PART D
CONSTRUCTION OF LOW VOLUME ROADS

- General Introduction
- Project Implementation
- Road Construction
- Borrow Pit Management
- Construction of Small Structures
- Quality Assurance and Control
- Technical Auditing

Part D
Construction of Low Volume Roads
## ACRONYMS

<table>
<thead>
<tr>
<th>A</th>
<th>Annual Average Daily Traffic</th>
</tr>
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<tbody>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>AC</td>
<td>Asphalt Concrete</td>
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<tr>
<td>AFCAP</td>
<td>Africa Community Access Partnership</td>
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<tr>
<td>AIDS</td>
<td>Acquired Immune Deficiency Syndrome or Acquired Immunodeficiency Syndrome</td>
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<tr>
<td>ALD</td>
<td>Average Least Dimension</td>
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<tr>
<td>ARRB</td>
<td>ARRB Group, formerly the Australian Road Research Board</td>
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<td>ARVs</td>
<td>Antiretroviral</td>
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<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<tr>
<td>B</td>
<td>Binder Course (Base Course)</td>
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<td>BDS</td>
<td>Bid Data Sheet</td>
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<tr>
<td>BSD</td>
<td>Bituminous Surface Dressing</td>
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<td>BRD</td>
<td>Bituminous Road base</td>
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<tr>
<td>C</td>
<td>Clay Brick (fired)</td>
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<tr>
<td>CBO</td>
<td>Community Based Organisation</td>
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<tr>
<td>CBR</td>
<td>California Bearing Ratio</td>
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<td>CI</td>
<td>Complementary Interventions</td>
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<tr>
<td>CMG</td>
<td>Crown Agents Core Management Group</td>
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<td>COLTO</td>
<td>Committee of Land Transport Officials (South Africa)</td>
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<td>CPT</td>
<td>Cone Penetrometer Test</td>
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<tr>
<td>CS</td>
<td>Cobblestone</td>
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<tr>
<td>D</td>
<td>Drybound Macadam (Dense Bitumen Macadam)</td>
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<td>DC</td>
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<td>DCP</td>
<td>Dynamic Cone Penetrometer</td>
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<td>DF</td>
<td>Drainage Factor</td>
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<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>DFID</td>
<td>UK Government’s Department for International Development</td>
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<td>EF</td>
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<td>e.g.</td>
<td>For example (abbreviation for the Latin phrase exempli gratia)</td>
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<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EMP</td>
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<td>ENS</td>
<td>Engineered Natural Surfaces</td>
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<td>EOD</td>
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<td>esa</td>
<td>Equivalent Standard Axles</td>
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<td>Fine Aggregate Crushing Test</td>
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<td>g/m²</td>
<td>Grams per Square Metre</td>
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<td>Gross Domestic Product</td>
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<td>gTKP</td>
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<td>GVW</td>
<td>Gross Vehicle Weight</td>
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<td>ha</td>
<td>Hectare</td>
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<td>HDM 4</td>
<td>World Bank’s Highway Development and Management Model Version 4</td>
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<td>HIV</td>
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<td>Hand Packed Stone</td>
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<tr>
<td>ICB</td>
<td>International Competitive Bidding</td>
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<td>ICT</td>
<td>Information Communication Technology</td>
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**PART D: CONSTRUCTION OF LOW VOLUME ROADS**
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>IDA</td>
<td>International Development Association</td>
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<tr>
<td>i.e.</td>
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<td>Intermediate Means of Transport</td>
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<td>Internal Rate of Return</td>
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<td>Instructions to Bidders</td>
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<td>K</td>
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<td>km</td>
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<td>LIC</td>
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<td>LVR</td>
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<td>m³</td>
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<td>mg/m³</td>
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<td>m/s</td>
<td>Metres per Second</td>
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<td>Medium Curing</td>
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<td>MoFED</td>
<td>Ministry of Finance and Economic Development</td>
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<td>MPA</td>
<td>Megapascal (a unit of pressure equal to 1000 kilopascals (kPa), commonly used in the building industry to measure crushing pressure of bricks)</td>
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<td>MSSP</td>
<td>Mortared Stone Setts or Pavé</td>
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<td>MoWUD</td>
<td>Ministry of Works and Urban Development</td>
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<td>Definition</td>
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<td>NBP</td>
<td>Non-Bituminous Pavement</td>
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<td>Non-Motorised Transport</td>
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<td>Non-reinforced Concrete</td>
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<td>Non-reinforced Concrete pavement</td>
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<td>OMC</td>
<td>Optimum Moisture Content</td>
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<td>ORN</td>
<td>Overseas Road Note</td>
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<td>Oromiya Rural Roads Authority</td>
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<td>PCU</td>
<td>Passenger Car Unit</td>
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<td>PDM</td>
<td>Pavement Design Manual</td>
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<td>PPA</td>
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<td>Public Private Partnership</td>
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<td>Particle Size Distribution</td>
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<td>Productive Safety Net Programme</td>
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<td>R</td>
<td>Radius</td>
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<td>RC</td>
<td>Reinforced concrete</td>
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<td>RFP</td>
<td>Request for Proposals</td>
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<td>SADC</td>
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<td>SBL</td>
<td>Sand Bedding Layer</td>
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<td>Description</td>
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<td>SDMS</td>
<td>Surfacing Decision Management System</td>
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<td>SE</td>
<td>Super Elevation</td>
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<td>SMEs</td>
<td>Small and Medium Enterprises</td>
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<td>SSP</td>
<td>Stone Setts or Pavé</td>
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<tr>
<td>SEPT</td>
<td>Small Element Pavement Tiles (Structures)</td>
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<td>TBA</td>
<td>To Be Advised</td>
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<tr>
<td>Tc</td>
<td>Time of Concentration</td>
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<tr>
<td>ToR</td>
<td>Terms of Reference</td>
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<tr>
<td>TRL</td>
<td>Transport Research Laboratory</td>
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<td>United Kingdom</td>
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<td>United States of America</td>
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<tr>
<td>USCS</td>
<td>Unified Soil Classification System</td>
</tr>
<tr>
<td>USD</td>
<td>United States Dollar</td>
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<td>UTRCP</td>
<td>Ultra Thin Reinforced Concrete Pavement</td>
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<td>VI</td>
<td>Impinging Velocity</td>
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<td>V_{AVE}</td>
<td>Average Velocity</td>
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<td>VP</td>
<td>Parallel Velocity</td>
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<tr>
<td>vpd</td>
<td>Vehicles per Day</td>
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<tr>
<td>VOCs</td>
<td>Vehicle Operating Costs</td>
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<td>VST</td>
<td>Vane Shear Test</td>
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<td>WBM</td>
<td>Waterbound Macadam</td>
</tr>
<tr>
<td>WC</td>
<td>Wearing Course</td>
</tr>
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</table>
2WD
Two Wheel Drive vehicle or equipment.

4WD
Four Wheel Drive vehicle or equipment.

Abney Level
Small hand held slope measuring and levelling equipment.

Aggregate (for construction)
A broad category of coarse particulate material including sand, gravel, crushed stone, slag and recycled material that forms a component of composite materials such as concrete and asphalt.

Apron
The flat invert of the culvert inlet or outlet.

Asphalt
A mixture of inert mineral matter, such as aggregate, mineral filler (if required) and bituminous binder in predetermined proportions.

Atterberg limits
Basic measures of the nature of fine-grained soils which identify the boundaries between the solid, semi-solid, plastic and liquid states.

Basin
A structure at a culvert inlet or outlet to contain turbulence and prevent erosion.

Berm
A low ridge or bund of soil to collect or redirect surface water.

Binder, Bituminous
Any bitumen based material used in road construction to bind together or to seal aggregate or soil particles.

Binder, Modified
Bitumen based material modified by the addition of compounds to enhance performance. Examples of modifiers are polymers, such as PVC, and natural or synthetic rubbers.

Bitumen
A non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties, softens gradually when heated, is substantially soluble in trichlorethylene and is obtained from crude petroleum by refining processes.

Blinding
a) A layer of lean concrete, usually 5 to 10 cm thick, placed on soil to seal it and provide a clean and level working surface to build the foundations of a wall, or any other structure.

b) An application of fine material e.g. sand, to fill voids in the surface of a pavement or earthworks layer.

Brick (clay)
A hard durable block of material formed from burning (firing) clay at high temperature.
**Bridge**
A structure usually with a span of 5 metres or more, providing a means of crossing above water, a railway or another obstruction, whether natural or artificial. A bridge consists of abutments, deck and sometimes wingwalls and piers, or may be an arch.

**Camber**
The road surface is normally shaped to fall away from the centre line to either side. The camber is necessary to shed rain water and reduce the risk of passing vehicles colliding. The slope of the camber is called the crossfall. On sharp bends the road surface should fall directly from the outside of the bend to the inside (superelevation).

**Carriageway**
The road pavement or bridge deck surface on which vehicles travel.

**Cascade**
A drainage channel with a series of steps, sometimes with intermediate silt traps or ponds, to take water down a steep slope.

**Catchpit**
A manhole or open structure with a sump to collect silt.

**Catchwater Drain**
See Cutoff.

**Causeway or Vented Drift**
Low level structure constructed across streams or rivers with openings to permit water to pass below road level. The causeway may become submerged in flood conditions.

**Cement (for construction)**
A dry powder which on the addition of water and other additives, hardens and sets independently to bind aggregates together to produce concrete.

**Check Dams**
(see also Scour Checks) Small checks in a ditch or drain to reduce water velocity and reduce the possibility of erosion.

**Chute**
An inclined pipe, drain or channel constructed in or on a slope.

**Coffer Dam**
A temporary dam built above the ground to give access to an area which is normally, or has a risk of being, submerged or waterlogged. Cofferdams may be constructed of soil, sandbags or sheetpiles.

**Collapsible soil**
Soil that undergoes a significant, sudden and irreversible decrease in volume upon wetting.

**Compaction**
Reduction in bulk of fill or other material by rolling or tamping.

**Concrete**
A construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel or crushed stone plus a fine aggregate such as sand), water, and chemical admixtures.

**Counterfort Drain**
A drain running down a slope and excavated into it. The excavation is partly or completely filled with free draining material to allow ground water to escape.
**Cribwork**
Timber or reinforced concrete beams laid in an interlocking grid, and filled with soil to form a retaining wall.

**Crushed Stone**
A form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using crushers.

**Cut-off/Catchwater Drain**
A drain constructed uphill from a cutting face to intercept surface water flowing towards the road.

**Debris Rack or Grill**
Grill, grid or post structure located near a culvert entrance to hold back floating debris too large to pass through the culvert.

**Deck**
The part of a bridge that spans between abutments or pier supports, and carries the road traffic.

**Design speed**
The maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed.

**Ditch (Open Drain)**
A long narrow excavation designed or intended to collect and drain off surface water.

**Drainage**
Interception and removal of ground water and surface water by artificial or natural means.

**Drainage Pipe**
An underground pipe to carry water.

**Drift or Ford**
A stream or river crossing at bed level over which the stream or river water can flow.

**Earth Road**
See ENS.

**Embankment**
Constructed earthworks below the pavement raising the road above the surrounding natural ground level.

**ENS (Engineered Natural Surface)**
An earth road built from the soil in place at the road location, and provided with a camber and drainage system

**Expansive soil**
Typically, a clayey soil that undergoes large volume changes in direct response to moisture changes.

**Ford**
See Drift

**Formation**
The shaped surface of the earthworks, or subgrade, before constructing the pavement layers.

**Gabion**
Stone-filled wire or steel mesh cage. Gabions are often used as retaining walls or river bank scour protection structures.
Gravel
A naturally-occurring, weathered rock within a specific particle size range. In geology, gravel is any loose rock that is larger than 2mm in its largest dimension and not more than 63mm.

Hand Packed Stone
A layer of large, angular broken stones laid by hand with smaller stones or gravel rammed into the spaces between stones to form a road surface layer.

Incremental paving
Road surface comprising small blocks such as shaped stone (setts) or bricks, jointed with sand or mortar.

Invert
The lowest point of the internal cross-section of a drain or culvert.

Kebele
Administrative division in Ethiopia equivalent to sub-district or ward. Smallest administrative unit in Ethiopia.

Labour Based Construction
Economically efficient employment of as great a proportion of labour as is technically feasible throughout the construction process to produce the standard of construction as demanded by the specification and allowed by the available funding. Substitution of equipment with labour as the principal means of production.

Layby
An area adjacent to the road for the temporary parking of vehicles.

Low Volume Road
Roads carrying up to about 300 vehicles per day and less than about 1 million equivalent standard axles over their design life.

Macadam
A mixture of broken or crushed stone of various sizes (usually less than 3cm) laid to form a road surface layer.

Manhole
Accessible pit with a cover forming part of the drainage system and permitting inspection and maintenance of underground drainage pipes.

Margins
The right of way or land area maintained or owned by the road authority.

Mitre Drain (Turn Out Drain)
leads water away from the Side Drains to the adjoining land.

Open Drain (Ditch)
A long narrow excavation designed or intended to collect and drain off surface water.

Otta Seal
A surface layer formed by rolling natural gravel into a soft bituminous seal coat.

Outfall
Discharge end of a drain or culvert.

Parapet
The protective edge, barrier, wall or railing at the edge of a bridge deck.
Pavé
See Sett

Paved Road
A road that has a bitumen seal or a concrete riding surface

Pavement
The constructed layers of the road on which the vehicles travel.

Permeable Soils
Soils through which water will drain easily e.g. sandy soils. Clays are generally impermeable except when cracked or fissured (e.g. ‘Black Cotton’ soil in dry weather).

Plumbing
Using a calibrated line, with a weight attached to the bottom, to measure the depth of water (e.g. for checking erosion by a structure).

Profile
An adjustable board attached to a ranging rod for setting out.

Reinforced Concrete
A mixture of coarse and fine stone aggregate bound with cement and water and reinforced with steel roads for added strength.

Riprap
Stones, usually between 5 to 50 kg, used to protect the banks or bed of a river or watercourse from scour.

Road Base and Subbase
Pavement courses between surfacing and subgrade.

Roadway
The portion within the road margins, including shoulders, for vehicular use.

Scour
Erosion of a channel bed area by water in motion, producing a deepening or widening of the channel.

Scour Checks (see also Check Dams)
Small checks in a ditch or drain to reduce water velocity and reduce the possibility of erosion.

Scuppers
Drainage pipes or outlets in a bridge deck.

Seal
A term frequently used instead of “reseal” or “surface treatment”. Also used in the context of “double seal” and “sand seal” where sand is used instead of stone.

Selected Layers
Pavement layers of selected gravel materials used to bring the subgrade support up to the required structural standard for placing the subbase or base course.

Sett (Pavé)
A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.

Shoulder
Paved or unpaved part of the roadway next to the outer edge of the pavement. The shoulder provides side support for the pavement and allows vehicles to stop or pass in an emergency. Shoulders are used by non-motorised transport and pedestrians.
Site Investigation
Collection of essential information on the soil and rock characteristics, topography, land use, natural environment, and socio-political environment necessary for the location, design and construction of a road.

Slope
A natural or artificially constructed soil surface at an angle to the horizontal.

Slot
A sample cross section of the road or drain constructed as a guide for following earthworks or reshaping.

Slurry
A mix of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water, used for filling the voids in the final layer of stone of a new surface treatment or as a maintenance treatment (also referred to as a slurry seal).

Sods
Turf but with more soil attached (usually more than 10 cm).

Soffit
The highest point in the internal cross-section of a culvert, or the underside of a bridge deck.

Spray Lance
Apparatus permitting hand-application of bituminous binder at a desired rate of spread through a nozzle.

Squeegee
A small wooden or metal board with a handle for spreading bituminous mixtures by hand.

Stringer
Longitudinal beam in a bridge deck or structure.

Subbase
See Road Base.

Subgrade
Upper layer of the natural or imported soil (free of unsuitable material) which supports the pavement. Also refers to the native material underneath a constructed road pavement.

Sub-Soil Drainage
See Underdrainage.

Surface Treatment
Construction of a protective surface layer e.g. by spray application of a bituminous binder, blinded with coated or uncoated aggregate.

Surfacing
Top layer of the pavement. Consists of wearing course, and sometimes a base course or binder course.

Template
A thin board or timber pattern used to check the shape of an excavation.

Traffic Lane
The portion of the carriageway usually defined by road markings for the movement of a single line of vehicles.

Transverse Joint
Joint normal to, or at an angle to, the road centre line.
**Traveller**
A rod or pole of fixed length (e.g. 1 metre) used for sighting between profile boards for setting out levels and grades.

**Turf**
A grass turf is formed by excavating an area of live grass and lifting the grass complete with about 5 cm of topsoil and roots still attached.

**Turn Out Drain**
See Mitre Drain.

**Underdrainage (Sub-Soil Drainage)**
System of pervious pipes or free draining material, designed to collect and carry water in the ground.

**Unpaved Road**
For the purpose of this Manual an unpaved road is a road with an earth or gravel surface.

**Vented Drift**
See Causeway.

**Wearing Course**
The upper layer of a road pavement on which the traffic runs and is expected to wear under the action of traffic.

**Weephole**
Opening provided in retaining walls or bridge abutments to permit drainage of water in the filter layer or soil layer behind the structure. They prevent water pressure building up behind the structure.

**Wereda**
Administrative division in Ethiopia equivalent to district.

**Windrow**
A ridge of material formed by the spillage from the end of the machine blade or continuous heap of material formed by labour.

**Wingwall**
Retaining wall at a bridge abutment to retain and protect the embankment fill behind the abutment.
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1.1 Background

The construction of a low volume road (LVR) is a practical manifestation of the previous planning, investigation and design phases of the project cycle. In this phase, the roads agency faces the challenge of adopting a construction strategy that is appropriate to the requirements of the project, as well as to the prevailing social, economic and technical environment within which the project is being undertaken. Such a strategy, for example, may be aimed at making maximum use of the relatively abundant resource of labour, local materials, and the use of intermediate plant that is better suited to the use of labour-based methods of LVR construction than heavy construction plant.

