pressures.

**POT HOLE**
A hole in the roadway surface.

**PRELIMINARY LINE (P-LINE)**
The initial survey of a road route, measuring bearing, distance, and grade between survey points, and measuring the cross-sections at the survey points.

**RAVELLING**
The loosening of stones or particles forming the surface course of a pavement.

**RECONNAISSANCE**
The initial field examination of a roading plan to determine its feasibility.

**REFUSAL DENSITY**
The density of a compacted material that prevents a penetrative implement such as a Dynamic Cone Penetrometer from further penetration.
REVETMENT
A facing of stone or other material laid on a sloping face of earth to maintain the slope in position or to protect it from erosion

RIGHT-OF-WAY
Strip of land on which a road is to be constructed

RIP-RAP
Rough stones of various sizes placed compactly or irregularly on the ground surface to prevent scouring by water or debris or to hold a fill in place

ROAD
The entire way devoted to travel, including berms, footways, etc. The whole width between abutting property boundaries where the road is in a surveyed road reserve

ROAD PRISM
The cross-sectional road structure between the top-of-cut and toe-of-fill. The road prism contains the cut and fill slopes, subgrade, drainage structures, and pavement structures.

ROPS
Roll-Over Protective Structures that protect the operator if a machine overturns

ROUGHNESS
Unevenness of a pavement, which is commonly assessed by the ride it provides

RUN OFF
That part of tile water precipitated onto a catchment area, which flows from the catchment area past a specified point

RUT
A depression in the wheel path of the road caused by vehicles

SADDLE
Low point in a ridge, having higher ground in both directions along the ridge often a control point during road planning and layout

SCARIFYING
The systematic disruption and mechanical loosening of the top of a pavement or of natural ground

SCREENINGS
Aggregate of small size, usually passing a 26.5 mm sieve and retained on a 4.75 mm sieve.

SECONDARY TRANSPORT
Movement of wood from the landing or transfer point. Includes movement by truck, rail, or water
**SHEEPSFOOT ROLLER**

Steel drum with short metal rods on the outside; sometimes shaped like a sheep’s foot. Used for compacting soil.

**SHOULDER**

The portion of the road continuous and flush with the pavement on either side of the road, which is not used by the travelling traffic.

**SHRINKAGE PRODUCT**

Soil measurement combining linear shrinkage and sieve analysis. It is measured by multiplying bar linear shrinkage x % passing the 0.425 mm sieve.

**SIDE CASTING**

Pushing spoil to one side, usually over the edge of the road being constructed. Nearly always associated with hill side roads where the spoil is wasted.

**SIDE DRAIN**

A surface drain approximately parallel to and between the formation and the road boundary also known as a ditch.

**SIEVE**

A box or tray whose base is made of woven wire or similar material or of perforated metal plate, having apertures of defined shapes and sizes.

**SILT**

A material intermediate in particle size between sand and clay. It is usually non plastic.

**SLOPE**

The incarnation of a surface with respect to the horizontal expressed as rise or fall in a certain longitudinal distance, i.e., 1 in 10 or as a percentage 10% or as an angle 5.5 degrees. An inclined surface.

**SOAK PIT**

A large hole maybe filled with rock or stone to create a large surface area in the surrounding ground so that surface run off can soak away.

**SPUR ROAD**

A dead-end, class C, road, less than 2 km in length, accessing a harvesting compartment or compartments.

**SUB BASE**

Area below the base course construction.

**SUB GRADE**

The trimmed or prepared portion of the formation on which the pavement is constructed. Generally taken to relate to the upper line of formation.

The surface produced by grading and compacting natural soil to support a pavement structure.
**SUPER ELEVATION**

The continuous transverse slope normally given to the road surface at horizontal curves.

**TEXTURE**

A term indicating the coarseness or fineness of a soil. The texture of soils for pedological classification is determined by a triangular chart and is based on the results of mechanical analysis.

Surface texture of a chip sealed roadway.

**TRETON IMPACT VALUE**

A test used to measure the durability and strength of aggregate material. See Appendix 5 for details.

**TOE-OF-FILL**

The location where the fill slope intercepts the natural ground surface.

**TOP-OF-CUT**

The location where the cut slope intercepts the natural ground surface. Also can be described as where the cut slope begins.

**VERTICAL CURVE**

A curve in longitudinal profile of a carriageway to provide for gradual change of grade

**VISCOSITY**

Internal friction due to molecular cohesion in fluids.

The numerical assessment of this property maple according to an agreed method.

**VIBRATING ROLLER**

A roller which uses vibration to assist compaction. Characterised primarily by frequency amplitude and mass.

**VOIDS**

The voids in a soil refer to that volume not occupied by solid materials and include the volume occupied both by water and by air.

**WEARING COURSE**

That part of the surface courses that directly supports the traffic.

**WEINERT N-VALUE**

An index used to correlate climate, geological conditions, and weathering in southern Africa.
Cited literature


Chapter 2 - Road Planning

Derivation of Optimum Road Spacing

In the derivation of optimum road spacing it is assumed that extraction is from both sides of the road. If extraction is only from one side of the road, the average primary transport distance is doubled (i.e., S/2 instead of S/4). Thus, the optimum solution would have to be multiplied by √(1/2) (=0.707107) or the constant value of 40 in the equation, replaced by 20.

The total cost for the off-road transport and access is:

\[ C_t = C_v + C_f + C_r \]

where

- \( C_t \) is total cost
- \( C_v \) is variable cost per m\(^3\) of off-road transport
- \( C_f \) is fixed cost per m\(^3\) of off-road transport
- \( C_r \) is the road cost per m\(^3\) (variable with road spacing)

and,

\[ C_v = M_c \left[ \frac{S}{4D_e} + \frac{S}{4D_i} \right] * \frac{P}{L} = M_c (L-1)pS \left[ \frac{D_e + D_i}{4D_eD_i} \right] \]

\[ C_f = M_c \frac{T_i}{L} \]

\[ C_f = M_c T_i L^{-1} \]

\[ C_r = 10 \frac{R_c}{VS} \]

\[ C_r = 10R_c V^{-1} S^{-1} \]

To solve for the minimum/maximum value for the \( C_t \) (total cost) the first derivative in respect to \( S \) (spacing) of the total equation is taken. The resulting equation is then set to 0 and \( S \) is solved for. The second derivative is taken to determine whether the value is a maximum or minimum; a negative value indicates a maximum, while a positive value indicates a minimum.

The first derivative of the equation is:

\[ \frac{dS}{dC_t} = M_c L^{-1} p \left( \frac{D_e + D_i}{4D_eD_i} \right) + 0 - 10R_c V^{-1} S^{-2} \]

Solving for \( S \),

\[ -M_c L^{-1} p \left( \frac{D_e + D_i}{4D_eD_i} \right) = 10R_c V^{-1} S^{-2} \]
The following mathematical steps will result in the optimum road spacing equation:

- Multiply by $s^2$
- Multiply by $L$
- Divide by $M_c$
- Divide by $p$
- Multiply by 4
- Multiply by $(D_e*D_l)$
- Divide by $(D_e+D_l)$

Since the second derivative yields a positive value we know that the first derivative result is a minimum. The optimum road spacing equation that minimise the total cost of off-road transport and road construction is as follows:

$$S = \frac{\sqrt{40RcLD_eD_l}}{M_cVp(D_e + D_l)}$$

It must be noted that the optimum road spacing should only be used as a guide to assist in road planning. This is because most logging areas are not perfectly flat. As a general rule though, if you must deviated from the optimum road spacing, it is best to increase the distance between roads rather than to decrease it.

Another road equation is in regard to $D_{max}$. $D_{max}$ is the maximum distance to the back of the felling area, after which the sum of primary transport and the building of a route into the cut area is cheaper than just primary transport out to the existing road. This is applicable since there is a dead zone from which wood will be transported to the existing road, thus the full benefit of the potential additional route is not gained (Figure 4). The optimum road spacing information is combined somewhat to simplify the equation:

- $C = \text{marginal skidding cost (Rand/m^3/m)}$
- $R = \text{road cost (Rand/ha)}$

If no spur roads are built the cost = $D/2*C$, where
- $D$ is the distance to the back of the block (m)
- $C$ is the marginal off-road transport cost (Rand/m^3/m)

If spur roads are built the cost = $S$. $S = \frac{S}{4C} + \frac{R}{V}$

- $S$ is the optimum road spacing (m)
- $C$ is the marginal off-road transport cost (Rand/m^3/m)
- $R$ is the road cost (Rand/ha)
- $V$ is the volume removed (m^3/ha)
The break-even point is when the two equations are equal:

\[
\frac{D_{\text{max}}}{2C} = \frac{S}{4C} + \frac{R}{V} \\
D_{\text{max}} = \frac{S}{2} + \frac{2R}{VC}
\]

Because at this point the dead zone has not been accounted for, you will notice that \(D_{\text{max}} = S\), and thus \((2*R)/(V*C)\) is equal to \(S/2\). The road cost component must be multiplied by a factor equal to the area serviced by the road divided by the reduced area due to the dead zone. This factor is equal to \(S^2/(S^2-S^2/4)\).

\[
D_{\text{max}} = \frac{S}{2} + \frac{S}{2} \left[ S^2 \left( S^2 - \frac{S^2}{4} \right) \right]^{-1}
\]

If a decision is made to build spurs then they should be built at the optimum spacing \((S)\) and they should end so the average skid distance at the back of the block is equal to \(S/4\).

---

**Back of felling area**

\[ D = \text{distances from road to back of block.} \]

If \(D*p > D_{\text{max}}\) then you build the additional route into the block to get the optimum off-road transport distance.

---

**Section 3.1 - Forest Road Design**

**Superelevation of Curves**

An equation for curve superelevation is given as follows:

\[
E = \left( \frac{V^2 * 0.6}{5R} + F \right)
\]

- \(E\) = superelevation rate (%)
- \(V\) = Velocity (kmph)
- \(R\) = Curve radius (m)
- \(F\) = Side slip friction factor (determined from tables)

**Minimum Curve Radius**

The minimum radius \((R_{\text{min}})\) required for a given design speed and superelevation can be derived from the following formula:

\[
R_{\text{min}} = \frac{V}{127(n + f)}
\]

where:
- \(V\) = Design speed (determined by the desired road standard and the terrain)
- \(n\) = Superelevation (m/m or %/100) (slope of the road surface expressed as a decimal - maximum of 0.0626 (6.26%) is suitable for timber trucks. For speeds less than 25 km/h, superelevation is not needed and normal crossfall is used)
- \(f\) = Coefficient of friction (see table below)
Table: A2-1 Coefficient of friction.

<table>
<thead>
<tr>
<th>Road surface</th>
<th>Static coefficient of traction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (Portland cement)</td>
<td>0.70</td>
</tr>
<tr>
<td>Asphalitic concrete</td>
<td>0.60</td>
</tr>
<tr>
<td>Hard packed gravel</td>
<td>0.60</td>
</tr>
<tr>
<td>Firm soil</td>
<td>0.50</td>
</tr>
<tr>
<td>Sand</td>
<td>0.15 to 0.40</td>
</tr>
<tr>
<td>Mud</td>
<td>0.15 to 0.40</td>
</tr>
<tr>
<td>Hard packed snow</td>
<td>0.20 to 0.25</td>
</tr>
<tr>
<td>Five centimetres of dry loose snow on gravel</td>
<td>0.30</td>
</tr>
<tr>
<td>Ice free of snow</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Curve Widening**

The most common equation used to calculate vehicle off-tracking is the modified Voshell equation:

\[
O.T. = \frac{400}{R}, \text{ where } R \text{ is the curve radius in feet.}
\]

To convert this to metric, we use the following equation:

\[
O.T. = \frac{42}{R}, \text{ where } R \text{ is the curve radius in metres.}
\]

This is the minimum amount that should be added to the inside of the horizontal curve.

**Sight Distance**

If sight distance is less than vertical curve length

\[
S = \frac{L}{2} + \frac{C}{2A}
\]

If sight distance is greater than the vertical curve length

\[
S = \sqrt{\frac{LC}{A}}
\]

where:
- \( S \) = Sight distance (m)
- \( C \) = \( 200(\sqrt{h1} + \sqrt{h2})^2 \)
- \( h1 \) = Height of eye above road (m)
- \( h2 \) = Height of object above road (m)
- \( L \) = Vertical curve length (m)
- \( A \) = Difference in grade (G1-G2)(%) (Note that G2 is negative if downhill)
The recommended sight distance is calculated for a vehicle approaching a stationary object on the road (e.g., a fallen tree), where:

\[ h_1 = 1.16 \text{ m (eye height of the driver in a car)} \]
\[ h_2 = 0.2 \text{ m (height of a stationary object above the road)} \]

The formulae above can be used for specific heights of driver and object (e.g., for a truck approaching a truck).

Obstructions can also affect the sight distance on the horizontal alignment. The following formulae can be used to calculate the sight distance.

\[
O = R \left[ 1 - \cos \left( \frac{28.65S}{R} \right) \right]
\]
\[
D = \frac{R}{28.65} \left[ \cos^{-1} \left( \frac{R - O}{R} \right) \right]
\]

where:
- \( D \) = Sight distance (m)
- \( O \) = Offset (m) \( 200(h_1 + h_2)^2 \)
- \( R \) = Radius (m) (can also be estimated in the field using Figure 3.?)

**Section 3.2 - Pavement Design**

**Pavement Thickness**

\[
T = t + \left( 1 + \frac{C_t}{100} \right) \times \left( GL_p \times L_d \right)
\]

Where
- \( T \) = design thickness in mm
- \( t \) = minimum thickness required for subgrade protection (mm)
- \( C_t \) = traffic induced compaction (%)
- \( GL_p \) = predicted annual gravel loss (mm)
- \( L_d \) = design life of road or regravelling frequency (years)

Thickness should be rounded up to the nearest 50 mm.

**Predicted annual gravel loss**

The annual gravel loss can be predicted with a high degree of confidence with the following model:

\[
AGL = 3.65 \left[ ADT \left( 0.059 + 0.0027N - 0.0006P_{26} \right) - 0.367N - 0.0014PF + 0.0474P_{26} \right]
\]

where
- \( AGL \) = annual gravel loss (mm)
- \( ADT \) = average daily traffic
- \( N \) = Weinert N-value
- \( P_{26} \) = percentage passing the 26.5 mm sieve (analysis recalculated to 100% passing 37.5 mm)
- \( PF \) = plastic factor (plastic limit x per cent passing 0.075 mm (analysis recalculated to 100% passing 37.5 mm)

The product of the annual gravel loss and the design period will indicate the material that will be lost by erosion and traffic whip-off over the design life of the road.
Appendix 3 - Culvert Design for Fish Passage

A3.1 Introduction

Improperly designed culvert installations have been responsible for blocking access to thousands of kilometers of suitable fish habitat. Throughout the world, forest managers are installing fish-passable culverts and rehabilitating habitat in the drive to sustainably manage forests.

This section will describe state-of-the-art techniques for engineering and installing culverts that pass fish upstream and downstream, and pass peak flows.

Figure A3-1: Fish passage culvert terminology.

A3.2 Design Process

1.) Determine the drainage area of the catchment.
2.) Determine the peak design flow.
3.) Perform a level 2 or 3 survey of the crossing location.
4.) Select the appropriate culvert structure based on size, shape, and gradient.
5.) Prepare diagrams and installation plans.
6.) Properly install and maintain culvert.

A3.3 Determining Drainage Area of Catchment

The first step in calculating the peak flow that a culvert needs to pass is to determine the drainage area of the catchment that will flow through the culvert. The easiest way to do this is to use a topographic map and mark the boundaries of the catchment, beginning at the culvert location and proceeding around the catchment. The boundary will always be at right angles to the contour lines. After the boundary has been determined, the area can be calculated with a dot grid, planimeter, or digitiser. Alternatively, a GIS system can be used very efficiently for calculating areas.
For small catchments, the drainage area can be effectively traversed with a hand compass and string box or by pacing. The accuracy level of this traverse does not have to exceed 1:100.