Whatever construction strategy is adopted, the ultimate goal of all parties to the contract is to make optimal use of the available resources to meet the prescribed standards in the most efficient and effective manner. Moreover, the quality of the construction process is critical as it can impact significantly on the subsequent costs of maintaining the road. Thus, a system of quality control is required to reduce the possibility of errors throughout the construction process and this is usually embodied in ‘quality assurance’ (QA) plans.

Other important issues include the careful exploitation of locally available materials from borrow pits. This operation needs to be carefully managed if such materials are to be efficiently utilized. Finally, in some cases, there could be merit in undertaking a Technical Audit of the project to ensure that the professional services provided by all parties to the contract are carried out to acceptable standards in an efficient and cost effective manner.

1.2 Purpose and Scope

Part D of the ERA Manual for Low Volume Roads deals with a wide range of issues relating to the construction of LVRs that the contractor and supervisor need to consider and to act upon, whether these parties are provided in-house or externally procured. Construction issues include the choice of construction method, material utilisation options, control of the quality of the works (especially compaction and layer thicknesses), and proper management of borrow pit operations. The construction of small drainage and watercourse crossing structures (typically < 10 m in length) is covered. The manual also includes guidance on undertaking Technical Audits. Reference is made, where relevant, to ERA’s Quality Manual (2012) which aims to increase efficiency and reduce wastage in the planning, design and implementation of the ERA roads programme.

1.3 Structure

Part D of the Manual deals with various aspects of the construction of LVRs and is structured as follows:

- Chapter 1 (this chapter): Introduction
- Chapter 2: Project Implementation
- Chapter 3: Road Construction
- Chapter 4: Construction of Small Structures
- Chapter 5: Quality Assurance and Control
- Chapter 6: Borrow Pit Management
- Chapter 7: Technical Auditing

Each chapter includes a bibliography which has been provided for those readers who wish to obtain additional information about any of the topics included.
2.1 Introduction

2.1.1 Background

The key to successful execution of a LVR project is to ensure clearly defined requirements and adequate provisions are included in all bidding and contract documents. A clear understanding of the requirements for both the works contractor and the supervising engineer is needed.

Bidding documents need to contain all relevant information and provisions for the interested bidders to prepare viable and accurate submissions. The bidding document informs interested bidders on all of the tender procedures to be followed, documents to be submitted, the bid evaluation procedure and the process for award of the contract.

Bidding documents need to provide the bidder with all essential information for successful completion of the project. The approach used for execution of LVRs can differ in many respects from the traditional road provision approaches. For example, as mentioned in Section 1, the Employer may favour labour-based approaches; the use of intermediate equipment; sub-contracting to empower small enterprises; and/or additional enhancements through Complementary Interventions (Part C). It is therefore important that the provisions within the bidding documents clearly reflect these preferences and adjust the provisions of the contract accordingly. Thus, the construction strategy to be adopted by the contractor must be reflective of Government policy, as embodied in the bidding documents.

Failure to properly differentiate LVR approaches can lead to complications during the bidding procedure or execution of the contract. Moreover, clear and well prepared bidding documents are essential to ensure that sufficient companies or organisations are confident to bid for works.

The procurement process also need to be undertaken in a fair and transparent manner, so as to ensure that project is awarded to the most favourable offer. However, there are a number of aspects of the procurement process which are specific to LVRs and which need to be carefully considered, including the contract provisions to support Complementary Interventions.

2.1.2 Purpose and Scope

The purpose of this chapter is to address various aspects of the project implementation process as a basis for achieving best value for money from Government investments in the provision of LVRs. The chapter outlines the various steps in the procurement process which provides a yardstick against which current procurement practice, as presented in ERA’s Quality Manual Volume 3 – Procurement (2012) (hereafter referred to as the Procurement Manual), may be compared and improved, where appropriate. The chapter also presents an overview of the various model bidding documents that have been prepared by ERA for use of works of differing complexity as well as the tendering process that is typically followed in procuring the works. Finally, the outline requirements of the Request for Proposals (RFP) for the supervising consultant are presented.

2.2 Procurement Process

2.2.1 General Approach

The important principles on which the procurement process is based are guided by various national and regional directives as presented in the Procurement Manual and may be summarised as follows:

- An overriding need to obtain the best available value for money, considered in terms of the quality of the item procured and the effective cost to the purchasing agency.
- Best value for money is assumed to be achieved through open competition. In turn, more competition is assumed to arise from wider advertising of bids and removal of regulatory barriers to entry.
Corruption and other abuses of the procurement processes are deterred by a high level of transparency and by adherence to process.

All bidders receive equitable treatment.

To the greatest extent possible, bids are compared and evaluated based on price. Where possible, non-price criteria are valued and used to adjust the bid price (only for the purpose of bid evaluation). Criteria that cannot be converted into a money value (for example, the qualifications of a consultant) are handled as objectively as possible.

### Guiding Principles

There are a number of guiding principles that should be adhered to in order to achieve the value-for-money objective while also enhancing local governance, local economic development and the capacity of local communities. These principles include:

**Principle 1: Appropriate roles and responsibilities**

The different types of roles and responsibilities typically assumed in the procurement process are as follows:

- Technical responsibilities, including conducting the procurement process and making recommendations to the decision-making authority.
- Decision-making responsibility, for example, the person who signs the contract on behalf of the buyer.
- Oversight responsibility, meaning ensuring that the procurement rules are respected and that the decision is rational and in accordance with the rules, but not advising or determining the outcome of a procurement process directly.

In terms of good practice, the three types of responsibility should be separate in that one person or agency should not undertake more than one type of responsibility.

**Principle 2: Value for money**

Value for money remains the defining objective of the public procurement process. Value for money means:

- Defining the objectives of the Employer as clearly and precisely as possible (this may include such things as generating local employment, for example, through the use of labour-based methods).
- Implementing the investment by the lowest-cost means that achieves the project objectives.

Where value for money is sought through competitive bidding, the procurement process should be designed to encourage and facilitate bids from local firms that have sufficient technical capacity to fulfil the contract.

Community implementation should be considered in cases where the beneficiary community has sufficient technical capacity and is able to implement for a lower cost than private sector contractors.

Direct implementation (force account) may be considered where this will result in better value-for-money and where there is no conflict with the other principles outlined here.

**Principle 3: Transparency**

Transparency in public procurement may be considered to have three main components:

- So far as it is consistent with efficiency and commercial confidentiality, all key information concerning the procurement process should be available to all stakeholders and to ordinary citizens.
- There should be a full written record of all stages of the procurement process that can be checked by an auditor.
- All decisions should be based on objective criteria. Selection criteria (the criteria for selecting the winning bid) should be made known to bidders before they submit their bids.
Principle 4: Equity

All bidders should receive equal treatment except in the case where the procurement rules allow specific preferences (for example, for locally based firms). Equitable treatment includes equal sharing of information with all bidders as well as fair evaluation of bids.

Principle 5: Efficient risk management

Wherever possible, the risk to the Employer should be reduced using means that do not limit competition or increase the cost or difficulty of participating in bidding. For example:

- By ensuring that irresponsible behaviour is not rewarded. For example, if contract conditions and contract administration procedures punish poor performance by the contractor, the bidders have an incentive not to submit unrealistically low bid prices or seek to win more contracts than they have the capacity to implement.
- A contractor who defaults should bear the whole cost to the public purse of his default. At the simplest, this may just mean that no advance payments are made, so that if the contractor defaults the buyer will not lose money.

Principle 6: Efficient Process

When comparing between alternative procurement procedures, the cost of the more expensive procedure should not exceed the cost of the cheaper procedure by more than the increase in value for money that can reasonably be expected. The cost of a procurement procedure should be considered to include the costs imposed on bidders as well as the costs paid directly by the buyer.

2.2.3 Issues to Consider During Contract Preparation

Contractors normally depend strongly on their cash flow to meet their financial obligations for the project. The following aspects should therefore be given particular attention in preparation of contracts for construction of LVRs:

- A contractor may be reluctant to stockpile materials well ahead of construction in order to improve management of materials, unless there is separate payment for borrow pit operations that secures his cash flow.
- A contractor is unlikely to select the better of two materials that both meet minimum quality requirements if he/she has to carry the entire amount of any additional cost incurred.
- The application of haulage cost in the contract plays a key role in directing and creating incentives for the contractor to use desirable material sources, and also in directing whether the benefits of using locally available materials go to the contractor or the road agency.
- Although the specification should be written to cater for producing an acceptable end product with non-conventional and variable materials, there may be instances where exceeding the specification minimum may be beneficial to the project. However, a contractor is unlikely to use additional resources or time in the processing to achieve a better than specified end result unless there is an appropriate reward scheme in place.
- In the choice between use of machinery or manual labour, a contractor is likely to select the option that gives the best utilisation of his own resources and gives the better cash flow. This may not coincide with the optimal resources for the project from a national socio-economic perspective. Thus, where warranted, it may be necessary to specify certain operational methods in the conditions of the contract and to ensure that the contractor is reimbursed for any additional costs.

2.2.4 Use of Model Documents

The model documents available from ERA for use on LVR projects include:

- Standard Bidding Documents for Major Work, International Competitive Bidding (ICB) and National Competitive Bidding (NCB) versions – Unlimited Contract Value.
2.2.5 Key Documents Requiring Attention

For the preparation of Works Bidding Documents, the key documents requiring attention are:

**Letter of Invitation (LoI):** This is an invitation sent to a bidder or shortlist of bidders to make a formal and detailed offer to supply the services required. It is important that the LoI contains all the information and detail needed to enable a bidder to compile a fully formed tender for the requirement. Recognition that the context of the works is using low volume road approaches should be highlighted in the LoI. The aim should be to ensure that the bidder is fully appreciative and understands the Employer's perception for implementation. If Complementary Interventions are built into the prospective works, the evaluation should ensure that the Complementary Interventions are fully understood by the bidders.

**Instructions to Bidders (ITB) and the Bid Data Sheet (BDS):** The ITB is a standard document, slightly varying for different Employers. For a LVR project the Employer should include an additional clause that draws the attention of the bidder to the low volume road approach and any requirements for Complementary Interventions. The BDS is linked to the ITB and provides specific project information.

**Conditions of Contract:** This includes standard provisions for execution of the contract. The conditions apply unless amended in the Conditions of Particular Application. For major and intermediate works, contract amendments may be required to reflect the desired approach for low volume road works. The simplified Conditions of Contract with the Standard Bidding Documents for Minor and Micro works do not normally require amending.

**Conditions of Particular Application:** This is where any Provisions in the General Conditions of Contract may be amended to make them more appropriate to the requirements of the low volume road approach, including Complementary Interventions.

In promoting small and medium scale enterprises, emergent contractors, employment intensive or labour-based works, and the utilisation of intermediate equipment options, due consideration should be given to the clauses referring to Performance Security, Performance Programme, Insurances, Cash Flow, Plant, Equipment & Workmanship, Payments, Retention and Advances, Price Adjustment and currency restrictions. There are cases where the General Conditions of Contract may prevent, or work against, the small scale industry and these should be adjusted accordingly to promote competition and fairness within the emergent industry.

Due consideration should also be given to strengthening clauses aimed at promoting sub-contracting/assignment, local employment and conditions (particularly for women), rights and insurances, and for strengthening Complementary Interventions.

**Standard Technical Specifications:** These define the scope of the technical requirements of the contract, including the type and quality of materials and equipment, the standards of workmanship. The “Standard Technical Specification and Method of Measurement for Roadworks” forms a separate volume in the ERA documentation and may be used on LVR construction projects. However, for smaller projects using a labour-based approach it is recommended that the ERA “Standard Specifications and Method of Measurement for Labour Based Construction of Wereda Roads” should be adopted.
**Particular Specifications:** This is where any detailed technical requirements and specifications, and implementation mechanisms specific for the project should be clearly defined. The Particular Specification should include any specifications and limitations on the freedom of choice for the contracting company related to the execution of works. Particular Specifications add further detail to complement or replace those stated in the Standard Technical Specifications.

**Drawings:** Some standard detailed drawings may be applied directly for low volume roads works (e.g. cross-sections, standard culvert design and signage). Supplementary drawings, linked to the Particular Specifications, may be required where new, innovative or special approaches are included. Where trail bridges are included within the contract, as a Complementary Intervention, a separate volume of drawings is provided.

**Bills of Quantities or Schedules of Rates:** This should be linked by item number to the Standard Technical Specifications and to the Particular Specifications; and is where the schedule of activities and estimated quantities are set out for the bidder to price.

**Information to Tenderers:** This typically includes information that may be crucial to the pricing of the tender by the tenderer and includes items such as materials investigation reports. However, it must be stressed to the tenderer that such information does not form part of the contract.

### 2.3 Tendering Process

#### 2.3.1 General

The tendering process is guided by an Activity Schedule and List of Standard Forms, Letters and Checklists presented in the Procurement Manual. This process typically follows the following sequence of activities:

- Call for tenders.
- Tender evaluation.
- Award of contract.

#### 2.3.2 Call for Tenders

The call for tenders varies according to the size and type of procurement. For a small, simple procurement, the call for tenders may involve simply inviting one or more contractors to submit bids. For competitive procurement, the call for tenders includes advertising and distribution of bid documents. This may be done in one stage (open bidding, with any firm permitted to submit a bid) or there may be a two stage process. At the first stage, firms are invited to express their interest in bidding and to submit some preliminary information. A short-list of pre-qualified firms is then prepared based on this information. The pre-qualified firms are then invited to prepare and submit detailed bids. Sometimes, the road agency may have a permanent list of pre-qualified contractors who are invited to submit bids.

#### 2.3.3 Tender Evaluation

The evaluation of the tenders must ensure fairness and transparency in determining which of the bids represents the best value for money for the Employer. It should follow a process that ensures that all the important aspects of the various offers received are properly evaluated.

Factors that can be taken into account during evaluation include:

1. The bid price.
2. The evaluation of past performance by the same contractor.
3. The timing: when the works will be complete.
4. Other factors that may affect the cost to the Employer, for example, the timing of payments to the contractor. If most of the payments are early in the contract period, this may represent a bigger cost to the Employer than if the payments are mostly late in the contract period.
5. Other factors that the Employer may want to consider; for example, preferences for firms that demonstrate capacity and willingness to utilise labour-based methods for appropriate activities.
In some cases, especially on smaller contracts, both the time for completion of the works and the price are fixed by the Employer and do not form part of the technical evaluation of tenders.

The evaluation process should culminate in a report on the findings, including:

- Tender information
- Addenda
- Tenders received
- Completions of tenders
- Arithmetical errors and omissions
- Qualifications
- Alternatives offered
- Proposed sub-contractors
- Programme and cash flow
- Balancing of rates
- Analysis of the tenders
- Competency of tenderers
- Developmental aspect evaluation
- Conclusions
- Recommendations
- Annexures.

The tender evaluation document is provided to the Employer, who then makes the final decision on the contract award.

2.3.4 Award of Contract

It is common for a further process of negotiation to take place between the Employer and the contractor, after the winning bidder has been identified and before the contract is signed. These negotiations may cover details of how the contract will be implemented. Where price is a factor in the selection of the contractor, no further negotiation on price is permitted at this stage. However, the contract may allow variations to the quantity of works assumed for the tender. Such a change in quantities is known as a “variation”. It is not a negotiation, and is a decision that is made by the Employer alone. The unit prices submitted by the bidder apply to the revised quantities unless the variation is large and the supervising engineer determines that a different rate should apply.

Notification of the award of contract should take place within the period of validity of the bids. If for any reason this cannot be done, bidders should be requested in writing to extend the period of validity. However, bidders may refuse to extend the period without penalty.

The traditional method of awarding a contract is for the Employer to send a Letter of Acceptance to the winning bidder. A standard Letter of Acceptance format is often included in the bid document. The Letter of Acceptance, together with the bidders Form of Bid, is deemed to constitute a legally binding contract. The two parties then agree to meet to sign the contract document.

2.4 Supervision Services

In addition to adequately defining the scope and understanding of the project and its approach for the works bid, it is essential that the same level of understanding is reflected in the Request for Proposals (RFP) for the supervising consultant. The RFP should specifically include appropriate inputs of key personnel with the requisite skills to meet the requirements of the low volume roads project approach. The supervising consultant should be fully familiar with the techniques and approaches to be employed on the works, including any Complementary Interventions.
The RFP should include:

- Clear definition of the role of the supervisor in the context of the project. If small scale or emergent contractors are employed, the Employer may require the consultant to act both as supervisor and mentor or to provide training, for example to Employer or authority staff;
- Clearly defined and appropriate inputs for key personnel with requisite experience on the construction of low volume roads;
- Requisite skills to cater for socio-environmental supervision and oversight of any Complementary Interventions;
- Reference to this Manual and supporting documents.

Bibliography

3. **Introduction**

3.1 **Background**

The construction processes required for a LVR does not, in principle, differ markedly from that adopted for other types of road. However, LVRs are much more sensitive to the social, economic and technical context in which they are built. Variations can be significant with regard to the choice of construction method, type of resources available and type of construction materials being used. This requires the adoption of an appropriate construction strategy which, on some projects, may require the contractor to create productive employment through the use of labour-based methods of construction.

3.1.2 **Purpose and Scope**

The purpose of this chapter is to highlight the typical range of activities that a contractor will need to consider in undertaking the construction of a LVR. These include the adoption of an appropriate construction strategy as well as appropriate techniques for undertaking earthworks and pavement construction operations using locally available materials. The importance of compaction is highlighted, as well as problems that may be encountered in dealing with poor soils, such as expansive, collapsible and dispersive soils. Finally, the precautions that should be followed in undertaking shoulder construction and surfacing of LVRs are addressed.

3.2 **Construction Strategy**

3.2.1 **General**

Of particular interest in the construction of Wereda roads is the utilisation of labour-based and intermediate equipment technology. The objective of this approach is to maximise the number of job opportunities per unit of expenditure. This approach involves using a combination of labour and light equipment instead of heavy plant, without compromising the quality of the end product. It optimises the use of labour, and employs equipment only for those activities which are difficult for a labour force alone to undertake efficiently and cost-effectively.