A3.4 Determining the peak design flow

Determining an appropriate design flow is critical in achieving fish passage. Fish passage needs to be possible at all times except for periods of extreme high or low flows. Many studies have been performed to determine what water velocities different fish are capable of traversing. If this information is available for the types of fish found in the project area, attempt to obtain it.

Many formulas have been developed to determine the peak flows from a given catchment.

A3.5 Culvert Design Survey

The engineer should perform a level 2 or level 3 survey of the proposed crossing location. The appropriate level of precision depends on the size of the crossing structure, peak flow, and potential environmental consequences, were the structure to fail.

The survey should extend upstream for a minimum of 100 m and downstream for at least 50 m. The survey should record the following information:

1.) Bearing, distance, and gradient of the centerline of the stream channel;
2.) Cross-sections of the stream channel at survey points;
3.) Measurement of stream channel widths, including high-water marks and average channel widths;
4.) Discussion of streambed materials, including aggregate size, type, and depth, and notation of bedrock.

The stream gradient should be measured preferably with a hand level and a level rod, because of their greater accuracy than a clinometer. Often, the areas immediately above and below an existing culvert have an artificial gradient. The upstream areas are artificially flat due to sediment deposit, and the areas below a culvert are artificially steep due to scouring action from culvert outlet flows. The profile should extend far enough in both directions to determine the natural stream gradient.

The streambed material should be surveyed to determine if a culvert design that requires sinking is feasible. For a streambed simulation installation, there needs to be a mixture of different sizes of sediment that can wash into the culvert and remain stable. The following table is a good guideline for determining streambed material sizes:

<table>
<thead>
<tr>
<th>Size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock</td>
<td>&gt; 4 m diameter – Bigger than a car, or continuous underlayer</td>
</tr>
<tr>
<td>Boulders</td>
<td>0.3 m – 4 m – Basketball to car size</td>
</tr>
<tr>
<td>Cobble</td>
<td>65 mm – 300 mm – Tennis ball to basketball size</td>
</tr>
<tr>
<td>Gravel</td>
<td>3 mm – 65 mm – Ladybug to Tennis ball size</td>
</tr>
<tr>
<td>Fines/Sand</td>
<td>&lt; 3 mm</td>
</tr>
</tbody>
</table>

The depth of streambed material needs to be estimated to determine the type of culvert installation that can be constructed. If there is very little substrate or there is extensive exposed bedrock, it can make a simulated streambed culvert which is embedded very difficult, if not impossible, while a deep valley fill will make it very difficult and expensive to install an open-bottom arch on concrete footings. A thorough study can save much time and expense later on.

The active channel width needs to be determined to ensure that the culvert installation will not cause a constriction resulting in increased velocities and outlet scour, and deposition of
sediment upstream from the culvert. Ideally, the new culvert installation will have a width equal to or greater than the active channel, or "bank-full width". This generally corresponds to a 1-2 year return flow and is a period where upstream fish passage is not assumed to occur. The active width is determined by taking at least 10 measurements 1-2 channel widths apart, and averaging. These measurements should be taken upstream of the crossing above where any existing structure has influenced the stream structure.

The active channel width can often be determined by abrupt changes in streamside vegetation or texture.

### A3.6 Fish Passage Strategies

There are six basic options for providing fish passage. They are listed below in the order of preference.

1. Remove/abandon stream crossing;
2. Channel-Spanning structure;
3. Drifts;
4. Streambed Simulation;
5. Bare culvert placed at zero grade;
6. Hydraulic culvert design.

1. Remove/abandon stream crossing. If re-routing the road to avoid the stream crossing is a feasible alternative, this is the best alternative. Often, this is not a viable option, but when it is, it should be thoroughly investigated.

2. Channel Spanning Structure. This includes bridges and open-bottom culverts. The structure should span the entire width of the stream and be placed on sturdy footings. The structure must be properly sized, as scour resulting from an undersized structure can undermine the footings or result in a bedrock chute, preventing fish passage.

   As stream size increases, or as gradient increases, this becomes a more attractive option. High-gradient streams, especially when flowing over exposed bedrock become problematic when trying to design a culvert structure. Water velocities are often excessive for juvenile fish passage, requiring a complex hydraulic culvert design with weirs and baffles. These are high-maintenance and expensive. A channel spanning structure is often competitive price-wise, and easier to maintain.

3. Drifts. Drifts can be a preferred strategy for very low-use roads because so little fill material is used. The road should be private and gated to minimise non-forest use. Drifts are best used when the natural streambed has a high content of cobble and coarse material, which is durable under traffic and does not discharge high quantities of sediment when traveled over. Drainage structures should be installed above the crossing to prevent ditch water from entering the stream. If the streambed does not have durable aggregate, it may be necessary to place durable material in the streambed prior to traffic.

4. Streambed Simulation. This method involves sinking a culvert into the streambed and allowing the culvert barrel to partially fill with native streambed material, creating the illusion of a natural streambed to the fish. Streams with a gradient of up to 8% can successfully use this technique. Ideally, the resulting culvert installation will have a width equal to, or greater than the active stream channel. Constructing the channel at the culvert crossing will often result in an increase in water velocity through the culvert. This increase in velocity can scour streambed material out of the culvert or present a barrier to juvenile fish attempting to swim upstream.

   For stream gradients between 4% and 8%, countersinking is a desirable technique. This involves sinking the inlet end of the culvert to a greater depth than the outlet end, resulting
in a culvert gradient of 1-2% less than the stream gradient. This method allows the culvert to recruit and retain streambed material easier, especially when the substrate is dominated by fine-grained material.

The design method for the Streambed Simulation technique uses the streambed profile to determine the actual grade through the crossing location. The natural channel elevation is determined, and the culvert is sunk relative to that elevation.

For round culverts, the sinking depth should be at least 40% of the culvert diameter or 60 cm, whichever is greater. For pipe-arch culverts, the sinking depth should be 20% or 45 cm, whichever is greater. This allows the culvert to hold enough material to prevent exposure of the culvert bottom during the natural fluctuations of the streambed elevation. If the natural streambed is deficient in material, the culvert may need to be manually “seeded” to assist recruitment.

5. Culvert Installed at 0% grade. This strategy is only suitable for locations where the stream gradient is < 0.5%. Since most forest roads are in locations with steeper gradients, it is rarely used. The outlet should be buried at least 15 cm and the inlet should be buried to a depth greater than 15 cm so that the culvert is installed at a zero grade. Elevation control during installation is critical, and a tripod-mounted level is the best tool. A clinometer is not accurate enough for this type of installation. The culvert width should be similar to the active channel width. This, combined with the low gradient will prevent the culvert flows from becoming a velocity barrier to juvenile fish.

6. Hydraulic Design. This method involves the installation of culverts with complicated engineering features such as weirs or baffles designed to obstruct flow. These flow obstructions can reduce water velocities or aid in the recruitment of streambed material. Often, these designs are beyond the scope of on-staff forest engineers and may require outsourcing to a reputable hydraulic engineer.

Successful installations have been recorded on streams with gradients up to 12%. Often, these installations have costs similar to a bridge or open-bottom culvert, and those options should be thoroughly investigated prior to commencement of a hydraulic culvert design. A proper design will involve hydraulic computations ensuring that low-flow and high-flow velocities are within the acceptable limits for fish passage.

Situations where this may be a suitable alternative include: areas of high stream gradients with deep valley fills or where the stream gradient is at or near bedrock, or areas with upstream wetlands where streambed material transport is not desirable.

**A3.7 Information to Include in a Culvert Plan**

- Stream name and legal location;
- Peak flow calculations, including a watershed map;
  - Area in Ha,
  - Complete runoff calculations,
  - Include loss of flow from culvert sinking/countersinking,
- Fish passage method (from above);
- Active channel width;
- Stream gradient;
- Streambed material (including depth, if known);
- Length of stream crossing;
- Elevation benchmarks;
- Culvert gradient,
• Depth of inlet and outlet sinking;
• Hydraulic design plans (if needed);
  o Baffle/weir configuration,
  o Depth of flow calculations for high and low flows,
  o Backwater length and depth at outlet;
• Any other site-specific information.

A3.8 References and Further Reading:


Appendix 4 - Pavement Design Supplement

A4.1 Methodology

The following methodology for determining the optimal mix ratio for blending two or more materials to meet the South African unsealed road specification is proposed.

- Identify potential material sources that can be used to improve the available material.
- Determine the particle size distribution of the material from each source (TMH1 Method A1(a) – see Appendix 6) recalculated with 100% passing the 37.5 mm sieve.
- Determine the percentages of silt and clay (< 0.075 mm), sand (0.075 - 2.0 mm) and gravel (2.0 - 37.5 mm) for each source.
- Plot the material properties on the ternary diagram as points a and b respectively.
- Connect the points. When the two points are connected, any point on the portion of the line in the shaded area indicates a feasible mixture of the two materials. The optimum mixture should be at point c in the centre of the shaded area.
- The mix proportions are then the ratio of the line ac:bc. This can be equated to truck loads and dump spacing.

Once the mix proportions have been established, the Atterberg Limits of the mixture should be determined to check that the shrinkage product is within the desirable range (100 - 240). The quantity of binder added should be adjusted until the required shrinkage product is obtained, but ensuring that the mix quantities remain within the acceptable zone.

If the line does not intersect the shaded area at any point, the two materials cannot be successfully blended and alternative sources will have to be located, or a third source used for blending.

The relative proportions for each material are plotted onto the ternary diagram as points a and b which are then connected (Figure A4-2). The midpoint of the line within the shaded area is located at point c. The mix proportions are thus the ratio of the line ac:ab. In this instance, the ratio is approximately 1:4, which indicates that one part of Material b should be mixed with four parts of Material a (ie one truck load of Material b for every four truck loads of Material a). After blending, the grading coefficient and shrinkage product are 18 and 138 respectively, which fall within Zone E of the specification.

A flowchart summarising the procedure for mechanical blending is provided in Figure A4-3.

Example

Source “A” – Grading coefficient of 20 and a shrinkage product of zero. This material plots in Zone B of the specification and is therefore likely to corrugate and ravel.

Source “B” – Grading coefficient of 4 and shrinkage product of 470. This material plots in Zone D of the specification and would typically be dusty when dry and slippery when wet.

The particle size distributions and other relevant data of each material are provided in Table A4-1.
Figure A4-1 (top): Ternary diagram for blending unsealed road materials.

Figure A4-2 (bottom): Example of the use of the ternary diagram.
### Table A4-1: Characteristics of materials.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Material</th>
<th>A</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>% passing 37</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td></td>
<td>42</td>
<td>97</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>38</td>
<td>96</td>
</tr>
<tr>
<td>0.425</td>
<td></td>
<td>20</td>
<td>94</td>
</tr>
<tr>
<td>0.075</td>
<td></td>
<td>7</td>
<td>92</td>
</tr>
<tr>
<td>Linear shrinkage</td>
<td>NP</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Shrinkage product</td>
<td>0</td>
<td>470</td>
<td></td>
</tr>
<tr>
<td>Grading coefficient</td>
<td>20</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>% silt/clay (P075)</td>
<td></td>
<td>7</td>
<td>92</td>
</tr>
<tr>
<td>% sand (P2 - P075)</td>
<td></td>
<td>31</td>
<td>4</td>
</tr>
<tr>
<td>% gravel (100 - P2)</td>
<td></td>
<td>62</td>
<td>4</td>
</tr>
</tbody>
</table>

#### A4.2 Chemical Stabilisation of Pavement Materials

Each of the dust palliative categories is discussed below. There is no one product suitable for all applications. Product selection should be based on engineering judgement supported by product information provided by the supplier, gravel characteristics, traffic and climate. A matrix to assist with product selection is provided in Table A4-2.

##### A4.2.1 Hygroscopic Salts

These products, which include calcium chloride, sodium chloride and magnesium chloride, absorb moisture from the atmosphere and bind the material particles together, thus preventing them from becoming entrained in the turbulence generated by vehicles. Comprehensive local guideline documentation, including performance prediction (savings in gravel loss and maintenance) is available for calcium chloride.

The gravel specification for calcium chloride is similar to the South African unsealed road specification discussed above, except that the shrinkage product specification has been relaxed to between 50 to 365 as a result of the binding ability of the product.

---

*Figure A4-4: Predicted performance for calcium chloride treated materials*
Performance on the other material categories will be as follows:

Zone A: Although fines loss will be reduced, the application of calcium chloride is unlikely to prevent erosion in the short term. Regular applications over a period of time are likely to bind the material and ultimately reduce the potential for erosion. Particular attention should be given to the shape and drainage of the road to limit any erosion.

Zone B: The application of calcium chloride will slow ravelling and the formation of corrugations, but is unlikely to completely prevent it if the material is totally non-plastic (ie shrinkage product of zero). A suitable maintenance program (eg dragging) will have to be implemented if these materials are treated.

Zone C: The application of calcium chloride will slow the rate of ravelling, but is unlikely to prevent it. Material blending should be carried out before the road is treated.

Zone D: The application of calcium chloride will control the loss of fines during dry periods, but will aggravate the slippery conditions during and after rainfall. The material should be:

- Blended with a coarser material to reduce the shrinkage product, prior to treatment with calcium chloride.
- Stabilised to reduce the clay activity, before being treated with calcium chloride.
- Treated with an alternative product.

Since calcium chloride is dependent on the relative humidity of the atmosphere in order to perform, the product should not be used in areas were the Weinert N-value is greater than four. It is thus suitable for general use in all forestry regions in South Africa.

Calcium chloride can be spray applied to the road surface (between 1.5 and 1.8 l/m²), or mixed into the gravel during reshaping or regravelling operations. It requires an annual rejuvenation in the form of a light spray at the beginning of each dry season. Grader maintenance should only be carried out when the road surface is moist, in order to prevent damage to the surface.

**A4.2.2 Natural Polymers**

These products, which include lignosulphonates, molasses and tannin extracts, bind fine material particles together in a simple gluing action, thus preventing them becoming entrained by air turbulence behind moving vehicles. Interim guideline documentation, including performance prediction (savings in gravel loss and maintenance) is available for lignosulphonate. Limited documentation is available for molasses and tannin extracts.

The gravel specification for lignosulphonate has had the shrinkage product specification has been relaxed to between 50 and 400 as a result of the binding ability of the product.

*Figure A4-5: Predicted performance for lignosulphonate treated materials.*
Performance on the other material categories will be as follows:

Zone A: Although fines loss will be reduced, the application of lignosulphonate is unlikely to prevent erosion in the short term. Regular applications over a period of time are likely to bind the material and ultimately reduce the potential for erosion. Particular attention should be given to the shape and drainage of the road to limit any erosion. Lignosulphonate is highly soluble in water and is thus also likely to leach out of the wearing course materials on poorly drained gradients.

Zone B: The application of lignosulphonate will slow ravelling and the formation of corrugations, but is unlikely to completely prevent it if the material is non-plastic (ie shrinkage product of zero). A suitable maintenance program (eg dragging) will have to be implemented if these materials are treated.

Zone C: The application of lignosulphonate will slow the rate of ravelling, but is unlikely to prevent it. Material blending should be carried out before the road is treated.

Zone D: The application of lignosulphonate will control the loss of fines during dry periods. Slippery conditions are unlikely to be improved in the short term, nor aggravated during and after rainfall. However, after a number of rejuvenations and in association with traffic compaction, slipperiness should be reduced as the addition of lignosulphonate reduces the linear shrinkage and hence the shrinkage product.

Lignosulphonate is not dependent on climate, however, roads in areas where high intensity storms are common should not be treated (due to the solubility of the product) unless more frequent rejuvenations are possible.