3.2.2 **Labour-Based Construction**

Despite the substantial potential benefits offered by labour-based construction, a number of myths and problems still prevail in the minds of many people concerning this technology. These need to be fully appreciated if the labour-based approach is to be successfully deployed on Wereda projects.

Common myths:
- Standards should be lowered to allow for labour-based methods
- Labour-based construction is out-of-date and incompatible with the modern world
- Labour-based methods can be used for any construction activity
- Labour-based construction is only for welfare relief schemes
- Ill-educated contractors will never understand tender procedures
- Voluntary labour can be used to keep costs down.

Typical challenges faced:
- Lack of suitable documentation for the management of labour-based contracts
- Employers not open to considering a labour-based approach for new projects
Employers are unable to process payment for labour and materials fast enough to keep a labour-based contract operating smoothly.

**Countermeasures**

In order to correct and overcome the above myths and problems, it is necessary to raise awareness of the benefits of labour-based construction amongst stakeholders. In addition, it requires the formulation and propagation of appropriate strategies by key Ministries of Government, based on broad policy directives.

**Standard Specification and Method of Measurement**

ERA’s Standard Specification and Method of Measurement for Labour-Based Construction of Wereda Roads provides an important component of the Contract Document and facilitates the adoption of this approach in the construction of LVRs in the country.

**Suitability of Construction Activities for Labour-Based Works**

A number of activities are well suited to labour-based methods such as site clearance/bush clearing and ditch excavation while other activities, such as compaction of pavement layers or haulage of materials over long distances (typically > 5 km) are not. Some construction activities, for example manipulating heavy precast sections, are not possible without the help of the right machinery. Emphasis is given in this chapter to those activities than can be effectively undertaken by labour-based methods, including the choice of appropriate plant.

*Plate D.3.1: Screening of Aggregate for Road Surfacing*
Labour-based projects usually employ a relatively large number of labourers. In such a situation, the site management staff require to be particularly good “people-managers” with a strong managerial as well as technical background. They need to be familiar with local traditions and social structures in order to avoid disputes on site that could threaten the progress of construction and the sustainability of the project.

### 3.2.3 Equipment-Based Construction

Some projects, especially large ones, may require heavy plant and equipment for various reasons:
- Large volumes of earthworks may need to be moved.
- Haul distances are long and large quantities of fill and pavement materials may be required.
- Large volumes of materials are required from borrow-pits or quarries which have to be excavated and adequately rehabilitated after completion.
- Heavy watering and compaction may be required to achieve specified in-situ densities.
- Crushing of pavement and surfacing materials, where specified, may be required.
- Large quantities of concrete or asphalt may be required.

Generally, the overall size of the project and the amount of materials to be moved within a fixed construction period, are the governing factors when determining whether labour-based or plant-intensive methods are to be used. However, even the largest plant-intensive projects can accommodate many labour-based tasks within the works, and the designer should always try to incorporate these into the contract documents, where required, to assist with the government’s aim of job creation and poverty reduction.

### 3.3 Construction Equipment

#### 3.3.1 General

The choice of the most appropriate type of equipment for a particular project is normally dependant on the following major factors:
- Site conditions
- Type of operations
- Size of the project
- Soil conditions and material types being used
- The degree to which manual labour is used in the operation.
Equipment in current use for the construction of LVRs varies from heavy equipment for major highways to the light plant used for labour-based methods. It is often not appropriate to use high-capacity, heavy equipment on LVR sites due to smaller quantities of materials and dimensions of the works. Such equipment is not appropriate where labour-based methods are used to any significant degree. Use of manual labour for major construction operations requires flexible solutions with many smaller units of equipment.

3.3.2 Equipment Used with Labour-Based Methods

Labour-based methods include the use of hand tools for excavation and spreading of material and equipment such as wheel barrows and animal drawn carts for transport. In addition, hand-operated compactors may be used for compaction. These compactors require the use of specific methods to be effective, such as the construction of maximum layer thickness of 75 mm. They are unlikely to be effective in operations where pavement materials require compaction on a large scale. Heavier compaction equipment may also be required for the compaction of pavement layers for sealed roads. Penetration macadam, emulsion treated base and thin reinforced concrete pavement can all be constructed entirely by labour-based methods, whereas densely graded materials require the use of plant-based methods in order to be effective.

Labour-Adapted Equipment - Tractor Units

Construction units that use agricultural tractors as a power unit provide flexibility in the use of equipment in small units. This approach suits operations where manual labour is a major part of the resource input. The uses of agricultural tractors in key operations include:

- **Loading/transport**: A few tractors can operate many small trailers intermittently, thereby giving labourers sufficient time to load the trailers and maximising the utilisation of the mechanical units. Such trailers usually have a practical height for manual loading. Otherwise, it may be necessary to use the bench method for loading by hand (see Chapter 6 on Borrow Pit Management).
- **Spreading/shaping**: Towed graders are available in several sizes to carry out these operations, although spreading and shaping can also be done by hand.
- **Watering**: Towed water bowsers.
- **Mixing on the road**: Towed agricultural disc harrows drawn by a large tractor are very effective.
- **Compaction**: Towed vibrating, grid or tamping rollers. Rollers on labour-based works are often hand controlled.
- **Surface reparation**: Towed mechanical brooms.
- **Bitumen operations**: Towed bitumen sprayers can be used for priming and binder application in conjunction with suitable heating and pumping plant. Emulsions are generally preferred to hot binders on labour-based sites to avoid the need for heating to high temperatures, and to ensure the safety of the workforce.
- **Surfacing aggregate**: Spreading aggregate by hand from towed trailers; tractors may be used for towing chip spreader units.
3.3.3 Advantages of using tractor units.

Tractor based units have the following advantages for use by emerging contractors and for operations in remote areas:

- Plant operation: fewer mechanical items are in use and units are simple to maintain with local mechanical skills; easy access to spare parts compared to heavy construction machinery.
- Plant availability: often relatively easy to find locally available tractors outside the ploughing season, thereby offering flexibility in fleet management.
- Better utilisation rates of agricultural tractors than heavy plant.
- Income to the community outside of the ploughing season.

3.3.4 Heavy Equipment Units

The use of construction units based on conventional equipment, as opposed to tractor based units, is widespread in Ethiopia. Units of this kind typically have the following features in the context of the construction of LVRs in remote areas by small local contractors:
Bulldozers for stockpiling: Have generally been replaced with more economical excavators. Caterpillar D8 or larger bulldozers are difficult to utilise economically where material sources are small, scattered and of variable quality within each borrow pit. Caterpillar D7 or smaller models are normally better suited. Bulldozers require regular preventive maintenance, typically every 250 hours.

Front-end loaders: Front End Loaders come in a variety of sizes. Those mostly used for loading gravel for layer works are the Cat 936/950/966 Loaders or similar. This depends on the size of tipper trucks available. For labour-based construction, a Tractor Loader Backhoe is suitable and can load a 6 cubic metre truck in 5 minutes.

Scraper-operations: These are effective where earthworks quantities are large and where material quality is not critical. The control of materials quality is very difficult when using scrapers. The advantage of scrapers is that they can be used for cutting the road way, excavation of drains, filling, spreading and to some degree compaction with a single machine. However, motor scrapers typically incur very high investment and operational costs with high requirements for utilisation and mechanical skills for their maintenance. They are expensive to operate and tend to be replaced by a combination of other plant.

Motor-graders are versatile and are typically used to level tipped heaps, spread gravel, break down oversize material, mix in water, place gravel layers for compaction, cut levels, shape the road prism, shape cut-off berms and cut mitre drains. Most operations carried out by motor graders can be undertaken by labour-based methods. However, on higher trafficked roads, it may be preferable for good riding quality to cut the final levels with a motor grader. This can be carried out as a one-off operation whenever a sufficient length (say 20 km) of base has been placed by hand.

Plate D.3.5: Motor Graders are Versatile for Processing Materials on the Road

Excavators: Large excavators can carry out earthmoving operations of both a bulldozer and a front end loader in the road way and in the borrow pits. This is often an economical option. Selection of material quality is difficult using excavators and such operations can therefore only be used only where material quality in the borrow pit is uniform, or the material can be mixed (e.g. for bulk earthworks).

Articulated dump trucks: These incur high investment and operational costs with stringent requirements for mechanical skills in their maintenance. They can be efficient in high capacity operations and provide both an off-road and an on-road driving capability where the units can legally use public roads. Loading of dump trucks normally requires the use of mechanised plant.

Tipper trucks: Ordinary tipper trucks are often favoured by emerging contractors because they can be used for other transport purposes and are readily available on the second hand market, generally with readily available spare parts. The skills required for their mechanical maintenance are moderate.
3.3.5 Compaction Equipment

Types of plant

In addition to conventional rollers for compaction there are examples of equipment that give particular benefits in the construction of earthworks and pavement layers for LVRs. Some of these are:

**Grid roller:** This is a static roller towed at a relatively high speed of 15 km/hour for breaking down oversize and 8 km/hour for compaction. In this manner the material is better utilised and problems due to oversize particles are avoided. Good results are generally obtained with the use of this plant for compaction of pavements constructed with natural gravel and of fill layers with lower quality materials which can sometimes be difficult to compact to the full layer depth.

The grid roller allows compaction of the layer to take place in several smaller lifts at the same time as the graders spread the material. The pattern of the surface of the roller ensures that compaction is achieved without forming laminations and shear planes within the layer.

**Very heavy towed pneumatic rollers:** This type of roller can be up to 50 tonnes mass on one axle and has been used successfully for compaction and proof rolling of the roadbed, especially in thick single-sized graded sand. Its advantage is in the provision of a uniform and sound foundation for the pavement, achieved by collapsing and densifying any soft areas.

Impact compactors: These are non-circular, relatively high-energy 'rollers', typically three-, four- or five-sided. Large-wheeled tractors are used for pulling the compactors at operational speeds of 12 – 15 km/h producing a series of high amplitude/high impact blows delivered to the soil at a relatively low frequency (90 – 130 blows per minute). The energy per blow varies between 10 and 25 kilojoules, depending on the mass and amplitude of the compactor.
Due to their very high energy density per blow, the main advantage of impact compactors over conventional compaction plant is their depth effectiveness, typically of the order of one metre of fill or in situ layers, thereby producing deep, well-balanced, relatively stiff pavement layers. These rollers are well suited for densifying collapsible soils. They have been successfully used in low-cost road systems and, when appropriately specified, offer a cost-effective option for LVR construction.

Selection of compaction plant

Figure D.3.1 provides a broad guide to the selection of compaction equipment. Each roller has been positioned in its economic zone of application. The exact positioning of the zones can vary with differing material conditions.

![Compaction equipment guide](image)
3.4 Construction Issues

3.4.1 General

There are a number of issues that must be dealt with before construction starts. These are varied in nature and may include:

- Land acquisition and utilities.
- Environmental studies of various types.
  - Temporary environmental issues caused by the construction process itself.
  - Overall environmental issues potentially caused by the longer term existence of the new road.
  - Environmental Impact Studies leading to an Environmental Impact Mitigation Plan and an Environmental Improvement Plan.
- Traffic logistics and control during construction.
- Social issues.

In view of the above, after the award of the contract, and prior to the start of the construction works, the contractor should acquaint himself with the various environmental and social management stipulations included in the Procurement Manual Volume 5: Environmental and Social Management. These stipulations include the following:

- Activity Schedule and List of Standard Reports and Checklists
- Agenda for Environmental Management Meetings
- Standard Report Formats for the Environmental Management Plan
- Checklist for Environmental Issues, Implementation
- Agenda Environmental/Social Progress Report and Meetings
- Standard Report Format, Environmental Audit Report
- Environmental Clearance Certificate.

3.4.2 Labour versus Equipment Based Construction

The approach to construction of the works will be in accordance with the Contractor’s construction strategy as discussed in Section 3.2. Although both labour-based and equipment-based methods are feasible for executing the LVR works, there may often be a preference for utilising the former approach in economies, such as in Ethiopia, with a low wage level and a shortage of foreign exchange. In such an environment, serious consideration should be given to the use of the abundant resource of labour and to limit the use of scarce foreign exchange for imported plant and equipment.

The use of labour-based methods of construction is well documented in ERA's Labour-Based Road Construction and Maintenance Technology Manual (2014) which promotes the use of this technology when the right conditions are present in a given area. These conditions include:

- Sufficient numbers of under- or unemployed persons in the areas where the work is required plus local availability of construction materials;
- Low wage levels (under US$ 4.00 per day according to World Bank studies);
- Shortage of conventional construction equipment and high capital costs;
- Government commitment to the development of employment and generation of income in the rural areas;
- Small contractors skilled in labour-based technology and capable of supervising the work efficiently; and
Competence of the public sector agencies responsible for rural infrastructure works in the areas of contracting and supervision of contractors’ performance.

In the following sections various aspects of LVR construction are described in which both labour-based and equipment-based methods of construction are considered. The more general use of labour for such activities as setting out of the works and the construction of earthworks, embankments, drainage, drifts and gravelling are addressed in detail in ERA’s Labour-Based Road Construction and Maintenance Technology Manual (2014) and are not repeated in this chapter.

3.4.3 Utilising Natural Gravels and Soils

In areas where natural gravel and soils are available for road building purposes, these materials constitute the most valuable resource in the construction of LVRs. Hence, every effort must be made to use them in a creative manner. However, particular attention must be paid to the manner of their utilisation and to the construction techniques adopted to ensure that optimal use is made of natural gravels. High quality materials should not be used for lower layers, since such materials will be treated only as subgrade during future upgrading of the road.

3.4.4 Materials Issues on Site

A good appreciation of the properties of natural gravels is required if they are to be used successfully in the construction of LVRs. For example, some of these materials often include some weak larger particles. When such materials are compacted, these larger particles may break down, hence changing the properties of the material as a whole. An assessment of the consequences of this is required in order to establish whether or not the material meets the specifications following construction.

As is the case with all materials used in LVR pavements, the level of performance is directly related to successful construction methods and workmanship. Aspects of materials utilisation that require particular attention are discussed below.

3.4.5 Materials Management

Proper management of the material sources is essential to ensure that the best qualities of available material are used in the top layers of the pavement structure. Efforts made in locating the best quality of locally available and often scarce materials for road base are of no avail if this material ends up in earthworks layers due to poor management of the resources. This is far more critical for LVRs than in the construction of more highly trafficked roads, where high quality processed material is used.

Many naturally occurring materials are found in thin seams and utmost care is required not to indiscriminately mix different quality materials during their extraction. This issue is discussed in more detail in Chapter 6 – Borrow Pit Management.

3.4.6 Dealing with variability

Natural gravels are inherently variable. The mixing of two different materials to achieve a quality that exceeds that of the two individual sources is the most common, and probably one of the best methods of improving the engineering properties of natural gravels. For example, mixing fine graded materials with sources that lack fines, such as some volcanic tuffs, can create a material with less potential for breaking down under compaction. The resulting material may have a higher density after compaction due to improved grading, and improved stability and workability.

3.4.7 Stockpiling

This forms an important part of materials management by promoting appropriate selection of materials, and providing the opportunity to perform testing before transportation of the materials to the road. The biggest threat to good materials management is when borrow pit operations are not kept sufficiently ahead of the construction.

The following sequence of procedures ensures good management of the material resources:

1) Initial investigation of material sources by trial holes.
2) Stockpiles to be clearly marked.
3) Allocation of materials for specific layers on specific sections of the road after stockpiles are completed; laboratory testing should be conducted if possible.

4) Loading from stockpiles according to allocation for transportation to site (avoiding segregation).

5) Re-testing for suitability of material after breaking down and compaction.

The procedure outlined above ensures that acceptance or rejection of materials is carried out at the source, before the material has been transported to the road. However, this requires sufficient plant for opening of borrow pits to avoid the construction demand exceeding material supply from the borrow pits. In cases where opening of borrow pits cannot keep ahead of construction, there is a considerable risk that materials selected for base-course, for example, will end up in the lower layers of the pavement. This causes pressure on material supply when base course materials are needed at a later time.

3.4.8 Mixing technique on the road

Motor graders should be used for mixing two types of material on the road. Graders may be used in combination with disc harrows to achieve a homogeneous mix. As illustrated in Plate D.3.9, the method should be typically as follows:

- Dump gravel A on the road in the required quantity then flatten the heaps and spread the gravel over half the width of the layer.
- Dump gravel B on top of the spread material A and then spread also over the same half width.
- Mixing should proceed as normal with the blading of both material A & material B.

Plate D.3.9: Mixing of Materials on road with a Motor Grader

3.5 Roadbed Preparation

3.5.1 Clearing, Grubbing and Top Soil Removal

It is important to take account of environmental aspects at the early stages of construction so that sensitive operations such as clearing and grubbing are conducted as carefully as possible. Damage to vegetation cover should be minimised, and shifting of soil and associated damage due to erosion avoided. Any mitigation measures set out in the Environmental Impact Mitigation Plan must be observed.

All topsoil that is stripped should be stockpiled for use in areas that are being reinstated for farming purposes or to promote re-vegetation. Any tree limbs or stumps being removed should be handled and stockpiled in such a manner that the wood can be of benefit to the local community, e.g. as firewood.
Suitability for labour-based operations

Clearing and grubbing is suitable for labour-based operations where the required speed of construction and availability of labour makes it possible. Labourers may experience problems in achieving the required result as described in specifications due to the need for ripping, depth of grubbing, size of roots, etc. In such cases it is advisable to review the specifications in the light of the requirements of a low volume road and to ascertain whether there is a realistic risk of damage to the pavement due to reduced standards of grubbing.

3.5.2 Roadbed Preparation

After clearing and grubbing, any unsuitable materials should be removed to appropriate depths (clays, black cotton soils, dispersive soils, etc.) and the roadbed graded.

The roadbed should then be compacted, either to a specified percentage density or by using a method specification. A method specification usually consists of watering the roadbed and applying a specified number of roller-passes to the roadbed at the in situ natural moisture content. A trial-section should be prepared and the in situ compaction measured after each pass of the roller. This can be done by density tests (or by using DCP measurements in some materials). Once the required compaction has been achieved, then the number of passes should be used thereafter for the rest of the roadbed compaction where soil conditions are homogeneous. Method specifications are very practical and time-saving and their use should be encouraged.