Lignosulphonate should be mixed into the road in a rip-and-recouple operation when roads are reshaped, or as part of the regravelling program (typically at a rate of 1.0 kg/m²). It requires at least one rejuvenation annually (depending on traffic and environmental conditions) in the form of a light spray. This should be done at the beginning of each dry season. Grader maintenance should only be carried out when the road surface is moist, in order to prevent damage to the surface.

A4.2.3 Modified Waxes

Modified waxes are manufactured as part of the oil from coal process in South Africa. Limited studies have indicated that, in their current form, they provide only short-term fines retention before penetrating the road surface, after which dust levels begin to increase. However, preliminary studies have shown that waxes can be used to increase the water resistance of calcium chloride and lignosulphonate. No guidelines on the use of wax in this role had been made available at the time of preparing this document.

The performance of wax is dependent on ground and ambient temperatures. Product is either sprayed onto the surface or mixed in during reshaping or regravelling operations. Specialised (heated) application equipment is required. No information on rejuvenation and maintenance of treated roads was available at the time of preparing this document.

A4.2.4 Synthetic Polymer Emulsions

Synthetic polymer emulsions, or polymer dispersions, are suspensions of synthetic polymers in which the monomers are polymerised in a dominantly aqueous medium. Numerous formulations have been developed for various soil conditioning applications, many of which are suitable for fines retention on unsealed roads. A number of products are currently available. Most of the documented research on polymers has been conducted in the agricultural industry where the products have been used to bind soils to prevent erosion by wind and water. Only limited documented research has been conducted on the application of the products to roads and no comprehensive guidelines were available at the time of preparing this document.
The performance of synthetic polymer emulsions is unlikely to be affected by climatic conditions. Products should be applied as a mix-in treatment during reshaping or regravelling. Spray-on treatments appear to be unsatisfactory, as products tend to form a surface skin, that is easily ravelled, rather than penetrating the surface. No information on rejuvenation and maintenance of treated roads was available at the time of preparing this document.

These products show good potential for use on forest roads. However, until such time as more comprehensive information is made available, a decision to use a synthetic polymer emulsion should only be made after experimentation and cost-benefit analysis.

A4.2.5 Petroleum Resins

Petroleum resins are imported into southern Africa from the United States, where research on product performance has been conducted. Limited research has been conducted in South Africa, but no locally applicable guideline documentation had been prepared at the time of preparing this document. Performance does not appear to be affected by climate. Product is applied as either a surface spray or mix-in treatment. No information on rejuvenation and maintenance of treated roads was available at the time of preparing this document. A decision to use a petroleum resin should therefore only be made after experimentation and cost-benefit analysis.

A4.2.6 Tars and Bitumens

Tar and bituminous products are offered by most petrochemical and bitumen suppliers as part of their product line. Tar-based products are derived from coal tar distillates to which solvents are added to improve penetration. Bituminous products are generally 80/100 Penetration Grade bitumens to which solvents are also usually added. Products range in price and durability from simple spray-on applications that will last approximately four weeks before requiring rejuvenation, to thicker applications that can be blinded with sand, which perform similarly to sand seals and which can last up to three years before requiring rejuvenation. Although fairly widely used, only limited documentation is available.

The performance of these products is very dependent on the quality of the base material and on the drainage. Weak materials will deform under traffic, causing rutting and potholing, which have to be repaired manually. Cracking of the surface with time allows the ingress of water, which leads to rapid deformation of the road that cannot be maintained with a grader. If the base materials are of adequate strength and if the pavement can be kept dry at all times, the products can provide an all weather surface (similar to a sand seal) as a short-term measure until the road can be upgraded.

A4.3 Product Selection

The choice of product for fines retention depends on the material characteristics, climate, traffic, road geometry, available equipment and the needs of the client.

This matrix does not pretend to be exhaustive and should be used as a general guide and introduction to dust control only, with the particular circumstances of each application being thoroughly considered and investigated before a choice of product is made. An economic analysis should be carried out to assess the cost implications of treatment and whether upgrading the road to a sealed standard is justified.

Individual products in the various categories may also be modified by the manufacturer to suit the particular conditions of an application and to overcome one or more of the general limitations of that category. The matrix also assumes that mechanical modification of the material is not carried out prior to application. Changes to the product and/or improvement of
the material prior to application would obviously alter the parameters used in the selection matrix. Product performance under the conditions of the particular road should be discussed with the product suppliers before a decision on the choice of product is made.

Most products will require an annual rejuvenation, which needs to be considered in maintenance planning and costing.

Table A4-2: Interim Product Selection Matrix.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Wetting agents</th>
<th>Calcium chloride</th>
<th>Lignosulphonate</th>
<th>Modified waxes</th>
<th>Synthetic polymers</th>
<th>Petroleum resins</th>
<th>Tars and bitumens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive SA guidelines available</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>High PI materials (PI &gt; 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium PI materials (PI 3 - 10)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Sandy materials (PI &lt; 3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All weather passability</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steep gradients</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy vehicles (mine/quarry)</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High traffic volumes (&gt; 250 vpd)</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short term applications (deviations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long term applications* (maintenance progs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spray-on application</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mix-in application</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grader maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tars and bitumens: Dependent on characteristics of individual products

A4.4 Chemical Improvement - Chemical Modification

Materials with a higher percentage of clay minerals are susceptible to increased moisture sensitivity, with concomitant problems in retaining shear strength should the material become wet in service. This is a limiting factor when considering the use of Category D materials or materials with a CBR of less than 15 in unsealed forest roads or pavement layers when upgrading from unsealed to sealed standard.

To utilise clay-bearing natural materials with any degree of confidence some type of “water-proofing” mechanism is necessary. The term “water-proofing” refers to the action of making the strength of road materials less moisture dependent by inhibiting the adsorption of water onto the clay particles.

Traditional chemical stabilising agents such as lime and cement are expensive and have problems of their own when used in unsealed roads and thin pavement structures. They will not be discussed further in this document.

Numerous so-called “alternative stabilisers” have been introduced to the roads industry over the last 20 years, with various often unsubstantiated claims being made as to their ability to improve the performance of marginal materials. As with many of the dust palliatives, minimal specification of their properties or records of their performance have been made available and very few properly controlled comparative tests on the effectiveness of the products from different producers and suppliers have been carried out in full-scale field trials.
In order to facilitate the selection of an appropriate product for particular conditions, chemical stabilisers have been divided into the following four categories:

- Pozzolanic (lime and cement);
- Bitumen;
- Sulphonated oils;
- Enzymes.

Pozzolanic and bitumen products are not suitable for stabilising unsealed roads and require specialist designs for use in sealed pavements in cases where unsealed roads are being upgraded. For the other two categories, products have been shown in many instances to influence the properties and moisture susceptibility of clayey materials. They can be used to chemically stabilise marginal quality local materials which would otherwise be unsuitable for road construction.

When considering chemical modification, the same issues as those discussed under fines retention need to be considered before selecting a particular product, namely:

- Can the supplier provide a comprehensive guideline document covering traffic, material, climatic, construction and application and maintenance issues, based on the monitoring of scientific experiments comparing the performance of treated and untreated roads?
- Will the road owner be able to reliably predict the improved performance of a treated road compared with that of an untreated road in order to evaluate whether the product is cost-effective?
- Does an analysis for the specific road indicate that application of a product is justified?
- Are you sure the active ingredient of the chemical to be used is not a banned substance? (persistent, toxic or accumulates in the environment)

If the answers to the above questions are yes, the product can be considered in the design process.

A summary of each product category is provided below:

**A4.4.1 Sulphonated Oils**

Sulphonated Oils or Sulphonated Petroleum Products (SPPs) rely on ionic exchange reactions to perform their expected functions satisfactorily. As they are all proprietary products, it is not possible to establish their exact compositions. It would appear, however, that their active "ingredients" are mostly mineral oils (hydrocarbon chains) modified with sulphuric acid to form a sulphonic acid. The mineral oil may be a natural petroleum derivative (oil or bitumen) or an artificial oil.

Sulphonated oils are all "surface active agents" (surfactants) and have the ability to fix, displace or replace exchange cations in clays and to make the soil materials (particularly clay minerals but not necessarily only clays) hydrophobic by displacing adsorbed water and water of hydration and preventing re-adsorption of this water.

Sulphonated oils can be considered as anionic surface-active agents. They are highly susceptible to ion exchange reactions in which appropriate inorganic ions present on mineral surfaces (particularly clays) and in clay interlayers are replaced by, or attached to, the organic molecules. This reduces the mobility of the ions and functionally reduces the plasticity of the material. Once an ion exchange reaction has occurred and the sulphonic acid is attached to a mineral particle, the so-called hydrophobic tails of the sulphonated oils are directed away from the particle and form an oily protective layer around it. In theory, this has the effect of reducing the thickness of the electrical double layer and of preventing water from gaining access to the clay mineral particle. With this reduced double layer thickness, it now becomes theoretically possible to achieve a greater degree of compaction in the material and also to reduce the possible water absorption of the material in the long term.
A4.4.2 Enzymes

As with sulphonated oils, enzymes are proprietary products, the formulations of which are not made public. Very little useful documentation on the exact process of stabilisation is available, although some form of microbial activity to neutralise the activity of the clay is a central theme of product brochures. However, material requirements (in terms of clay content and plasticity), application rates and method and performance claims are similar to those advocated by the suppliers of sulphonated oils.

Given the lack of appropriate documentation on enzymes at the time of preparing this document, these stabilisers will not be covered in further detail.

A4.4.3 Material Compliance for Sulphonated Oils

Material requiring treatment must have an adequate quantity of suitable clay mineral (not necessarily the clay-sized fraction). This clay shall have an appropriate cation exchange capacity and the cations should be capable of being exchanged (some clays, particularly micas and illites, “fix” potassium, which is then not easily displaced or removed).

The determination of the suitability of materials for stabilisation with sulphonated oils should proceed as follows:

- Determine the indicator and classification properties of the natural material to be treated, (i.e. Atterberg limits, grading, compaction characteristics, soaked CBR strengths).
- Carry out an X-ray diffraction analysis and cation exchange capacity determination to identify the type and activity of the clay minerals.
- Evaluate the suitability of the material for sulphonated oil treatment based on the criteria given in Table A 4.3.

Table A4-3: Recommended material requirements for sulphonated oil treatment.

<table>
<thead>
<tr>
<th>Property</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive clay minerals present</td>
<td>Yes</td>
</tr>
<tr>
<td>(Montmorillonite, vermiculite, chlorite and their interlayers)</td>
<td></td>
</tr>
<tr>
<td>Cation Exchange Capacity (meq/100g)</td>
<td>&gt; 15</td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>&gt; [(0.287 x P75) + 2.2; 8]</td>
</tr>
<tr>
<td>Bar Linear Shrinkage</td>
<td>&gt; [(0.205 x P75) + 0.7; 3.9]</td>
</tr>
<tr>
<td>Percentage passing 0.075 mm (P75)</td>
<td>15 - 55 %</td>
</tr>
<tr>
<td>Minimum laboratory CBR at OMC (after treatment)</td>
<td>35 for &lt; 50 vpd 45 for 50 - 250 vpd 55 for &gt; 250 vpd</td>
</tr>
<tr>
<td>Maximum DCP penetration rate (DN) (mm/blow) at OMC (after treatment)*</td>
<td>7 for &lt; 50 vpd 5.7 for 50 - 250 vpd 4.9 for &gt; 250 vpd</td>
</tr>
</tbody>
</table>

* this can be done on moulds in the laboratory or during proof rolling and can be used for compaction control in the field
Evaluate the results as follows:

- If the material has a low plasticity, low fines content and/or little active clay components (vermiculite, montmorillonite, chlorite or interlayers of these minerals) the "clay stabilisation" reaction will not occur and a less concentrated solution of the product (e.g. 0.01 l/m$^2$ for a 150 mm compacted layer) could be used purely as a compaction aid.

- If the material has significant quantities of the active clays described above and a cation exchange capacity of more than 15 meq/100g, the material is suitable for treatment (usually at 0.03 l/m$^2$).

Materials with properties lying between these two (usually low PI or fines content A2-4, A2-5, A4, A5: Table A4-4) can sometimes be successfully treated with many of these products at an intermediate concentration (0.02 l/m$^2$).

Once the results have been evaluated, an application rate should be determined. Table A4-4 provides an approximate guide to the application rates of the chemicals, based on the AASHTO soil classification system and assuming a treated compacted thickness of 150 mm.

<table>
<thead>
<tr>
<th>AASHTO Classification</th>
<th>Application rates in l/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stabilisation</td>
</tr>
<tr>
<td>A1, A3</td>
<td>N/A</td>
</tr>
<tr>
<td>A2-4, A2-5, A4, A5</td>
<td>0.02</td>
</tr>
<tr>
<td>A2-6, A2-7, A6, A7</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Controlled laboratory testing, using different application rates, should then be carried out to obtain an indication of potential improvements in the field. Although the testing techniques and procedures currently used for material characterisation in road construction (e.g. TMH1) have generally proved to be unsuitable for testing materials treated with sulphonated oils when they are used at the standard dilution recommended by the suppliers, a modified CBR test will provide an indication of strength improvement.

The following procedure should be followed:

- Select a number of products based on the above evaluation.
- Determine the correct application rates for each product as described above. It is essential that the correct quantity of chemical is added as an excess will usually result in weakening of the material.
- Prepare the sample as per TMH1, adding product to the water, ensuring that the material is thoroughly mixed.
- Allow the moist, treated material to cure for seven days in a sealed plastic bag.
- Complete compaction, soaking and testing as per TMH1.

The product that gives the largest increase in CBR when compared with an untreated control should then be selected. The minimum CBR thus obtained should not be more than 10 per cent lower than the design requirements.
Figure A4-6: Flow chart for testing liquid stabilisers.

A4.5 Specifications for Chemical Additives

No method currently exists for the specification of the quality of sulphonated oils. Since it is not known what the exact constituents of each product are, it is difficult to specify limits applicable to a range of products without disadvantaging or benefiting individual suppliers. It is thus recommended that only products supplied with approved certificates of quality from their manufacturing process be used. This places the onus on the individual suppliers to develop quality control specifications for their products and to make these available to potential users prior to any project. Aspects such as ionic reactivity, pH and surface tension should be included in the quality assurance process.

Product quality specifications must make use of tests which can be carried out in commercial chemical laboratories and which would enable the client to have independent testing carried out should he so desire. In this way each supplier will consistently supply a product with a well-specified composition and properties. This will permit independent arbitration of contractual claims resulting from alleged poor performance of the chemicals.

It is also recommended that current materials specifications be modified for additive treated materials for lightly trafficked roads and that end-product type specifications are developed. Instead of specification of the properties of the source or construction material, a final product in terms of in-situ density, moisture and strength (at a specified moisture content or contents) should be achieved, based on the strengths (or preferably E moduli) required for the design traffic of that road.

A4.6 Pozzolanic Stabilisation

Pozzolanic stabilisation is the treatment of soils with lime, cement or cement blends. This type of stabilisation is not suitable for unsealed wearing courses, as the surface cannot be maintained with a grader after construction. Its use can be considered in subgrade and subbase treatment for unsealed and sealed roads. However, specific design and testing procedures need to be followed and an economic analysis carried out to ensure that optimal performance and benefits are obtained. Pozzolanic stabilisation should therefore only be considered under the guidance of an experienced engineer and be carried out by an experienced contractor with appropriate plant.
A4.7 Bitumen Stabilisation

Bitumen stabilisation also has only limited application in unsealed roads. Unless substantial quantities of bitumen are added, its binding action will be insufficient to prevent surface ravelling. Such high contents of bitumen are usually not economical. It can be considered for subbase base stabilisation of sealed roads, and like pozzolanic stabilisation requires specific design and testing procedures. Bitumen stabilisation should also only be considered under the guidance of an experienced engineer and stabilised roads constructed by an experienced contractor.