If collapsible soils are found beneath the roadbed, it is necessary to pre-collapse them before commencing the earthworks. There are a number of ways of achieving pre-collapse, but the recommended methods are those that minimise the amount of water required by using Heavy Impact Rollers or Heavy Vibrating Rollers. Countermeasures for dealing with collapsible soils are included in ERA LVR Manual Part B.

Existence of hard stratum

The existence of a hard stratum below the roadbed can present drainage problems, particularly in cut areas. The solution for dealing with this depends on a number of factors including the proximity of the rock stratum to the finished road level, the thickness/hardness of the rock stratum, and whether the road is in cut or fill. Remedial measures for dealing with the hard stratum are:

- **Relatively thin (< 1m) stratum.** Breaking up the rock layer using jack hammers or by blasting in order to provide a vertical drainage path to an underlying pervious stratum. Providing lined drains to minimise seepage of water under the road pavement.

- **Relatively thick (> 1m) stratum:** Raising the road embankment through provision of a 300mm capping layer over the hard stratum and/or providing lined drains to minimise seepage of water under the road pavement; provision of a capping layer is preferable if suitable material is available.

3.5.3 Subgrade Construction

The best techniques and methods for undertaking earthworks and subgrade operations are dependent on available equipment in addition to the operational skills and experience of the field staff. An indication of the advantages and disadvantages of the various types of equipment available for earthworks operations is given in Section 3.3.4.

When compacting earthworks and subgrades it may be difficult to adjust the in situ moisture content before compaction, especially when using clayey material where a good distribution of water in the material is difficult to achieve. To mix water into such materials requires much effort and is not very effective.

Adjusting moisture contents of earthworks is also particularly difficult in wet climatic regions whereas, in drier areas, it is possible to dry out materials that are too wet. Careful timing of earthworks, where possible, can alleviate these problems.

The use of labour-based methods in earthworks operations is appropriate where there is a large source of labour available for the work of the quantities are relatively small.
Pavement Layer construction

Aspects of construction that require particular attention are as follows:

- Natural gravels with high contents of fines or clay particles gain their strength as a result of suction following drying back, rather than from friction between particles. This means that the in-service moisture regime of the pavement, achieved through appropriate internal drainage measures, is of vital importance for the performance of the layer.

- Correct moisture content (ranging between 1% above and 2% below optimum moisture) and achievement of the specified density for the different layers, is essential.

- Depending on the construction plant used, a good surface finish is sometimes difficult to attain. It is critical that the base course has a smooth finish before sealing. Correct after-care following construction is important for a good bond between the base course and the bituminous seal and subsequent performance of the pavement.

- Natural materials often consist of soft particles and placing, mixing and compaction may result in a change in the material properties. An assessment of the consequences of this processing action is required in order to establish whether the material meets the specification requirements following construction.

3.6 Compaction

3.6.1 General

Compaction is a vital aspect of LVR construction. Good compaction results in all-round improvements of soil properties and in their performance as a pavement supporting layer. A well-compacted subgrade possesses enhanced strength, stiffness and bearing capacity, is more resistant to moisture penetration and less susceptible to differential settlement.

3.6.2 Subgrade Compaction

Effective subgrade compaction is one of the most cost-effective means of improving the structural capacity of pavements. A well compacted subgrade possesses enhanced strength, stiffness and bearing capacity; is more resistant to moisture penetration; and less susceptible to differential settlement. The higher the density, the stronger the subgrade support, the lesser the thickness of the overlying pavement layers and the more economical the pavement structure. Thus, there is every benefit to achieving as high a density and related strength as economically possible in the subgrade.

3.6.3 Compaction to Refusal

One of the critical aspects of using natural gravels is to maximise their strength and increase their stiffness and bearing capacity through effective compaction. This can be achieved, not necessarily by compacting to a pre-determined relative compaction level, as is traditionally done, but by compacting to the highest uniform level of density possible without significant degradation of the particles. This compaction to refusal is illustrated in Figure D.3.2. It results in a significant gain in density, strength and stiffness, the benefits of which generally outweigh the costs of the additional passes of the roller.
Compaction to refusal ensures that the soil has been compacted to its near elastic state, as shown in Figure D.3.2, with the significant benefit of reduced permeability and, hence, susceptibility to moisture ingress.

A maximum allowable moisture content during construction should be specified and proper precautions for surface and sub-surface drainage (where required) should be taken on all roadbuilding projects to ensure optimal performance from the road.

In general, the effectiveness of the compaction process depends on three important, inter-related factors, namely:

- Soil moisture content during compaction
- Soil type, and
- Type and level of compactive effort.

Different types of soils respond to compactive effort in different ways. Thus, it is important to ensure that the compaction plant being used is appropriate for the type of soil being compacted and the purpose intended. For example, sand or sandy soils are most efficiently compacted with high frequency vibrating rollers whereas cohesive soils are most efficiently compacted by static pressure, high amplitude compaction plant. Furthermore, if the requirement is to compact and produce a good riding quality of base course, this is unlikely to be achieved with a very heavy roller that compacts to a great depth and, in the process, disturbs the surface.

Compaction to refusal may result in cracking due to over-compaction. This manifests itself in faint cracks which may develop into a failure point during the service period. Compaction to refusal should be implemented in the presence of skilled personnel.

### 3.6.4 Moisture for compaction

Thorough mixing of water with soil over the full width and depth of the layer and at the optimum moisture content of the admixture is essential for achieving the required density and an even surface finish. The optimum moisture content determined in the laboratory is a good guide to the amount of water required in the field compaction process, bearing in mind that modern compaction plant normally requires a lower moisture content than the optimum indicated from laboratory compaction methods. The moisture content can be reduced if a higher compactive effort is used.

Natural gravels used in LVR pavements often have a high fines content and therefore require much larger amounts of water for compaction than crushed or coarser, well-graded, materials. Effective mixing is therefore of particular importance when utilising these materials. Mixing equipment such as ploughs or
Part D: Construction of Low Volume Roads

3.6.5 Compaction of Pavement Layers

Compaction of all pavement layers is specified as a percentage of the maximum dry density (MDD). Such a requirement should desirably be that obtained at “refusal” density, for the reasons discussed above. To achieve a well-balanced pavement, the compactive effort is increased in each layer as the pavement prism is built, and the quality and therefore the physical strength of material is greater in each ascending layer, thereby making the pavement stiffer at the top than at the bottom. Whatever level of compaction is specified it is important to achieve it on site for each layer by ensuring that the material is appropriately watered and mixed before starting the compaction of each layer. The higher the density in the underlying layer, the stiffer and more deeply balanced the pavement structure will be. Moreover, when the underlying layer is properly compacted it is easier to achieve the required level of compaction for the upper layer. Similarly, if the underlying layer is not well compacted it is more difficult (or impossible) to achieve the required compaction of the upper layers.

3.6.6 Water Usage, Evaporation and Temperature Variations

Before deciding the required moisture content, the in-situ moisture content must be determined. It is normally necessary to provide more water than needed to achieve the OMC to allow for evaporation during the construction process. In dry areas it may be necessary to provide 50% more water than needed to achieve the OMC.

Some areas of Ethiopia have high daily temperature and evaporation rates. The Eastern parts of the country (Afar and Somali regions), for example, can reach high temperatures in excess of 30°C during the day. Such high temperatures result in an extremely high evaporation rate leading to excessive loss of water. Hence, it is prudent to programme watering and mixing activities very early in the morning or late in the afternoon to prevent such losses. For LVRs the cost of transporting water may constitute a substantial part of the total cost and any means of reducing this cost should be considered.

Generally, the lower temperatures do not affect pavement layers unless freezing of free water in a layer causes expansion and de-densification. This can be easily checked by re-testing the following day and re-processing the layer. However, high temperatures (i.e. > 30°C) cause high evaporation during processing and care must be taken not to compact the layer when it is too dry of OMC because it will be impossible to achieve the specified density. Compaction at too low a moisture content may also impose a high risk of lamination at the top of the layer. Thus, during hot days, it may be necessary to add water frequently during processing to arrive at the correct moisture content immediately prior to compacting.
3.6.7 Compaction at low moisture content

In the arid or semi-arid, north-eastern and south-eastern regions of Ethiopia where rainfall is less than 500mm per annum, water is often scarce and problems arise when large quantities (up to 2,000 m³/km) are needed for road construction. In these regions qualified consideration can be given to “dry compaction” techniques for the compaction of the subgrade and pavement layers. As illustrated in Figure D.3.3, high densities can be achieved at low moisture contents using conventional compaction plant. However, as shown in Figure D.3.4, soils compacted at low moisture contents will have high air voids. As indicated above, should the degree of saturation increase in service, this may allow an ingress of water into permeable pavements even if the road surface and shoulders are sealed, resulting in a loss in soil strength and resulting deformation of the pavement structure. A life-cycle analysis will allow a determination to be made of the preferable option.

![Extended Compaction Curve for Low Moisture Contents](image1)

**Figure D.3.3: Extended Compaction Curve for Low Moisture Contents (Parsons, 1992)**

Impact compaction provides an alternative to conventional compaction plant for undertaking compaction at low moisture contents.

**Minimum Compaction Requirements:** Table D.3.1 gives the minimum compaction requirements for the various layers in the pavement. Where higher densities can be realistically attained in the field (compaction to refusal) from field measurements on similar materials or other established information, they should be specified by the Engineer.
Table D.3.1: Minimum Compaction Requirements

<table>
<thead>
<tr>
<th>Pavement Layer</th>
<th>Material Class</th>
<th>Target Density (Relative Compaction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadbase</td>
<td>G80 G65 G55 G45</td>
<td>98% – 100% T180</td>
</tr>
<tr>
<td>Subbase</td>
<td>G30</td>
<td>95% -97% T180</td>
</tr>
<tr>
<td>Subgrade/Fill Wearing Course</td>
<td>G15 G7</td>
<td>93% -95% T180</td>
</tr>
<tr>
<td>Roadbed</td>
<td>Sand Gravel</td>
<td>100% T180 93% -95% T180</td>
</tr>
</tbody>
</table>

3.6.8 Quality Attainment

LVR design procedures assume that both the material properties and levels of density specified are achieved in the field. However, in order to attain the specified densities, it is essential to ensure, as far as practicable, the uniform application of water, the uniformity of mixing and uniformity of compaction at or near OMC.

It is also important to note that layers below the one being compacted should be of sufficient density and strength to facilitate effective compaction of the upper layer(s). Adherence to the compaction recommendations given in Table D.3.1 should ensure this.

Granular materials which are well graded are easier to compact than poorly graded ones. It may therefore be more economical to get the gradation right (e.g. by mechanical stabilisation) before wasting time and energy with excessive rolling. Improved grading is also likely to improve the material strength to an extent where a subbase quality material could become eminently suitable for road base.

Whilst it is necessary for natural gravels to be brought to OMC for efficient compaction, it is necessary to ensure that premature sealing does not lock in construction moisture. This can be achieved by allowing a significant amount of drying out to occur before sealing takes place, particularly for materials that rely on soil suction forces for strength gain and improved stability.

The variability of natural gravels is a significant factor in the reliability of performance of the pavement. However, various measures can be taken during construction to reduce such variability. These include:

- **Careful selection during the extraction process.** Physical properties of natural gravels in most deposits tend to change with depth and location. Careful selection of the material during the winning process, coupled with appropriate testing on a grid pattern (e.g. use of the linear shrinkage test) will often facilitate uniform stockpiling of the material.

- **Processing of stockpiled material:** Power screens have been proved effective in screening out and blending in to overcome deficiencies and can be particularly useful in attaining the requirements for gravel wearing course materials.

- **Quality control and assurance:** Quality attainment and control are paramount when using unprocessed materials for LVR construction. Quality assurance procedures and the use of statistical control methods are recommended. Such measures will eliminate the costly ramifications flowing from arbitrary decisions to include or exclude the use of certain readily available materials. In addition to the more traditional Sand Replacement and Nuclear Density methods of compaction control, the DCP may also be used. In this latter method, the DCP is driven through the compacted layer and the penetration plotted against the number of roller passes. Once the maximum density has been achieved, the number of passes required is identified and the DCP penetration rate at that point can be used for control testing.
3.6.9 Drying-out of Layers

Natural gravels may need to be brought near to saturation moisture content for efficient compaction on hot days, but it is also good practice to allow a significant amount of drying back to occur before sealing takes place. This is particularly beneficial for fine-grained materials that rely on suction and cohesion as their predominant source of shear strength.

3.6.10 Single and Multi-Layer Construction

Single layer construction is usually specified for pavement layers from 75mm to 200mm thick. The most common layer thickness is 150mm. However, when a pavement layer is specified at a thickness greater than 200mm it is necessary to compact it in more than one layer of the same thickness in order to achieve uniform specified density throughout the layer. The maximum allowable size of any particle in the material should not exceed 2/3 of the layer thickness for layers <100mm or 1/3 of the layer thickness for layers of 150mm or more.

3.6.11 Finishing of Base-course

If the operation of mixing, spreading and compaction is not completed before drying out of the surface takes place, then a loose upper layer (biscuit layer) will result. If this happens, the bituminous surfacing will not have a hard surface on which to bond resulting in base course failures due to shearing from wheel loads. Such failures may appear to be the result of insufficient material strength, but studies of construction records, and evidence of good performance under similar conditions in base course layers of poorer material qualities, indicate that premature failure of the uppermost layer of the basecourse can often be linked to poor finishing of this layer. Careful finishing of the base course layer is vital and decisive for good performance of LVRs.

Figure D.3.5 illustrates a recommended procedure for finishing off base courses made of natural gravel. The advantage of this method is the speeding up of the processing of the base course to prevent drying out of the surface, whilst ensuring that full attention is given to surface finish instead of minor irregularities of geometric levels. Trimming of the surface should be confined to the action only of cutting off gravel to side spoil or off loaded for use in subsequent sections. Attempts to spread loose material over the surface in a thin layer is unacceptable. This is likely to prevent a firm finish of the layer and inhibit the bond with the bituminous surfacing.
3.6.12 Shoulder Construction

Construction difficulties and subsequent delays can easily occur if materials that differ from those used in the main carriageway are specified for the shoulders. When the surface is to be sealed, shoulders should always be constructed using the same material and specification as for the main carriageway. However, when the shoulders are unsealed, the surface needs to be durable when exposed and this places particular demands on the type of gravel materials that should be used. This type of design may require separate construction of shoulders and carriageway.

The seal used for the main carriageway should also be specified for the shoulders, i.e. the same seal for the full width of the surfaced area. Construction difficulties and delays are likely if the shoulder seal differs from the main carriageway seal.

3.7 Surfacing

3.7.1 Construction Procedure

All types of sprayed surfacings, such as surface dressings, Otta Seals and sand seals, follow a similar construction procedure, as follows:

1) Priming of the base, (sometimes may be omitted for some surfacings).
2) Base repair (chip & spray by hand using emulsion) to even out the occasional rut caused by a stone under the motor grader blade.
3) Spraying of bituminous binder.
4) Spreading of aggregate (Chip spreading requires uniform aggregate cover and a drag broom can assist this process on large areas).

5) Rolling, preferably carried out with pneumatic rollers but can also be done by trafficking.

6) If applying a double layer, repeat 2 to 6.

7) An emulsion “fog spray” is sometimes applied to chip seals.

In slurry seals and cold mix asphalt, crusher dust or aggregate, bitumen emulsion, water and cement filler are premixed with either a specialised “mix and spread” machine or in a concrete mixer for spreading by hand with squeegees. Mixing by hand may be used but is not encouraged.

Detailed approaches to the design of various types of bituminous and non-bituminous surfacings are presented in Part B of the LR Manual as well as in ERA’s Best Practice Manual for Thin Bituminous Surfacings (2013).

### 3.7.2 Need for good construction practice

There are a number of potential problems associated with the construction of surface treatments, particularly sprayed seals such as surface dressings and Otta Seals. The majority of instances of poor performance are related to the following:

- Poor transverse distribution of binder.
- Poor joint construction as illustrated in Plate D.3.12.
- Over or under spray.

*Plate D.3.11: Verifying Transverse Distribution of Binder*
Plate D.3.12: Example of Poor Transverse Joint Construction

Non-bituminous surfacings (e.g. cobble stone) offer potentially less construction problems than bituminous seals because they avoid the use of imported bitumen and relatively expensive construction equipment, as shown in Plate D.3.13 and in contrast to Plate D.3.14. In addition, they offer the advantage of promoting and utilising local industry in areas where stone such as granite or limestone may be won and shaped easily by local entrepreneurs, predominantly with hand tools. Thus, in a small-scale contractor environment, and in appropriate circumstances, they may offer an attractive option to bituminous surfacings. Cobble stone surfaces are generally much rougher than bituminous seals.

Plate D.3.13: Construction of Cobble Stone Paving
3.7.3 Use of Labour-Based Methods

The various types of surfacing provide varying scope for use with labour-based works in a practical, and economic manner. Table D.3.2 provides an assessment of the suitability of each surfacing type for the use of manual labour in production of aggregate and construction respectively.

Table D.3.2: Labour friendliness of various surfacing types

<table>
<thead>
<tr>
<th></th>
<th>Surface dressing¹</th>
<th>Otta seal²</th>
<th>Sand seal</th>
<th>Slurry³</th>
<th>AC⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production of aggregate</strong></td>
<td>Quality</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>Output</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Construction of surfacing</strong></td>
<td>Quality</td>
<td>Moderate</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>Output</td>
<td>Good</td>
<td>Good</td>
<td>Moderate</td>
<td>Poor</td>
</tr>
</tbody>
</table>

1. Hand-crushing of aggregate for surface dressing tends to produce flaky chippings with some rock types.
2. Oversize and fines can be removed by hand screening of natural gravel aggregate for use with Otta seals.
3. Output of aggregate production for slurry (crusher dust) depends entirely on availability on the commercial market.
4. Although included for comparison with other seal types, AC would not normally be used on a LVR.

As indicated in Table D.3.2, all seal types offer varying scope for labour-based operations, both as regards production of aggregate as well as construction on site. However, the uniform binder spray rates required for surface dressing are more difficult to achieve with labour-based methods. Thus, where labour-based methods are being considered, seal types that are most suited for this type of construction should be given priority. It should also be noted that all seals, except the slurry seal, need rolling, and therefore require some form of machine-based equipment for this purpose. Where traffic volumes are sufficiently high, it may be possible to rely on it for rolling, but at the risk of an inferior result.
Examples of surfacing operations that can be adequately undertaken by labour-based methods are illustrated in Plate D.3.15 and D.3.16.

Plate D.3.15: Screening Aggregate by LBM

Plate D.3.16: Spreading Gravel Using LBM

3.7.4 Concrete

There are a number of elements of LVR construction that require the manufacture of concrete. They include concrete strip and slab surfacings as well as various types of drainage elements, such as head and wing walls, box culverts, etc. The integrity of these elements will depend on the quality of concrete used. Appropriate measures must be observed to ensure that the strength of the concrete complies with the specified requirements. This issue is discussed in further detail in Chapter 4 – Construction of Small Structures.
4.1 Introduction

4.1.1 Background

The identification and development of good sources of pavement construction material at regular intervals along the length of a LVR is essential for achieving cost effective construction and ongoing maintenance operations.

Approximately 70% of the construction cost of a typical LVR may relate to pavement materials production and supply. Also, aggregate replacement costs are often as high as 60% of the maintenance costs of an unpaved road. There are therefore significant cost-benefits that can be achieved by implementing improved borrow pit management procedures and material supply strategies.

Proper management of material sources is essential to ensure that the best quality available materials are used in the top layers of the pavement structure. The efforts made to locate these often scarce materials for road base are of little use if this material is wastefully used in earthworks layers. Too often (and in particular for borrow pits located for low volume roads) borrow pit excavation is carried out with only the plant operator present and no correct supervision. In many cases this results in good quality gravel getting contaminated and having to be spoiled. Good management of materials (including skilful supervision during all operations in the borrow pit) is therefore a critical operation in LVR construction.

An awareness of the potentially damaging effects (negative impacts) that borrow pits and quarries may have on the local environment is also required so that mitigating measures may be incorporated in the tender documents for enforcement during the construction operations. However, borrow pits/quarries may also provide opportunities for Complementary Interventions which may benefit local communities. If so, they must be identified early in the tendering process.

4.1.2 Purpose and Scope

The main purpose of this chapter is to provide the basic principles of good borrow pit development, including the application of appropriate management strategies with the objective of encouraging cost effective selection and development of natural resources for LVR construction. In so doing, the chapter:

- Encourages improved record keeping relating to material resources and their utilisation. In particular, it provides guidelines on the establishment of material resource inventories and databases and promotes the benefits that may result from the use of such databases to improve materials management and design of material supply strategies.
- Highlights environmental and social issues associated with road material source development.
- Reviews possible negative impacts and provides guidelines in terms of gravel sources that may be implemented to prevent or reduce adverse effects on local populations and the environment.

This chapter provides an overview of the importance of materials and borrow pit management with a focus on borrow pit planning and preparation, material extraction (both by the use of labour based methods and plant), stockpiling, processing and control. Record keeping and materials data management are also briefly addressed. The chapter does not deal with the investigations required prior to the establishment of a borrow pit, such as prospecting, resource quantity estimation and borrow pit evaluation.

4.2 Environmental and Social Considerations

4.2.1 General

The development of borrow pits and quarries to supply road construction material may impose significant negative impacts on the local environment and its inhabitants. Therefore, appropriate precautions must be taken in the planning, development and operation of all borrow pits.
In relation to low volume road construction and maintenance, financial considerations are a major factor in all engineering decisions. As a result, the costs associated with minimising the environmental impact need to be in proportion to the funds available.

Key legal documents that must be referred to in order to assess and address environmental and social safeguards during the development and operation of any borrow pit are listed in Part A: Section 2.1 – Legal Framework.

4.2.2 Types of Material Source and Environmental Impact

There is a need to be aware of both the potential negative and positive aspects that may be associated with different types of borrow pit or quarry development. This is particularly relevant when there may be a choice of developing one or other type of resource.

Environmental impacts may be associated with extraction of the following main types of road building materials:

- River bed gravels
- Near-surface natural gravels (duricrusts, residual and transported soil)
- Alluvial terrace deposits
- Hill-slope material (weathered and/or closely fractured rocks)
- Hard rock.

River bed gravel borrow pits: The development of river bed gravel sources is a sensitive environmental issue. Negative impacts are typically associated with over-exploitation and careless extraction. The intermittent extraction of small quantities of sand and gravel from a large dry river bed is probably the least damaging form of material supply. This is because no productive land is lost and the deposits will be replaced during future high water flows. Problems arise when the quantities of material extracted greatly exceed nature’s ability to compensate for the loss. If there is any doubt about acceptable excavation volumes, then expert advice should be obtained.

One serious consequence of over-extraction close to bridges is loss of gravel around abutments and piers leading to scour damage. Gravel should always be extracted at a minimum distance of 300m downstream of bridges. If excavation is to be carried out in the river, then care must be taken to limit impacts on the water quality by fine sediment or, for example, by fuel pollution. There will typically be communities downstream who use the river water or perhaps obtain food from the river.

River gravels are typically non-cohesive and may be prone to ravelling if used as wearing course gravel.

Near-surface natural gravel borrow pits: LVR construction may rely heavily on winning construction materials from relatively thin and discontinuous, near-surface gravel deposits. These deposits include laterite, as shown in Plate D.4.1, residual quartz gravels and alluvial gravels.
Easily extracted deposits close to existing unpaved roads are becoming exhausted in many areas. This is now resulting in pressure to exploit marginal quality deposits in poor locations.

The working of deposits less than 2m thick should be subject to an environmental impact review. Working thin deposits involves a poor ratio between land take and resource size. This may become environmentally unacceptable in the following situations:

- In populated and cultivated areas, where pit development may result in permanent loss or down grading of productive land.
- In areas of natural beauty and or habitats justifying a high level of conservation.
- In areas where topsoil is thin and cannot be salvaged to enable adequate pit reinstatement and prevention of soil erosion.

In such circumstances consideration must be given not only to initial economics of extraction, but also to long term economic and environmental consequences. Hauling material longer distances from pits with less adverse environmental impact should to be considered

**Hill-slope borrow pits:** The development of borrow pits in mountainous and hilly terrain can have significant damaging effects on the local environment, if they are not carefully located and operated in an environmentally sensitive way.

Most hillside borrow pits exploit weathered and fractured rock materials. Topsoil is usually thin and stony and as a result difficult to salvage and replace.

Excavation of natural gravel from steep slopes can cause serious slope stability hazards that may endanger the workforce, road users and people living downslope. Slope failures on valley sides can result in heavy sediment pollution of rivers. Carefully constructed benched excavations are usually required.

On some hill roads there is a desire to open a large number of small pits (less than 3,000m³) at regular intervals. This can be very destructive in the short and long term. It is better to identify a few well located borrow sites with relatively large potential resource sizes at longer intervals. Thus, short haulage should not be a factor that overrides environmental considerations in hilly terrain.

If borrow pit development must be adjacent to the road, efforts should be made to locate sites where extraction will improve the road alignment, for example material from a spur or blind spot in the road.

**Hard rock quarries:** Environmental considerations are particularly important at the planning stage when construction materials need to be obtained from hard rock quarry sources. The following guidelines apply to quarry planning:

- Hard rock deposits rarely occur in isolation. Therefore, it is necessary to check the geological maps and consider environmental effects when looking for the best site for development.
- Quarry sites should be located as far away from settlements as possible. Quarry operations will produce noise, vibrations and dust that could impact on nearby residents even if controls are imposed. Steep quarry faces are a hazard to people and livestock, therefore fencing and site security measures are essential.
- The arrangement of the quarry operations should be designed to cause least visual impact on the landscape and to allow for future reinstatement. Natural vegetation (trees and bushes) should be preserved around the quarry.
- Quarry site development costs are high and negative environmental impacts significant. Therefore, quarry sites should be fairly widely spaced and located so that there is the potential to supply large quantities of material over a long period of time to various sites. Haulage of aggregates, between hard rock quarries, for distances of greater than 20km is usually economically and environmentally justified (when natural gravel deposits are not available).
- Crushing and screening plant and stockpile areas need not be located directly adjacent to the actual quarry excavations. Visual intrusion may be significantly limited, at no great additional cost, by processing aggregates at a concealed location a short distance from the outcrop.
**4.2.3 Borrow Pit Planning**

**Borrow pit location:** Borrow pits and quarries should be located in such a way that they cause a minimum of environmental damage and impact on the local environment.

Typically, the following guidelines apply, subject to the over-riding requirements of the various proclamations dealing with environmental and social impact assessment issues:

- Borrow pits should not be within 500m of a watercourse or human habitation.
- If possible, pits should be on land that is not suitable or currently used for cultivation and is not wooded.
- Areas of local historical or cultural interest should be avoided and borrow pits should not be located within 25m of grave sites.
- Wherever possible, borrow pits should not be visible from the road. Development should be designed to minimise visible damage to the landscape.
- There should only be one agreed access road to each borrow pit site.
- Borrow areas should not be on steeply sloping ground if it can be avoided.
- Borrow pits should have minimum overburden material.

**Land take:** Land used for material sources should always be minimised as far as possible and fair compensation should be paid to the owner. This applies equally to both permanent and temporary land take. No land should ever be used without formal authorisation.

**Pit working plan:** Borrow pits should never be opened in an uncontrolled manner – i.e. a proper working plan must be in place before any excavation begins. The plan must include:

- Arrangements for consultation with affected parties.
- A compensation agreement signed with the land user/owner, including agreed borrow pit access arrangements.
- The extent of each borrow pit/quarry, and possible future extension, clearly demarcated on the ground.
- An outline of the direction, timing and depth of working area, including suitable locations for stockpiling the topsoil and overburden materials.
- Provision for adequate drainage and implementation measures for sediment control, re-soiling and re-vegetation.
- Provisions for safety of workers at the borrow pit and the neighbouring community.
- A reinstatement plan which gives details of the final shape of the borrow pit and the method of achieving it, including possible Complementary Intervention plans for the affected community.

**4.2.4 Borrow Pit Development**

**Borrow pit location:** The first borrow pit development activity is the clearing of vegetation and the stockpiling of topsoil for re-instatement. Topsoil is the organic soil typically occurring as a surface layer, normally 150 to 200mm thick.

The future productivity of the restored land is totally dependent on careful replacement of the topsoil layer. Failure to adequately return topsoil materials will have a long term damaging effect on the environment and on the future ability of the land user/owner to earn a living from his/her land.

Any overburden soil (soil that rests on the gravel deposit and under the topsoil) should be stockpiled separately and overburden stockpiles should be located where they will not interfere with future pit extensions. They should be shaped in order to best resist the erosive actions of rainfall.

**Borrow pit layout:** Restoration of land used for borrow pits and quarries should be considered from the start of excavation. The borrow pit layout should be designed to enable easy reinstatement.
Unnecessarily high and steep slope faces should be avoided both to avoid reinstatement problems and to minimise danger to people and livestock.

Reduction in visibility of an excavation can often be achieved by identifying the best orientation of the working faces. However, despite the environmental desirability of a particular direction of working, the geological structure may determine the safest and most effective method of excavation and this will sometimes be the more important factor.

Borrow pit operation: The actual extraction and processing of pit or quarry materials can have several adverse effects on the local environment. The most significant of these is the creation of noise, air borne dust and the pollution of water courses.

- **Noise** may be generated by the excavation process. It is important to limit noise as far as possible both for the local residents and the workforce who should be provided with ear protectors and dust filters.

- **Dust** generated during the extraction of materials can be a health hazard causing respiratory diseases, it can cause of accidents in the pit and can inhibit the growth of plants. Care should therefore be taken to minimise dust emissions. The workforce should be provided with dust filter masks. The main sources of dust and appropriate methods of reducing emissions are listed below:
  - Drilling. Dust suppressers can be fitted to drilling rigs.
  - Movement of traffic. Dusty access/haul roads should be watered regularly during dry weather using bowsers (water trucks).
  - Dumping of dry aggregates in stockpiles. Material processing plants should be fitted with water sprays when stockpiling: this will not only suppress dust but also prevent aggregate segregation.

- **Water course pollution** may be associated with sediment entering streams from the borrow pit excavation. This can be prevented by constructing bunds to divert surface water away from the excavation and by ensuring that any water leaving the excavation passes through a settlement pond. Any re-fuelling or other plant maintenance activities carried out in the borrow pit should be controlled to avoid spills and water contamination. Any accidental spills should be cleared up immediately and disposed of safely.

- **Safety** aspects such as access to borrow pits and quarries with steep and potentially dangerous working faces must be controlled to avoid accidents involving local people and livestock. This may require construction of fences with warning notices and the posting of guards.

For the safety of the work force, dangerous loose faces should be made stable. Workmen and plant operators should receive suitable training that covers safe working practices in borrow pits and quarries. Appropriate safety clothing should be provided and may include hard hats, protective boots and road safety vests.

Special care must be taken when blasting takes place in quarries. Quarries should not be located close to settlements. Only suitably trained and qualified staff should handle explosives. Storage of explosives must comply with internationally recognised standards of practice in terms of security and safety.

### 4.2.5 Borrow pit / quarry reinstatement

During the planning phase (before appointment of a contractor), the possible use of the borrow pit/quarry after the construction phase should be discussed with the local community. For instance, many communities like to use the borrow pit/quarry as a collector of water for both human and animal consumption. Whether the borrow pit/quarry area should be fenced or not needs to be discussed and agreed, as the stored water can be hazardous for children (drowning). Ponded water also increases the potential for mosquito-borne diseases (Plate D.4.2).

Before any use by the community, the borrow pit must be cleaned up properly and shaped according to its use. The work required must be adequately described in the tender documents by way of a Bill item so that the contractor can price the work accordingly.
Before fully reinstating a borrow pit/quarry, the need for materials in future road maintenance should be assessed and appropriate quantities of gravel stockpiled for this purpose.

The environmental damage caused by inappropriate extraction and rehabilitation practices can extend over a wide area and may only become apparent after project completion. Hence, the borrow pit/quarry Preparation work must be carried out carefully and in such a way that the topsoil is stockpiled separately from overburden soils and shaped in such a way as to minimise any loss by erosion, wind and rainwater.

Reinstatement should follow simple procedures which minimize the limitations the construction activity has placed on future use of the land and is described below:

- Shape mounds and steep banks to a slope that is found naturally in the landscape. (steepest 1V:3H)
- Spread the topsoil evenly back into the pit in order to promote growth of vegetation.
- Ensure that the area is self–draining.

**4.3 Borrow Pit Preparation**

**4.3.1 General**

The preparation and arrangements that are typically necessary prior to material excavation, including administrative/planning activities and physical site preparations are often neglected. This is often the case for borrow sites that are opened for low volume roads.

Borrow pits for the supply of low volume road materials are usually not in continuous use. In the case of gravel wearing course sources, 3 to 5 years will typically occur between regravelling operations and paved roads will usually only require rehabilitation after more than 10 years. This should be taken into account during planning. The area stripped should only be large enough to provide aggregate for the immediate needs, with some stockpiling of maintenance materials.

Site survey: In the case of small borrow pits in remote uncultivated areas, it may be sufficient to prepare pit sketches with important dimensions determined by tape measure or GPS coordinates using a hand-held GPS. When a borrow pit will affect cultivated land and local inhabitants then an accurate site survey should usually be made and a plan prepared at a scale of about 1:500 to 1:1000 depending on the size of the proposed workings and nature of the site.

**4.3.2 Borrow Pit Working Plan**

Arrangements should have been made for consultation with affected parties and a compensation agreement reached with the users/owners. Access arrangements should also be agreed.
Borrow pits must be opened and operated in a controlled manner taking into account the considerations summarised under the working plan arrangements in Section 6.2.3. Other issues that must be considered include:

- Undertaking a survey for record purposes to define agreed limits of working area and time.
- Define the direction, timing and depth of working.
- Ensure that borrow pits are excavated to a regular width and shape. As far as possible, all existing trees, hedges, fences etc. should be preserved.

### 4.3.3 Access Roads

The following recommendations relate to the provision of access roads to borrow pits:

- Access roads should be designed to be strong enough to carry the expected haulage traffic without significant deformation or maintenance. Economies of construction may easily be outweighed by increased haulage costs.
- Adequate provision should be made for drainage in order to prevent soil erosion, sediment pollution or road closure due to flooding.

Borrow pit access roads should be aligned in such a way that they cause minimum disturbance to the local population and the environment. They should be located at a safe distance from permanent dwellings and if necessary, fencing should be provided to protect local people and livestock. Figure D.4.1 shows a sketch of an un-desirable access route and desirable access road.

![Figure D.4.1: Undesirable and desirable access road locations](Source: Roughton International (2000). Guidelines on borrow pit management for low cost roads.)

### 4.3.4 Site Clearance

In flat to rolling terrain road construction materials often occur in thin gravel seams beneath a similar thickness of topsoil and subsoil. As a result, excavation of the gravel will require a relatively large area of site clearance to obtain a relatively small quantity of construction material. In hilly to mountainous terrain exploitable deposits are often fractured rock materials occurring beneath very thin topsoil layer that rests on a variable depth of residual soil and highly weathered rock. (This may not always be true in the lowland areas of Ethiopia, where the alluvial deposits are thick, and in the highlands where the residual soils are also relatively thick).

Great care needs to be taken during the site clearance operations to expose the gravel bank or the rock materials, otherwise effective pit reinstatement may not be possible and significant environmental damage will result. Many current practices employed in respect of site clearance for borrow pits supplying materials are typically very poor. In particular, the following bad practice often occurs.
Bush clearing is often carried out by burning, prior to topsoil stripping. However, this practice removes organic matter and kills useful bacteria in the soil that assist in producing the required soil nutrients. If uncontrolled, extensive damage due to fire may affect the surrounding countryside.