A4.8 Experimentation

In many instances, a decision on the use of an additive can only be made after its performance has been evaluated in an experiment. The following guidelines should be followed when establishing and monitoring an experiment:

- Determine the purpose of the experiment and then design it to ensure that a reliable finding, on which a decision can be made, will be obtained on completion;
- Choose a site that is representative of roads on which the product/technique will be applied;
- Demarcate a one 300 m section for treatment and an adjacent similar 300 m section for a control;
- Sample and test materials with and without treatment;
- Monitor and record all aspects of the construction/application;
- Use established monitoring guidelines (eg Technical Methods for Highways, TMH12);
- Monitor through seasonal changes and maintenance on a regular basis (at least once a month and at significant events (eg first heavy storm));
- Do thorough performance comparison against the control and a cost-benefit analysis to determine if there are any advantages to using the product/technique.
## Appendix 5 - Checklists

### Checklist 1 - Desktop Study Methodology for Rock Source Development

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtain two sets of 1:50 000 topographic maps covering the route corridor. One set will be used as base maps for collation of information coming from various sources during the desk study. The other is for general project use and navigation in the field.</td>
<td>Mark out the road or route corridor on the base maps.</td>
</tr>
<tr>
<td>Confirm the quality and quantity of material required for the project.</td>
<td>Establish land use and land ownership (if applicable) and potential environmental constraints within the route corridor.</td>
</tr>
<tr>
<td>Obtain relevant materials investigation reports from previous projects.</td>
<td>Discuss existing and potential sources with relevant staff and other people with experience of the area.</td>
</tr>
<tr>
<td>Discuss existing and potential sources with relevant staff and other people with experience of the area.</td>
<td>Obtain geological maps, agricultural soils maps, aerial photographs and, if necessary, satellite images, as well as any past records for this and other roads in the area.</td>
</tr>
<tr>
<td>Obtain geological maps, agricultural soils maps, aerial photographs and, if necessary, satellite images, as well as any past records for this and other roads in the area.</td>
<td>Determine the coordinates of existing gravel sources and locate these on the base maps, photographs and images. Note the terrain features at these coordinates and then look for other similar features elsewhere along the proposed corridor. Transfer the information to the base map.</td>
</tr>
<tr>
<td>Determine the coordinates of existing gravel sources and locate these on the base maps, photographs and images. Note the terrain features at these coordinates and then look for other similar features elsewhere along the proposed corridor. Transfer the information to the base map.</td>
<td>Examine the topographic maps, looking for the occurrence of previously noted landforms.</td>
</tr>
<tr>
<td>Examine the topographic maps, looking for the occurrence of previously noted landforms.</td>
<td>Draw the road corridor on the geological map or a copy, in order to determine the approximate locations where differing geological units cross the road alignment. A 1:250 000 geological map is recommended for this exercise.</td>
</tr>
<tr>
<td>Draw the road corridor on the geological map or a copy, in order to determine the approximate locations where differing geological units cross the road alignment. A 1:250 000 geological map is recommended for this exercise.</td>
<td>Read the map legend and the accompanying geological report for any mention of rocks that are potential sources of gravel-sized weathering products. Note the geological units within which these are found.</td>
</tr>
<tr>
<td>Read the map legend and the accompanying geological report for any mention of rocks that are potential sources of gravel-sized weathering products. Note the geological units within which these are found.</td>
<td>Identify these geological units on the map, within the exploration corridor. Pay particular attention to ‘oddities’ on the map such as minor igneous intrusions and unusually prominent hills (often named). These features often contain gravels when the surrounding country has none.</td>
</tr>
<tr>
<td>Identify these geological units on the map, within the exploration corridor. Pay particular attention to ‘oddities’ on the map such as minor igneous intrusions and unusually prominent hills (often named). These features often contain gravels when the surrounding country has none.</td>
<td>Identify possible sources of material.</td>
</tr>
<tr>
<td>Identify possible sources of material.</td>
<td>Study the identified areas of geological interest in aerial photographs to pinpoint the locations most favourable for field investigation.</td>
</tr>
<tr>
<td>Study the identified areas of geological interest in aerial photographs to pinpoint the locations most favourable for field investigation.</td>
<td>Study the aerial photographs (in stereoscopic mode) in conjunction with information from the topographic, geological and agricultural soil maps to identify landforms associated with gravel. Make notes of all features, no matter how small, and mark their location and extent on the base map.</td>
</tr>
<tr>
<td>Study the aerial photographs (in stereoscopic mode) in conjunction with information from the topographic, geological and agricultural soil maps to identify landforms associated with gravel. Make notes of all features, no matter how small, and mark their location and extent on the base map.</td>
<td>Transfer all relevant information to the base map and identify the best potential sites, as well as the best location to begin field work and the route to follow.</td>
</tr>
<tr>
<td>Transfer all relevant information to the base map and identify the best potential sites, as well as the best location to begin field work and the route to follow.</td>
<td>Obtain the necessary permission or authorisation to prospect.</td>
</tr>
<tr>
<td>Obtain the necessary permission or authorisation to prospect.</td>
<td>Contact the landowners and arrange access to properties during the reconnaissance visit if applicable.</td>
</tr>
<tr>
<td>Contact the landowners and arrange access to properties during the reconnaissance visit if applicable.</td>
<td>Establish the most appropriate method for the field survey.</td>
</tr>
</tbody>
</table>
**Checklist 2 - Gravel Source Reconnaissance Survey Procedure**

<table>
<thead>
<tr>
<th>Begin the traverse of the project area well before the actual start (there may be very good material at the beginning of the project). Continually refer to the base map and aerial photographs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first traverse should confirm the conclusions drawn during the desk study. Visit existing gravel sources and potential sites identified. Use GPS to record their locations. Estimate the spatial extent and available quantities without excavation. This can be done with simple techniques such as a calcrete probe or a DCP (Dynamic Cone Penetrometer).</td>
</tr>
<tr>
<td>Identify any significant geomorphological, soil or vegetation characteristics at existing gravel sources that can be used to indicate similar sources elsewhere along the route. Identify these characteristics on the maps and aerial photographs and look for similar features elsewhere on the images.</td>
</tr>
<tr>
<td>Study the geomorphology and decide which areas are likely to have a high potential for material (e.g. scree slopes and drainage channels). Study the vegetation and note any significant changes, such as species groupings or changes in plant characteristics (e.g. shape, height, form).</td>
</tr>
<tr>
<td>Note accessibility to each site and record GPS coordinates and observations</td>
</tr>
<tr>
<td>Plot new sites on the sketch map. Review the pattern of sites on the map to see if they lie in clusters or straight lines, which would help in showing where to look for additional material.</td>
</tr>
<tr>
<td>Record other important information including thickness of overburden and ease of access.</td>
</tr>
<tr>
<td>Update the base map accordingly.</td>
</tr>
<tr>
<td>Draw up a plan for the detailed study, prioritising the most suitable sites according to the required material qualities and quantities. Identify a second set of sites in case the first selection proves to be unsuccessful.</td>
</tr>
</tbody>
</table>
**Checklist 3 - Field Survey Procedure for Gravel Source Development**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Demarcate the approximate spatial extent of the site with stakes.</strong> This can be determined with a calcrete probe or DCP. In sandy areas, the calcrete probe should also be used to determine the thickness of the overburden.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Identify the source with a unique location number, its distance and direction from the start of the route and the offset from the centreline.</strong></td>
</tr>
<tr>
<td>3</td>
<td><strong>Lay out a 50 m staggered grid.</strong> The grid pattern may be reduced to a 25 m spacing in one or both directions if the material within the potential source changes over a short distance. The grid can be aligned in any direction convenient to cover the shape of the deposit. Setting out of the trial pits should be carefully planned taking the characteristics of the site, such as vegetation and rock exposure, into consideration. Trial pitting should also incorporate as much of the potential gravel source as is necessary to establish the deposit’s extent and variability.</td>
</tr>
<tr>
<td>4</td>
<td><strong>Record the grid pattern with holes running in one direction left to right being labelled A, B, C, D, etc and holes running perpendicular to this (i.e. top to bottom) being numbered 1, 2, 3, 4, etc. Trial pits should be selected statistically (preferably on a stratified systematic herring bone pattern) and would then be numbered A.1, A.2..., B.1, B.2..., D.1, D.2 etc. The use of a grid system ensures a well co-ordinated study and simplifies the location of each trial pit. The system also facilitates selective stockpiling if different areas of the gravel source are recommended for different pavement layers or for blending.</strong></td>
</tr>
<tr>
<td>5</td>
<td><strong>Excavate a pit to the bottom of the suitable material.</strong> This can be done either manually or by machine depending on the circumstances of the project. The width of the pit will vary depending on the excavation method. Ensure that the necessary safety precautions are taken during excavation and examination of the pit.</td>
</tr>
<tr>
<td>6</td>
<td><strong>Describe the soil profile in detail using the standard Jennings, Brink and Williams (1973) method.</strong> The overburden and the ratio of overburden thickness to gravel thickness should be recorded. During profiling, identify the horizons that are potentially suitable for meeting the material requirements of the road design.</td>
</tr>
<tr>
<td>7</td>
<td><strong>Collect sufficiently large samples of material for the intended tests.</strong> Place the sampled material in bags (it is suggested that high quality sewn canvas bags are used for sampling) and carefully label each bag ensuring that the label is permanent. Label tags should be placed in a transparent waterproof plastic bag before being placed inside the sample bag to avoid moisture damage.</td>
</tr>
</tbody>
</table>
### Checklist 4 - Quality control during subgrade construction