The removal of topsoil and sub-soils is often carried out as one operation. This results in complete destruction of the fragile top soil.

Heavy plant is frequently used to remove, stockpile and replace surface soils. This can cause soil compaction that will reduce future agricultural productivity.

Site reinstatement often involves bulldozing the mixed surface soils back into the excavation. This practice can result in rocks and boulders being strewn across the surface. The overall effect is severe degradation of the agricultural potential of the land.

In mountainous terrain disposal of overburden soils is sometimes carried out by side tipping downslope. This degrades the agricultural potential of the hill-slope and frequently leads to slope instability (landslides that may involve just the spoil, or the spoil and the underlying weak soils).

Removal of vegetation: Vegetation clearance is often carried out by bulldozer when site growth comprises bush and trees. This can cause densification of the surface soils and should be avoided if possible. Manual removal of vegetation is the least damaging form of site clearance and should be used when manpower resources are available.

During site clearance any shrubs that would be suitable for any later use should be identified and protected. Transplanting or taking cuttings of the shrubs will preserve them for future replanting.

Removal of top soil, sub-soil and other overburden: Guidelines on appropriate procedures for topsoil removal, overburden soil stripping and pit reinstatement have been prepared by TRL (1999). Figure D.4.2 shows the recommended procedure diagrammatically. The process includes careful removal of topsoil and its stockpiling for subsequent reinstatement of the borrow pit as supplementation from other sources is normally not possible nor environmentally friendly. This is followed by extraction of identified sub-soil layers separately into stockpiles followed by borrow pit extraction.

![Figure D.4.2: Recommended procedure for removal of overburden and stockpiling](image)


The following recommendation applies to sub-soil and overburden stripping:

- The average thickness of overburden soils should be accurately known from site investigations and must be shown in the borrow pit plans. The overburden should be stockpiled in such a way that it does not interfere with the drainage of the adjacent land area. Where possible the overburden material should be used for construction works, e.g. embankment fill.
In mountainous terrain where there is limited space for storage of overburden materials, the soil should be hauled to a suitable disposal site or to a stockpile area located in stable terrain.

Side tipping of overburden soils on steep slopes besides the road should never be permitted.

### 4.3.5 Layout of Shallow Borrow Pits

The working of relatively thin near-surface deposits, whether the borrow pit is operated by labour-based methods or machine-based methods, involves a poor ratio between land take and resource size. Hence, these borrow pits have the potential to create significant adverse effects on the environment. Borrow pit layout and method of borrow pit operation can therefore help to reduce these negative impacts on the environment. Plate D.4.3 shows a small quarry operation using labour-based methods where the aggregate is crushed by hand. In contrast, Plate D.4.4 shows shallow borrow pit excavation using machine based methods.

**Shallow gravel borrow pits using labour based methods:** The layout of a borrow pit exploiting near surface deposits will be strongly influenced by whether it is to be worked by labour-based methods or using mechanised plant.

The following considerations should be taken into account when planning borrow pit development using labour-based methods:

- The optimum height of a face to be worked with a pick is about 700mm. The most efficient borrow pit layout should avoid multiple handling. When possible, excavation bays should be about 3.5m wide so that trailers/trucks can be backed in for loading.

- Provide sufficient space to allow tractors and trailers or trucks to manoeuvre in and out of loading positions without difficulty. It may be desirable to have both access and exit routes into the working area.

- Ensure that the borrow pit layout will, as far as possible, be self-draining not be subject to the accumulation of water (this may not always be possible in flat areas) and the development of soil erosion problems.

- In hillside borrow pits, emphasis should be given to allow easy loading of the material and ensure the safety of the workers.

**Plate D.4.3: Aggregate Crushed by LBM**

Shallow gravel borrow pits using machine-based methods: When mechanised extraction methods are employed the main influences on the borrow pit layout may be somewhat different from using labour-based methods, as follows:
The working face should be arranged in such a way that the excavation plant can operate efficiently. For example, bulldozers work best down a slightly inclined face, whilst backhoes usually operate most efficiently in a near vertical face several metres high.

The need for mixing or to avoid mixing of different deposits (strata), may influence both borrow pit layout and the selection of appropriate excavation plant.

Some stockpiling of excavated materials is typically associated with plant based extraction. Therefore, careful consideration needs to be given to the location of stockpile areas. They should not interfere with future development or extension of the pit and need to be arranged so that there is sufficient space for the efficient operation of loading plant and trucks.

If processing of the excavated materials is required, careful consideration must be given to the area required for this as such operations will require considerable space i.e. blending two different stockpiles.

Fencing is required to protect the local population and livestock when the borrow pit has hazardous steep faces. However, in shallow borrow pits fencing may not be required.

Plate D.4.4: Shallow Borrow Pit Excavation Using Machine-Based Methods

4.4 Borrow Pit Material Extraction Using Labour-Based Methods

4.4.1 General

The purchase and maintenance of equipment for materials extraction requires major foreign currency expenditure. Mechanised extraction can thus be relatively expensive: labour is usually readily available inexpensive and can provide social benefits to the local community.

4.4.2 Geological Considerations

Geological conditions required for efficient labour-based material extraction and supply may only be viable when:

- Un-cemented gravel occurs beneath a relatively thin overburden cover.
- Exploitable deposits occur at frequent intervals close to the road. Typically, it is more efficient to haul materials by tipper truck when distances exceed 5-10km. This is due to the long travel time for tractor/trailer combinations and because it is difficult to load tipper trucks efficiently by hand labour.
- Labour-based methods are most successful in areas where:
  - There is a widespread occurrence of near-surface weakly cemented laterite or calcrite deposits.
  - There are frequent exploitable river bed or river terrace gravel deposits.
4.4.3 Environmental Considerations

Labour based methods are sometimes used in mountainous terrain where there are roadside occurrences of suitably fractured residual rock. However, the development of frequent small borrow pits in terrain which is prone to soil erosion and slope instability is not good practice. In mountainous terrain it is better to open a limited number of carefully selected borrow pits in order to limit environmental damage. Large borrow pits and longer haulage distances then favour mechanised extraction and loading and tipper truck haulage.

4.4.4 Resources and Work Methods

A pit labour gang requires picks, crow bars, hoes, shovels and sledge hammers for effective excavation. In addition, they should be provided with drinking water, a first aid kit and head, hand and foot protection. Careful pit planning and preparation is particularly important in the case of material extraction using L-B methods. The plan should indicate some of the most important aspects of work to be considered when excavating and stockpiling in the pit. The minimum number of labourers will depend on the following:

- Size of the borrow pit site and quantity of overburden to be cleared. Large borrow pit operations may require between 40 and 60 labourers both for the site preparation and the subsequent excavation.
- Availability and capacity of the equipment used for hauling.
- Productivity rates, which will be influenced by the hardness of the in-situ material.

4.4.5 Gravel Excavation and Stockpiling

During gravel excavation and stockpiling activities, the following items should be considered in order to optimise the borrow pit operations:

- Gravel should be excavated, stockpiled and confirmed for use (Quality Control testing) before it is required to be hauled. Seven days are required to carry out the complete set of quality control tests.
- Gravel should be excavated and stockpiled alongside the loading bays to allow easy loading and avoid multiple handling.
- Where possible, loading bays should be constructed to allow trailers to be backed in for loading.
- Ramps into the loading bays must not be too steep for tractors hauling loaded trailers.

In hill-side borrow pits, material should be excavated such that loading is easy (lower instead of uphill) and to ensure that working conditions are safe. It is also important to ensure that the labourers have sufficient space to work comfortably and safely.

Figure D.4.3 shows details of a borrow pit development on flat land while Figure D.4.4 shows details of the development of a hill-side borrow pit.
PART D: CONSTRUCTION OF LOW VOLUME ROADS

STANDARD EXCAVATION BAY 3m WIDE AND 0.7m DEEP WILL ALLOW STOCKPILE BETWEEN BAYS. TRAILER CAN BE EASILY REVERSED INTO LOADING BAY. 4m LONG BAY WILL YIELD ABOUT 12m$^3$ OF GRAVEL (LOOSE) I.E. 4 TRAILER (3m$^3$) LOADS.

MAXIMUM COMFORTABLE HEIGHT OF EXCAVATION ABOUT 0.9m

MAXIMUM COMFORTABLE HEIGHT OF CENTER OF STRIKING RADIUS 1.2 - 1.4m ABOVE GROUND

1.2m APPROX

CONTINUE BAYS SPACE AVAILABLE

LONG BAY WILL YIELD ABOUT 12m$^3$ OF GRAVEL (LOOSE) I.E. 4 TRAILER (3m$^3$) LOADS.

Figure D.4.3: Sketch of a borrow pit development on flat land

Figure D.4.4: Sketch of a borrow pit development on hill-side land


Loading: Where possible, trailers should be parked at the same height as, or preferably below, stockpiles for ease of loading. The loading gang should be divided into groups of 4 to 6 workers and these groups load the empty trailers in the same order as they arrive in the borrow pit. All of the trailers must be loaded to the correct load line (capacity) to facilitate uniform dumping of material.
Figure D.4.5 shows details of the trailer loading height.


Dumping and spreading of the material should commence from where the borrow pit access joins the road to be regravelled/constructed. Initially the road should be gravelled/constructed away from the borrow pit access in both directions simultaneously. With short hauls this reduces congestion at the loading sites. When hauls exceed about 1 km, gravelling/construction should continue only in one direction at a time. The advantages of this are:

- The tractors and trailers compact the material as they haul over the already laid material.
- Damage to un-gravelled road formation is minimised.
- Gravelling does not interfere with reshaping activities.
- Gravelling can recommence sooner after rainfall.
- Ideally one tractor works with two or three trailers to maximise the use of the tractors.

Figure D.4.6 shows an ideal borrow pit arrangement using labour-based methods during trailer loading.

For sealed road construction without diversion roads, it may be necessary to start construction of the base away from the borrow sources, back towards the sources, to minimise damage caused by haul vehicles on the newly constructed base.
4.5 Borrow Pit Material Extraction Using Mechanised Plant Methods

4.5.1 General

The economic extraction and production of borrow pit materials for construction purposes using plant depends on the correct selection of mechanised plant for the project and the careful programming of the works. Mechanised plant used for borrow pit excavation may only be suitable for larger projects or when the haul distance is long. The use of mechanised equipment has a production output much greater than when using L-B methods. However, the environmental impact may also be greater.

4.5.2 Excavation Planning and Plant Selection

The types of plant suitable for heavy, medium and light excavation work in gravel and rock are summarised in Table D.4.1. Factors to consider when planning material excavation and use of mechanised plant include:

- Choose a method of extraction that produces the best quality “as dug” materials (i.e. does not generate a large proportion of oversize material that will be spoiled).
- If borrow pit materials are variable or inter-bedded, use plant and excavation methods that can produce a suitably mixed aggregate.
- Select plant that achieves an acceptable rate of material production; alternatively, programme stockpiling ahead of aggregate supply.
- When possible, use plant that can both excavate and load the aggregate.
- If aggregates are likely to deteriorate/segregate in the stockpile, try and combine excavation and supply activities.
- Carefully programme plant and borrow pit activities that require more than one type of plant (i.e. the dozer to strip overburden and the excavator to dig gravel for loading or stockpiling).
- Programme activities so that the plant does not stand idle in a borrow pit.
- In order to ensure satisfactory plant utilisation/output in the borrow pit the following should be considered:
  - All plant should be in a sound mechanical condition and well maintained.
  - All operators should be adequately trained and experienced.
All items of plant should be operated within the normal limits of their capacity. The plant on site should not be overworked.

There must be adequate supervision in the borrow pits to ensure that appropriate extraction methods and procedures are being followed by all concerned.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type of Excavation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill and Blast</td>
<td>✓</td>
<td>Pneumatic. Top-hammer rotary percussive methods can be used for drilling small diameter blast holes.</td>
</tr>
<tr>
<td>Bulldozer Ripping</td>
<td>✓</td>
<td>Single tine used for very heavy ripping (poorly fractured rock) and multiple tines for medium ripping (fractured or weak rock). The correct selection of tine, ripper arrangement and method of use will all affect the efficiency of excavation and the characteristics of the excavated material.</td>
</tr>
<tr>
<td>Bulldozer</td>
<td>✓</td>
<td>Blade excavation of fractured rock may reduce oversize associated with ripping (when feasible). However, when ripping is not required then use of plant that can excavate and load is desirable.</td>
</tr>
<tr>
<td>Grader</td>
<td>✓</td>
<td>Typically not efficient for excavation, but may be required for mixing material in the pit or on the road.</td>
</tr>
<tr>
<td>Excavator</td>
<td>✓</td>
<td>Versatile method of excavation and loading. Large selection of plant available. Face excavation may allow effective mixing of beds.</td>
</tr>
<tr>
<td>Tractor Backhoe</td>
<td>✓</td>
<td>Rate of production may be limited, but might be adequate particularly if material is stockpiled.</td>
</tr>
<tr>
<td>Drag-line Excavator</td>
<td>✓</td>
<td>May be required for excavating gravel from below the water table</td>
</tr>
<tr>
<td>Wheel Loader</td>
<td>✓</td>
<td>Ideal for excavating and loading loose gravel (after pit preparation)</td>
</tr>
<tr>
<td>Crawler Loader</td>
<td>✓</td>
<td>Usually not ideal due to lack of manoeuvrability on the tracks.</td>
</tr>
<tr>
<td>Scraper</td>
<td>✓</td>
<td>Best suited for large scale earthworks operations. will rarely be economical in low cost road construction.</td>
</tr>
</tbody>
</table>


4.5.3 Efficient use of Plant

The following gives a short description of the plant that is most commonly used for borrow pit extraction:

- Bulldozers.
Excavators.  
Backhoes.  
Graders.  
Front end loaders.

**Bulldozers**: This is the most commonly used plant to extract gravel from borrow pits. However, it is not necessarily always the most suitable plant. With softer materials, the use of a dozer may be an “overkill” as the material tends to get crushed under the tracks. Transport of dozers between the sites is slow and this may incur lost time and extra cost.

Crawler “dozers” are required when poorly fractured rock, weakly compacted rock or cemented gravels are to be extracted. Cutting and pushing downhill invariably improves the operating efficiency of bulldozer excavation, because the mass of the machine assists the process. Bulldozers may be used to push material up to about 150m into a stockpile. However, their use is unlikely to be efficient for moving material over distances greater than about 150m.

Bulldozers may be fitted with one or more ripper tines (shanks). The correct selection of tine, ripper arrangement and method of use affects the efficiency of excavation and the characteristics of the material being excavated. There are two basic types of ripper and several types of ripper tine (shank) and tip. They are:

- Radial ripper.
- Parallelogram ripper.

Refinements of the above two types of ripper are the adjustable radial and the adjustable parallelogram. These rippers have hydraulic controls to enable the operator to vary the tip angle while ripping. In very hard ground a single tine parallelogram ripper is usually the most effective arrangement.

Ripper tines and tips consist of two basic types, the straight and the curved. Straight tines provide the lifting action needed in tight, laminated materials plus the ripping ability in thick or slab type material. Curved tines work well in less dense material and require less ripping distance.

Efficient ripping for borrow pits: In order to maximise efficiency in ripping to produce road construction material, the following points should be considered as illustrated in Figure D.4.7.

- Ripping should proceed downhill as far as possible to obtain the benefit from the weight of the machine.
- Care should be taken to arrange for ripping to make optimum use of natural fracture orientation in the material. Ripping will be most effective when carried out in the direction of inclined fracture planes (or bedding) as this tends to pull the tine into the ground.

![Figure D.4.7: Poor and Optimum arrangement for effective ripping](image)

If the materials contain vertical laminations that run parallel to the cut, it is sometimes necessary to rip across the cut to obtain proper material break-up; ripping along the laminations may only produce deep channels in the material.

Ripping as deep as possible will loosen the maximum amount of material, but ripping to partial depth may reduce the proportion of oversize material produced.

Never remove all the ripped material before ripping deeper. Always leave a layer of at least 100mm to 150mm of ripped material to provide better traction. This also reduces track wear and minimises crushing of the surface materials.

**Excavators:** Excavators are versatile digging machines that are produced in a great variety of configurations. All excavators have boom-arm hydraulically operated digger buckets and are turntable-mounted on either a crawler track or with a wheeled chassis. The turntable can be horizontally rotated on the fixed chassis by a full circle. The reach of the boom arm for digging operations, either upwards or downwards, may be up to 6m.

In order to maximise efficiency in excavator digging and loading operations the following guidelines apply:

- Greatest efficiency is achieved if borrow pit materials can be loaded for haulage as they are excavated. The excavator and trucks should be arranged so that the operating cycle is minimised. Ensure that there are sufficient trucks so that the excavator does not have to wait for loading. However, in highly variable materials this step often eliminates stockpiling, which can be a good homogenising process. It also removes the opportunity to test the material before placing it on the road.

- The size of the bucket should be appropriate for the particular conditions on site, such as the quantity and type of material to be loaded and the trucks used for haulage.

- The rake or angle of the bucket should be adjusted to suit the particular material. For easy digging and low cuts, maximum rake should be used. For harder digging and higher faces a smaller rake should be adopted.

**Backhoes:** A backhoe comprises a bucket or shovel mounted on a hydraulic boom and attached to the rear of a crawler or rubber-tyred tractor. Backhoes are well suited to excavating relatively loose material from above or below the level of its wheels into trucks. The reach for digging and loading is controlled by the length of the boom, but is usually up to 4m.

Backhoes are easy to move between material sources and can also be useful for carrying out trial pit investigations during prospecting for borrow pit extension and or material prospecting.

**Graders:** In borrow pits graders are normally only used for the following:

- Topsoil and loose overburden stripping
- Mixing excavated materials (by windrowing)
- Maintenance of haulage and access roads
- Reinstatement of topsoil.

For mixing purposes, the blade is leaned forward at the top edge to enable the material to flow and rise freely.

Graders are frequently fitted with tines to allow hard road surfaces to be ripped to shallow depth, but graders are not generally efficient for borrow pit excavation work. Use of the ripping tines to aid extraction of borrow pit materials is liable to overwork the machine and also result in serious tyre wear.

**Front end loaders:** A front end loader is a bucket mounted on the front of a rubber-tyred or crawler tractor. Loaders are often used to excavate loose materials, such as river gravel. Tyres are likely to suffer excessive wear when excavating hard materials. Their main use in borrow pits is usually to load from the stockpiles into trucks.

Loaders may also be used to transport small quantities of material over short distances (up to 200 or 300m). For instance, loaders may be used to transport ripped materials to the grizzly feed of a screen or crusher. For the efficient use of front end loaders, the following guidelines apply:
Loaders are usually not efficient at winning material and loading at the same time. Loading from stockpiles is their normal use.

- Match the size and capacity of the loader to the trucks that they are working together with.
- Material should be stockpiled in such a way that a full bucket may be easily achieved.

### 4.6 Stockpiling

#### 4.6.1 General

It is often necessary to extract and store quantities of material either in the borrow pit or at a location close to the section of the road that is to be constructed or maintained.

Handling and stockpiling of aggregate needs to be undertaken with care to ensure that wastage of material is minimised and particle segregation does not occur. Segregation is the grouping together of similar sized particles that will result in pockets of coarse material with no fines in some places and pockets of fine material in others.

Sometimes there are different types of materials in the borrow pit and one may have the following options to utilise the material:

- Different stockpiles according to properties of the material
- Mixing the two gravel seams in the borrow pit
- Mixing the two material types on the road.

Stockpiling is an efficient way of reducing material variability because of the additional mixing that occurs during creation of the stockpiles and loading into the trucks for hauling.

#### 4.6.2 Segregation

In order to avoid segregation in the borrow pit the following method is recommended (Figure D.4.8).
During transportation of the materials, care should be taken to ensure that the loaded material does not segregate. On longer hauls, more segregation takes place and watering of the material is an option to avoid excessive segregation (and loss of dust during haulage). Segregation may also occur during end tipping of material on the road which may trigger a need for thorough mixing during the processing operations.

### 4.6.3 Mixing

Mechanical blending involves the mixing of two different materials to achieve a quality that exceeds that of either of the two individual materials. It is often the most cost-effective option for increasing the quantity of an acceptable material quality or improving the quality of the final material. However, careful mixing of the various components being blended is essential. The commonly-used procedure shown in Figure D.4.9 is seldom effective and is not recommended for a borrow pit.

**Figure D.4.9: Not recommended method for blending in borrow pit**


When materials are mixed in the borrow pit the proportions will normally be less accurate than when mixed on the road. When mixing on the road materials are loaded from two different stockpiles in the borrow pit as shown in Figure D.4.10.

**Figure D.4.10: Loading from two separate stockpiles in the borrow pit**

When materials are mixed on the road it is important that the correct quantity of the dominant material (i.e. the largest proportion) is evenly spread on the road and lightly compacted before spreading the subordinate material in the correct quantity on top. The two materials must then be carefully blended on the road before final compaction.

4.7 Material Processing and Control

4.7.1 General

There are various methods of improving the quality of “as dug” gravel road construction materials. Common materials defects include the presence of oversize particles and too much or too little fine grained “binder” material. Various procedures and treatments can be used to improve the engineering characteristics of “as dug” materials. The selection of the appropriate treatment will be strongly influenced by the severity of the problem and usually must consider economic issues.

Typically, it is cost effective to use the best-quality materials that are available. Good performance of the material on the road will result in significant cost savings that will nearly always outweigh the expense associated with processing. Unfortunately, some of the benefits are not easy to quantify and to take account of in a cost/benefit analysis.

4.7.2 Dealing with Oversize Material

Manual removal or breakage: The maximum aggregate size in a gravel wearing course should be no greater than half the layer thickness. This ensures that all large particles can be bound tightly in an interlocking structure as shown in Figure D.4.11. The presence of oversize material in unpaved roads results in rough roads that are difficult to maintain.

![Figure D.4.11: Maximum aggregate size to be no greater than half the layer thickness](image)

The various methods of dealing with oversize material either in the borrow pit or on the road (during material placement) are shown in Figure D.4.12. Each method is briefly reviewed below.
Where the proportion of oversize is material relatively small it may be treated effectively by manual removal or crushing either at the borrow pit or on the road. Plate D.4.5 shows a mobile vibrating screen used to remove oversize in the borrow pit. It may be beneficial to crush the oversize material and add it to the stockpile to optimise material usage and minimise wastage and spoil.
Plate D.4.5: Mobile Vibrating Screen Used to Remove Oversize Aggregate in the Borrow Pit.

Field experience has indicated that manual treatment of oversize (removal or breaking) may not be successful where the proportion exceeds about 20%, even when large teams of labourers are employed for this purpose. However, the upper limit will depend on the diligence of the labourers, the way they are supervised and the ease with which the particles can be broken down. In the case of weaker materials, any large particles that are not manually removed will be broken down during compaction.

The removal of hard oversize fragments at the construction site leads to considerable wastage and potential obstruction of side drains. It is therefore recommended that whenever possible, oversize material is treated or removed in the borrow pit. Special plant is required to break down the large particles during construction, for example a mobile hammer mill or grid roller may be used for this purpose during pavement laying.

Screening: Screening to remove oversize particles at the borrow pit can be a low cost solution when the proportion of oversize is in the range 15% to 40%. The screen comprises a frame supporting a mesh or slotted panel with an aperture designed to prevent large particles passing through. The oversize material removed by screening is rejected unless crushing plant is available.

Various methods of screening exist and each method is appropriate for use in different situations. Screening to remove oversize aggregates is an important and cost effective material processing technique. Figure D.4.13 illustrates the various types of simple screens.
Light Portable Grizzly That May be Used on the Ground or Placed on a Truck Body Before Loading

Skid Mounted Grizzly. Truck Backs Under it to be Loaded.

Slope = 25º - 60º

Slope 30-45º

Grizzly screen

Timber pole

Feeda truck or forms stockpile for loading

50 to 75 mm

65 to 90 mm

30 mm steel reinforcement bars

Example of simple fixed grizzly

Figure D.4.13: Examples of simple fixed grizzly screen


Crushing: Crushing of oversize aggregate is normally reserved for surfacing and concrete works and not used for graveling or pavement layer construction as it is expensive. Even primary crushing of rippable materials with a small mobile crushing machine may lead to aggregates that cost more than three times as much as natural occurring materials. As a result, production of high cost crushed gravel road surfacing materials may only be viable. Factors that should be considered before committing to the production of crushed aggregates include:

- Cost of hauling natural gravels from outside the area compared with the cost of producing crushed local materials.
- Relative quality of crushed stone compared with alternatives.
- Alternative of using a mobile hammer mill rather than conventional crushing equipment.
- Viability of stabilising local fine grained materials with, for example, lime or cement.
- Influence of climate and topography on the viability of using a particular material.
- Possible environmental benefits of the crushing of oversize.
- Use of mobile crushers, which are very effective and have a high mobility.
In steep hill country with high rainfall, well graded angular gravels stand up well to scour and traffic abrasion due to their good mechanical interlock. Hence, the use of crushed river gravel as opposed to rounded gravel may be justifiable for a gravel wearing course due to the resulting reduction in maintenance costs. However, both river gravel and crushed gravel tend to lack plastic fines and may be unsuitable for use as wearing course gravel.

When natural gravel is not easily accessible and the only option is to produce crushed aggregate, consideration should then be given to constructing a bituminous surfacing. This may be a more economical solution in the long term (life cycle costing), and allow for conservation of local materials.

Stabilizing gravel either with lime or cement can also be used to produce a suitable wearing course gravel, and may be cheaper than providing a bituminous surface. However, chemical stabilization is not commonly used in Ethiopia.

### 4.8 Excavation and Testing

#### 4.8.1 General

The quality of materials produced and the quality of the road constructed are dependent, to a large extent, upon the following:

- Careful selection of suitable material and avoidance of contamination with overburden or underlying unsuitable deposits.
- Continuous monitoring and supervision of any processing activities.
- Proper stockpiling methods.

A borrow pit supervisor should be appointed to control all extraction and processing operations. This is particularly important if the materials are variable or if the plant operators are changed frequently.

#### 4.8.2 Sampling and Testing

Prior to any gravelling/construction operations, laboratory testing should be carried out to determine:

- The characteristics of the excavated materials in all borrow pits that may be required to supply the section of road to be re-gravelled or constructed.
- Appropriate materials processing methods (if required).
- The expected characteristics and uniformity of the processed materials.

The type of tests and frequency are shown in Table D.4.2.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Frequency (Every)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atterberg Limits (PL, LL, LS)</td>
<td>2,000m³</td>
<td>Increase frequency if variable or marginal suitability</td>
</tr>
<tr>
<td>Grading Analyses</td>
<td>2,000m³</td>
<td>Increase frequency if variable or marginal suitability</td>
</tr>
<tr>
<td>Compaction and CBR</td>
<td>4,000 – 6,000m³</td>
<td>Dependent on uniformity of material</td>
</tr>
<tr>
<td>Particle Strength (AIV &amp; ACV)</td>
<td>4,000 – 6,000m³</td>
<td>Dependent on uniformity of material</td>
</tr>
</tbody>
</table>
4.9 Materials Management

4.9.1 General

Material supply strategies are often determined by field supervisors from undocumented knowledge (local experience). This may result in the exploitation of a diminishing number of local traditional natural gravel pits. In many areas, these existing material sources are rapidly becoming exhausted. The need for material prospecting, adequate borrow pit evaluations and material processing is very often not fully recognised. As a result, the best road construction materials are not always used and expensive over-haul is required due to perceived construction material deficiencies.

Some countries have established a national or regional borrow pit/quarry inventory that assembles and stores data concerning the location and engineering properties of road building material resources.

4.9.2 Record keeping

Records concerning the actual use of material need to be prepared following completion of a project. Observations concerning in-service performance of materials should be documented so that the quality rating of the material may be assessed. The following data should be recorded:

- The actual source of materials used to supply each section of road.
- The characteristics of the materials used to supply each road section.
- The cost per m$^3$ of material at the road side and the haulage cost per tonne-km.
- An estimate of the quantity of exploitable material remaining in each source after completion of construction.

4.9.3 Materials Database

The purpose of a materials database is to assemble existing records and ensure that valuable data are preserved, centralised and made readily available to all interested parties for future use. Paper records are bulky and are easily misfiled, lost or destroyed. The development of a computerised database is an ideal and cost effective solution to the problem of preserving existing borrow pit records and enabling all new information to be linked with historical data for analysis and evaluation.

In its simplest form a computerised materials resource database can be established using a spread sheet programme such as “Excel”. This is encouraged as an intermediate measure, for gathering information on a road by road basis prior to the establishment of a more powerful and appropriate database management system.

Figure D.4.14 shows an example of a Design Materials Resource Database.
EXISTING BORROW PIT/QUARRY DATA
- Local Data
  - Road Chainage/Offset
  - Map Data
  - Geological Data
  - Previous Use

LABORATORY TEST RESULTS
- Atterberg Limits
- Grading
- CBR
- Particle Strength

NEW FIELDS DATA FROM INVENTORY STUDIES
- Atterberg Limits
- Grading
- CBR
- Particle Strength

Figure D.4.14: Example of a Design Materials Resource Database


4.10 Bibliography


PART D: CONSTRUCTION OF LOW VOLUME ROADS
5.1 Introduction

5.1.1 Background

Small drainage and watercourse crossing structures, typically up to 10 metres in length, together with retaining structures, are an integral and essential component of the LVR network. Their importance is highlighted by the fact that when roads become impassable it is usually where they cross a watercourse. Although the length of these structures forms only a very small fraction of the total road length, it is essential that they are well constructed and durable, as their design life is generally much longer than that of the road pavement structure.

5.1.2 Purpose and Scope

The purpose of this chapter is to provide guidance on the actual construction of a range of small structures, from the preparatory work, through the various site activities to the completion of site works. It includes aspects of programming, construction, supervision and monitoring of works, whether the structure is built by a contractor, a road authority work force or a work group set up specifically for the task. The following typical structures are addressed:

- Drifts
- Simple culverts
- Vented fords
- Large bore culverts
- Small bridges.

The focus in the chapter is on the use of local labour that can be utilised for a range of tasks in the construction of small structures including:

- Timber growing for preparation of formwork
- Quarrying for dressed and crushed stone
- Fired clay brick production
- Masonry and brickwork in structures
- Retaining walls, ditch linings and culverts
- Collection and preparation of river gravel for structural fill
- Construction of components such as gabion baskets.

Not all issues dealt with in this chapter will arise during the construction of a structure, especially a small one. Checklists are provided and where appropriate the text refers to other documents for further reference and information. Other aspects of the provision of small structures, such as their planning, design, materials utilisation and maintenance are dealt with in Part E – Explanatory Notes and Design Standards for Small Structures.

5.2 Preparatory Work

5.2.1 General

Preparatory work of a varying nature, depending on the size and complexity of the small structure, is always required in terms of planning and mobilising all the resources required before the site work can begin. The following section describes the typical preparatory work involved in undertaking the construction of small structures.
Culverts

The limited resources and costs involved, and usually standardised nature of culverts, will often mean that the amount of preparatory work may be limited. However, some aspects of the preparatory work in the following sections for larger structures may be relevant.

Bridges, drifts and large culverts

The size, resources and funding required for larger structures will usually necessitate considerable preparatory work before the actual site works can begin.

It is assumed that structural survey and design will be carried out in accordance with the guidelines elsewhere in this Manual and with any locally established standards. It is also assumed that cost estimates, detailed drawings and bills of quantities will be prepared for the works.

If the work is contracted, appropriate contract documentation should be prepared in accordance with local standards and procedures. When a contractor will be appointed, local contractor classification, tendering, selection and award procedures should also be complied with. Arrangements should be in place for resolution of any disputes that may arise through the contract.

Arrangements for management, supervision, testing, approval and audit of the works should be established. All of these issues should be clearly documented and known to the parties involved in the construction process. If there is any doubt about the responsibilities, adequacy or arrangements for any of these issues, then professional advice should be sought to rectify the situation.

The construction of any structure for a public road involves risks and responsibilities which must be appreciated and should be assigned to the most appropriate parties.

Inadequate attention to some aspects of the work can result in a structure not fit for its purpose, waste of resources, or even serious damage or eventual loss of the structure.

Structure costing

It will usually be necessary to prepare a detailed costing of the structure, either for internal budgeting and funding purposes, or for contracting out the work. This will normally be achieved through preparation of a Bill of Quantities which can be priced by the Employer/promoter and by a contractor.

Table D.5.1 below (checklist for preparing a construction programme) may be used as the basis for developing a Bill of Quantities. Bills of Quantities in a national standardised format, with activity related items, will assist Employers and contractors in pricing works and assessing value for money.
Table D.5.1: Checklist of cost components for detailed costing of a structure

<table>
<thead>
<tr>
<th>Direct costs</th>
<th>Overheads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Supervisory and technical staff</td>
</tr>
<tr>
<td>Unskilled labour</td>
<td>Survey and setting out</td>
</tr>
<tr>
<td>Skilled labour</td>
<td>Main office, workshop costs</td>
</tr>
<tr>
<td>Equipment purchase</td>
<td>Supervision vehicles</td>
</tr>
<tr>
<td>Equipment operating costs</td>
<td>Transport to and from site</td>
</tr>
<tr>
<td>Equipment hire</td>
<td>Site camp and stores</td>
</tr>
<tr>
<td>Tools</td>
<td>Security measures and facilities</td>
</tr>
<tr>
<td>Temporary works</td>
<td>Communications (telephone, mail)</td>
</tr>
<tr>
<td>Services hired in</td>
<td>Insurances, bonds</td>
</tr>
<tr>
<td></td>
<td>Banking and other charges</td>
</tr>
<tr>
<td></td>
<td>Training</td>
</tr>
<tr>
<td></td>
<td>Protective clothing and safety</td>
</tr>
<tr>
<td></td>
<td>Traffic control/signs</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
</tr>
<tr>
<td></td>
<td>Welfare, pensions, social costs</td>
</tr>
</tbody>
</table>

Contingency/risks
(e.g. unforeseen additional work, late payment, delays)

Profit
The contractor should normally be expecting to make in the order of 10% profit on his work, after covering ALL other costs. However, this percentage will be affected by local market conditions, competition and perceived risks

5.3 Planning of Site Works

Good planning of the site works is essential, particularly as many sites of structures are remote from organisational bases, sources of some materials and skilled manpower, and communications can be difficult. Poor planning can lead to serious delays and increased costs.

Checklist for planning site works

1) List all construction and support activities and prepare a construction programme (using a bar chart) based on the Bill of Quantities, expected productivities and logical sequence of activities.

2) Prepare resource plan and cash flow requirements.

3) Plan in recognition of the seasonal watercourse conditions and expected flood conditions. Plan adequate arrangements for damming, diverting or control of water.

4) Ensure compliance with all laws and regulations regarding recruitment, labour, (permanent/casual) employment, gender and disadvantaged groups opportunities, payment, security for payment to labourers, conditions of work.

5) Plan compliance with environmental requirements, particularly with regard to materials exploitation, replacement of felled timber, watercourse pollution and waste disposal.

6) Inspect site. Check site survey. Review designs and documentation for compatibility and with the actual site conditions. Clarify any inconsistencies
7) Plan and arrange land (acquisition/lease/use) and setting up site, camp and stores. Cement to be stored in a secure, dry and well ventilated place.

8) Ensure adequate site access arrangements, particularly if the structure is being built in advance of the road works.

9) Plan water supply, other services requirements and sanitation arrangements.

10) Plan site security (particularly against theft of handtools & materials; cement is particularly susceptible)

11) Ensure availability and accessibility of funds and contingency finance.

12) Ensure payment arrangements for (sub) contractors, and suppliers are in place.

13) Plan staffing, identify skills locally available or required to be imported to the site area, accommodation, logistics, transport to site, recruitment and training of workforce.

14) Arrange for supplies of materials to site.