<table>
<thead>
<tr>
<th>Question</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has all timber been felled and cross-cut to contract specifications?</td>
<td>Has all timber been sorted and stacked appropriately?</td>
</tr>
<tr>
<td>Have all stumps, dead trees, and vegetation been removed from the road</td>
<td>Prism? Will any remaining stumps be likely to slide into the road prism or</td>
</tr>
<tr>
<td>Have all stumps, dead trees, and vegetation been removed from the road</td>
<td>side drain? Is all organic material removed from areas likely to support fill</td>
</tr>
<tr>
<td>Have all stumps, dead trees, and vegetation been removed from the road</td>
<td>material?</td>
</tr>
<tr>
<td>Have cuts and fills been started in the proper location?</td>
<td></td>
</tr>
<tr>
<td>Are cut and fill slopes at the appropriate angle?</td>
<td></td>
</tr>
<tr>
<td>Is the subgrade constructed to specified widths, grades, and curve</td>
<td>radii, including curve and fill widening as needed?</td>
</tr>
<tr>
<td>Is fill material being compacted with appropriate equipment, at optimum</td>
<td>moisture, and in suitable thicknesses?</td>
</tr>
<tr>
<td>Do all side drains meet contract specifications for width, depth, and</td>
<td>Do all side drains lead to a cross-drain or mitre drain?</td>
</tr>
<tr>
<td>Have all cross-drains been installed and backfilled with suitable cover?</td>
<td>Have downspouts or other outlet protection been added where needed?</td>
</tr>
<tr>
<td>Does the subgrade have appropriate camber, crown, inslope, or outslope,</td>
<td>in accordance with contract specifications?</td>
</tr>
<tr>
<td>Has the subgrade been compacted to a smooth, hard finish in preparation</td>
<td>construction?</td>
</tr>
<tr>
<td>Has all waste material, including fuel and oil containers, cable spools,</td>
<td>rubbish been cleaned up?</td>
</tr>
<tr>
<td>Have all waste material, including fuel and oil containers, cable spools,</td>
<td></td>
</tr>
<tr>
<td>culvert banding, and rubbish been cleaned up?</td>
<td></td>
</tr>
</tbody>
</table>
### Checklist 5 - Quality control during pavement construction

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has the surface been properly prepared?</td>
<td></td>
</tr>
<tr>
<td>Is an adequate quantity of suitable material available? Does material need to be stockpiled close to the project prior to beginning application?</td>
<td></td>
</tr>
<tr>
<td>Is appropriate compaction equipment available and on site?</td>
<td></td>
</tr>
<tr>
<td>Has a water source been located and pumps obtained, if necessary?</td>
<td></td>
</tr>
<tr>
<td>Is the material being spread in layers appropriate for the aggregate size and compaction equipment?</td>
<td></td>
</tr>
<tr>
<td>Is the material being watered and turned as it is spread?</td>
<td></td>
</tr>
<tr>
<td>Does the pavement thickness meet contract specifications, not too thick or too thin?</td>
<td></td>
</tr>
<tr>
<td>If a vibratory roller is being used, are the amplitude and frequency settings appropriate for the material and travel speed?</td>
<td></td>
</tr>
<tr>
<td>Have a suitable number of passes been made, ensuring that the surfacing has been compacted from edge to edge?</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 6 - Soil and Gravel Testing Methods

Uniform Soil Classification Method (UCS)

Scope

This test method describes the engineering properties of a soil based on the size of the particles, the amounts of the various sizes and the characteristics of the very fine grains. It can be carried out by either field examination or laboratory testing.

Special Apparatus

Sieves, 75 mm, 4.75 mm (ASTM No 4), 2.0 mm (ASTM No 10), 0.425 mm aperture (ASTM No 40).

Procedure

Field Classification Technique for Coarse-Grained Soils

1. Take a representative sample of soil (excluding particles > 75 mm) (see Note 1) and classify the soil as coarse-grained or fine-grained by estimating whether 50% by weight, of the particles can be seen individually by the naked eye. Soils containing > 50% of particles that can be seen are coarse-grained soils; soils containing < 50% of particles smaller than the eye can see are fine-grained soils. If the soil is predominantly coarse-grained, identify as being a gravel or a sand by estimating whether 50% or more, by weight, of the coarse grains are larger or smaller than 4.75 mm (No 4 sieve size).

2. If the soil is a gravel, identify as being “clean” (containing little or no fines, < 5%) or “dirty” (containing an appreciable amount of fines, > 12%). For clean gravels final classification is made by estimating the gradation: the well-graded gravels belong to the GW groups and uniform and gap-graded gravels belong to the GP group.

Dirty gravels are of two types: those with non-plastic (silty) fines (GM) and those with plastic (clayey) fines (GC). The determination of whether the fines are silty or clayey is made by the three manual tests for fine-graded soils.

3. If a soil is a sand, the same steps and criteria are used as for gravels in order to determine whether the soil is a well-graded clean sand (SW), poorly-graded clean sand (SP), sand with silty fines (SM) or sand with clayey fines (SC).

4. If a material is predominantly (> 50% by weight) fine-grained, it is classified into one of six groups (ML, CL, OL, MH, CH, OH) by estimating its dilatancy (reaction to shaking), dry strength (crushing characteristics), and toughness (consistency near the plastic limit) and by identifying it as being organic or inorganic. (See Note 2.)
Dilatancy (Reaction to Shaking)

After moving particles > 0.4 mm (No 40 sieve size), prepare a pat of moist soil with a volume of about 10 cm$^3$. Add enough water, if necessary, to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and the gloss disappear from the surface, and the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics)

After removing particles > 0.4 mm (No 40 sieve size) mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit)

After removing particles larger than the 0.4 mm (No 40 sieve size), a specimen of soil about 10 cm$^3$ in size is moulded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about 3 mm in diameter. The thread is then folded and re-rolled repeatedly. During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays.

Highly organic clays have a very weak and spongy feel at the plastic limit.

References

Notes

1. This value is not included in the USCS. It is necessary to know the amount of particles > 75 mm if gravel content is required.

2. Many natural soils will have property characteristics of two groups because they are close to the borderline between the groups, either in percentages of the various sizes or in plasticity characteristics. For this substantial number of soils, boundary classifications are used i.e. the groups symbols most nearly describing the soil are connected by a hyphen, such as GW-GC.

Proper boundary classification of a soil near the borderline between coarse-grained and fine-grained soils is accomplished by classifying it first as a coarse-grained soil and then as a fine-grained soil. Such classification as SM-ML and SC-CL are common.