15) Plan safe and adequate temporary arrangements for traffic and pedestrians where replacing an existing structure or facility.

16) Plan actual/contingency arrangements for de-watering and shoring of foundations.

17) Plan for concrete works with respect to weather, since both low, < 16°C and high > 32°C temperatures are not suitable for concrete works and curing.

**Checklist for preparing a construction programme**

The construction programme will involve some or all of the following activities:

- Clear trees, bush, and scrub, dispose of safely.
- Primary setting out and establishment of reference points.
- Remove topsoil, stockpile for re-use or disposal.
- Dig catchwater drains to protect site, and any side drains.
- Remove/bury nearby/break surface boulders (see below).
- Detailed setting out and establishment of levels and profile boards.
- Excavate foundations and any cut-off trenches.
- Temporary shoring, watercourse diversions, piling, cofferdams, de-watering/drainage.
- Drill and blast any solid rock.
- Replace “soft spots” in ground, clean and prepare foundation area.
- Construct foundations.
- Construct temporary works for superstructure.
- Erect abutments, piers, deck, wingwalls.
- Fix deck timbers and running boards where applicable.
- Erect kerbs, parapets barriers and safety structures.
- Install drainage layers and features against structure.
- Backfill against and adjacent to the structure, compacting each layer according to the specifications. Particular attention to be paid to all compaction within 5 metres of the structure.
- Construct road pavement/surfacing and markings, road shoulders.
- Construct road drainage features.
- Construct gabions and erosion control measures.
- Lay topsoil/turves and planting.
- Install traffic warning signs if necessary.
- Clear site, remove surplus materials and leave tidy.

The following productivity standards may be useful in estimating the resources and time required for each activity.

**Table D.5.2: Recommended productivity standards**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site clearance (bush clearing, tree felling, etc.)</td>
<td>100 – 350m² / worker day</td>
</tr>
<tr>
<td>Removal of tree stumps</td>
<td>1 / worker day</td>
</tr>
<tr>
<td>Soil excavation (and stockpiling alongside)</td>
<td>2 - 5m³ / worker day</td>
</tr>
<tr>
<td>Rock (fractured) excavation (solid rock will require drilling and blasting/splitting)</td>
<td>0.8m³ / worker day</td>
</tr>
<tr>
<td>Loading</td>
<td>8.5m³ / worker day</td>
</tr>
<tr>
<td>Haulage by wheelbarrow</td>
<td></td>
</tr>
<tr>
<td>0 - 20m</td>
<td>8.5m³ / worker day</td>
</tr>
<tr>
<td>20 - 40m</td>
<td>7.0m³ / worker day</td>
</tr>
<tr>
<td>40 - 60m</td>
<td>6.5m³ / worker day</td>
</tr>
<tr>
<td>60 - 80m</td>
<td>5.5m³ / worker day</td>
</tr>
<tr>
<td>80 - 100m</td>
<td>5.0m³ / worker day</td>
</tr>
<tr>
<td>100 - 150m</td>
<td>4.5m³ / worker day</td>
</tr>
<tr>
<td>Install only 600 or 900mm diameter culvert lines (including excavation and backfill)</td>
<td>0.8 - 1.2 linear metre per worker day</td>
</tr>
<tr>
<td>Mix and place concrete</td>
<td>1.0m³ / worker day</td>
</tr>
<tr>
<td>Erect masonry work</td>
<td>1.0m³ / worker day</td>
</tr>
</tbody>
</table>

Productivity depends on a number of factors, including worker nutrition, fitness, experience and motivation, site organisation, tool quality and condition, and climate. Individual small structures sites do not allow much scope for improvement of performance with experience due to the short time spans involved for individual activities. New workers under training will also be less productive. Poor quality and condition of hand tools can affect productivity by up to 25%.

The following checklist includes the range of skills which may be required on a structures site. The more specialist skills may need to be imported into the project area. Some skills may be taught through on-the-job training. This will involve costs and loss of productivity. Workers not from the area of the structure site may require temporary accommodation and incur costs relating to travel and allowances.

Potential skills requirements for a structures work site:
1) Surveying and setting out
2) Drilling and blasting
3) Piling/cofferdam
4) Carpentry
5) Masonry
6) Temporary works
7) Steel bending and fixing
8) Concreting
9) Equipment maintenance

The more specialist skills may need to be imported into the project area. Some skills may be taught through on-the-job training. This will involve costs and loss of productivity. Workers not from the area of the structure site may require temporary accommodation and incur costs relating to travel and allowances. Table D.5.3 provides a checklist of hand tools and site equipment that could be required to execute the works.

**Table D.5.3: Checklist of hand tools and site equipment**

<table>
<thead>
<tr>
<th>Handtools</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranging rods</td>
<td>Culvert moulds</td>
</tr>
<tr>
<td>Water tube level</td>
<td>Plate compactor</td>
</tr>
<tr>
<td>Profile boards &amp; travellers</td>
<td>Pedestrian vibrating roller</td>
</tr>
<tr>
<td>Tape measures</td>
<td>Water bowser</td>
</tr>
<tr>
<td>Tree felling saws</td>
<td>Water pump</td>
</tr>
<tr>
<td>Brush hooks</td>
<td>Concrete mixer</td>
</tr>
<tr>
<td>Pick axes</td>
<td>Bathing boxes</td>
</tr>
<tr>
<td>Hoes</td>
<td>Vibrating boxes</td>
</tr>
<tr>
<td>Shovels</td>
<td>Piling equipment</td>
</tr>
<tr>
<td>Wheelbarrows</td>
<td>Hydraulic excavator</td>
</tr>
<tr>
<td>Earth ‘stretcher’</td>
<td>Compressor and air tools</td>
</tr>
<tr>
<td>Hand drills</td>
<td>Craneage</td>
</tr>
<tr>
<td>Masons trowels</td>
<td>Aggregate crushing eqp.</td>
</tr>
<tr>
<td>Spirit levels</td>
<td>Aggregate screens</td>
</tr>
<tr>
<td>Lifting tackle</td>
<td>Supply and site transport</td>
</tr>
<tr>
<td>Mortar pans</td>
<td>Formwork/moulds</td>
</tr>
<tr>
<td>Water containers/drums</td>
<td>Traffic signs and barriers</td>
</tr>
<tr>
<td>Pointing tool</td>
<td>Safety helmets and equipment</td>
</tr>
<tr>
<td>Rakes/spreaders</td>
<td></td>
</tr>
<tr>
<td>Sandbags for water control</td>
<td></td>
</tr>
<tr>
<td>equipment</td>
<td></td>
</tr>
<tr>
<td>Concrete cube moulds and curing tank</td>
<td></td>
</tr>
</tbody>
</table>
Works must be carried out according to the specifications and drawings. Quality control arrangements should ensure compliance in accordance with specifications. The control of cement requires particular attention; this is a valuable commodity and it is difficult to detect reduced inputs until after construction. Batching should be carefully controlled and the making and curing of cubes should be closely supervised. It will normally be necessary to arrange for cubes to be crushed at a reliable laboratory remote from the site. The laboratory must be consulted to ensure that the testing can be carried out according to the standards specified. It is advisable to visit the laboratory to assess the standard of service provided.

The slump test (see Part E) should be used to control concrete workability and check the water: cement ratio. Treatment of permanent timbers should be closely supervised or guaranteed.

5.4.2 Simple Setting Out Techniques

The following setting out techniques are illustrated in the respective figures:

- Levelling with a water hose (Figure D.5.1).
- Setting out a right angle (Figure D.5.2).
- Use of batter boards (Figure D.5.3).

![Figure D.5.1: Levelling with a water hose](image1)

![Figure D.5.2: Setting out a right angle](image2)

![Figure D.5.3: Use of batter boards](image3)

5.4.3 Setting out culverts and drifts

The setting out should be according to the design. The principal setting out requirements are the establishment of the centreline of the barrels (for culverts), the extent of the structure (ends and corners) and the inlet/upstream and outlet/downstream invert/slab levels (See Figure D.5.4).
Figure D.5.4: Culvert arrangement A (flat outfall)

Wooden pegs should be used to establish key positions and levels. For minor culverts and drifts where no levels are provided, the invert of the culvert or drift slab should follow the level of the existing watercourse as closely as possible. The following guidance will minimise the possibility of silting or erosion of a culvert due to installation at an incorrect level.

Figure D.5.5: Culvert arrangement B (intermediate outfall)

Figure D.5.6: Culvert arrangement C (steep fall)
If the culvert site is flat, check the watercourse gradient for 20 metres downstream from the location of the culvert outlet. Use boning rods and Abney Level, or line and level, for this purpose. If the gradient is less than 5% (1 metre fall in a 20 metres), then construct the culvert in Arrangement A with the culvert invert as close to existing ground/water course level as possible. Also construct Arrangement A, if the height of embankment fill (measured from ground level to edge of road running surface) at culvert site is at least 1.1 metres. Otherwise proceed with the following steps to install Arrangement B or C.

**SETTING OUT OF 600 mm Ø CULVERT - ARRANGEMENT B OR C**

MAIN DIMENSIONS ARE FOR ROADWAY WIDTH OF 5.5 m. (DIMENSIONS IN BRACKETS ARE FOR CROSS SECTION WITH ROADWAY WIDTH OF ‘w’ METRES)

<table>
<thead>
<tr>
<th>PROCEDURE STEP BY STEP</th>
<th>EXAMPLE / EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEP 1</strong></td>
<td></td>
</tr>
<tr>
<td>Fix the centreline of the culvert. Establish two pegs (PEG A and PEG B) at the location of both roadway edges and at proposed finished roadway level. Make sure that pegs are on the same level (use line and level or Abney level).</td>
<td></td>
</tr>
</tbody>
</table>

**STEP 2**

Measure distance between PEG A and PEG B (5.50 m, or ‘w’ for other cross sections).

**STEP 3**

Calculate the minimum depth (d) to be excavated from the proposed road level to underside of culvert pipe at the inlet to ensure adequate cover (at PEG A).

| OUTSIDE DIAMETER OF CULVERT Ø 600 mm | 0.72 m |
| OVERALL (MINIMUM COVER)              | + 0.45 m |
| TOTAL DEPTH (d)                      | 1.17 m  |

**STEP 4**

Calculate the differences in culvert level between PEG A and PEG B with the chosen culvert gradient (4% is normally selected as the ideal gradient).

| GRADIENT: DIFFERENCE IN LEVEL: | 4% |
| 4% x 5.50 m                    | 0.22 m |
| 100%                           | (FOR ROAD WIDTH w, = 0.04 w) |

**STEP 5**

Calculate the depth to be excavated from proposed road level to the underside of culvert pipe at the outlet (at PEG B).

| ROAD WIDTH (m) | 5.50 (w) |
| INLET DEPTH    | 1.17 m 1.17 m |
| DIFFERENCE IN LEVEL | + 0.22 m 0.04 w |
| DEPTH AT OUTLET | 1.39 m y’ = (1.17 + 0.04 w) |

*Figure D.5.7: Procedure for setting out a culvert*
**Figure D.5.7 (continued)**

**PART D: CONSTRUCTION OF LOW VOLUME ROADS**

**STEP 6**

Raise level PEG A by the same measurement that you have calculated under step 4 by establishing a second peg (difference in level).

**SECOND PEG**

![Diagram of pegs](image)

**STEP 7**

Find the end of the outlet-drain by using boning rods and a stick or rod of length 1.39 m (‘y’ for other cross section road widths) (see sketch below): Walk S and rod away from B until the tops of A, B and S are in line.

![Diagram of outlet drain](image)

If the length of the outlet drain SB is less than 20 metres then establish the drain outlet peg at ground level at point S. Construct the culvert in Arrangement C. (i.e. the road alignment will not need to be raised). Establish the excavation level for the underside of the culvert pipe by measuring vertically down 1.39 m (‘y’ from peg B and the top of the second peg at point A. The excavation pegs should be 5.50m apart (‘w’ for other cross section road width).

**STEP 8**

If the drain outlet cannot be found within 20 metres of the culvert outlet then place a peg at ground level at point S, 20 metres away from the culvert outlet point B. Adjust the boning rod at point S until the tops of the 3 boning rods A, B and S are in line. Measure the distance from the bottom of the boning rod S to the ground level: z metres. The road level at A and B will have to be raised by 1.39 - z metres (‘y’ - z for other cross sections). To fix the culvert inlet excavation level, measure (1.39 - z) metres (‘y’ - z for other cross sections) down from the top of the second peg at point A. To fix the culvert outlet excavation level, measure (1.39 - z) metres (‘y’ - z for other cross sections) down from the peg at point B (these pegs should be 5.50 m apart, or w for other cross sections). This is Arrangement B. The road will need to be raised as indicated above and the vertical alignment raised or a suitable ramp constructed either side of the culvert.

**NOTE:**

1. Where pipes will be bedded on imported material, excavation levels will have to be lowered by the thickness of bedding materials.

2. For 900 mm Ø culverts the dimension in step 3 is increased to 1.05 + 0.70 = 1.75 m. In step 5 the depth at outlet will be 1.97 m (1.75 + 0.04 w).
**Figure D.5.8: (a) and (b): Setting out culvert profiles**

- a = CENTRELINE
- b = TRAVELLOR OR BONING ROD HEIGHT ABOVE INVERT

**Arrangement for Deep Excavation**
Plate D.5.1 shows an example of the setting out of a culvert apron and Plate D.5.2 shows a completed culvert and apron.

Plate D.5.1: Construction of Culvert Inlet Apron with Guide Pegs and Strings

Plate D.5.2: Completed Culvert Inlet Apron

5.4.4 Setting out bridges and large structures

Benchmarks and reference points must be established. They should be well marked and protected. The structure centreline should be set out. Front faces of abutments and centrelines of piers should be set out. All setting out pegs should be located well back from the main working areas and be protected by (preferably brightly painted) timber markers. Two pegs established in a line both sides of a structure will mean that lines can be re-established if one of the pegs is accidentally disturbed. Right angles can be set out using the ‘3:4:5 triangle’ rule (see Figure D.5.9 for simple setting out techniques).
5.4.5 excavations

Foundations (if not on bedrock) are usually the riskiest stage of the construction process. Whatever site surveys were carried out beforehand, the actual foundation conditions cannot be determined until full excavation takes place. Unforeseen problems may occur. If problems are not adequately tackled at the foundation stage, they can be particularly difficult or expensive to rectify later.

Particular care must be taken to ensure the safety of workers. Excavations can collapse, particularly in weak ground or where groundwater seeps into the excavation. Temporary shoring should be used if there is any risk of this.

Figure D.5.9: Basic setting out techniques for structures

Figure D.5.10: Safety issues
Foundations should be kept as dry as feasible and covered as soon as possible. If weak or soft spots are uncovered, then they should be replaced with imported suitable material such as clean gravel or crushed stone.

The bearing capacity of the actual foundation soil can be checked using simple apparatus such as the DCP (Dynamic Cone Penetrometer). The DCP may give a high strength result depending on the type of soil, and for large structures additional investigations are required.

A sump and drainage channels may be necessary to keep the foundation dry. Buckets or a water pump may be used to remove the water from the sump.

If the ground conditions are worse than expected, then the design engineer should be consulted (his or her availability at this critical stage should be ensured during the construction planning process).

If steel reinforcement is incorporated in the foundations it is advisable to use a blinding of lean mix concrete directly on to the trimmed soil to form a clean working platform for arranging and fixing the reinforcement. For other works, compacted gravel or crushed stone can be used for a clean working surface.

If the foundation is on bedrock a good key must be ensured. This can be achieved by chipping the complete rock surface and exposing a rough clean rock face. The drilling of holes and insertion of dowels may be necessary to ensure a good key. Sloping bedrock should be excavated in steps (benched) to provide a stable foundation.

Culverts on busy existing roads may be built in two halves with adequate traffic control and safety measures. Otherwise a diversion must be arranged with adequate warning signs and traffic control measures.

**Supervision check box – Excavation**

- Inspection and approval by engineer/senior technician
- Keep as dry as possible
- Trim to correct levels (and falls for a culvert or drift)
- Ensure firm foundation - remove soft spots and replace with good material
- Culvert excavations should be no wider than necessary to install culvert

**Temporary works**

Scaffolding, shuttering and temporary works should be constructed by skilled artisans to designs prepared taking account of the local materials and loadings expected.
5.4.7 Shuttering/formwork and steel reinforcement for concrete work

Formwork and steel reinforcement (where specified) for concrete should be constructed in accordance with current standards and guidelines. Each stage of the work should be thoroughly checked before concreting is permitted. Checks should include cleanliness, soundness and quality of formwork and to ensure that it will not move or leak under the loading of fresh wet concrete and workers. Details of the formwork for concrete slabs are shown in Figure D.5.12.

Timber chamfer fillets (e.g. 20mm x 20mm timber sawn at 45o) should be fixed on all external 90o angles to ensure smooth finished edges to the concrete.

![Formwork detail](image1)

**Figure D.5.12: Formwork detail**

The steps for formwork for concrete walls are shown in Figure D.5.13.

![Wall formwork detail](image2)

**Figure D.5.13: Wall formwork detail**
Formwork should be coated with mould oil to allow easy striking of formwork after the concrete has set. Linseed oil, old engine oil or other cheaply available oils may be suitable for this. The following is a checklist of precautions that should be taken in the erection of formwork.

**Supervision checkbox – Shuttering/formwork**

- Faces of sawn timber/plywood/sheet steel securely fixed and supported on a timber/bamboo/steel framework
- Erected to the correct levels, alignment and tolerances, strong enough to support the weight of wet concrete and operations without distorting/settling
- No gaps or holes in faces for wet concrete to escape
- Oiled to assist with striking/removal
- Weep holes/scuppers/fixings/joints etc. in correct locations
- Clean with all debris removed prior to concreting

### 5.4.8 Steel Reinforcement

The checklist below includes precautionary measures for steel reinforcement. Details of spacers for the reinforcement given in Figure D.5.14.

**Supervision check box - Reinforcement steel fixing**

- Ensure steel bar grades, sizes, numbers, spacing and shapes according to design drawings
- Ensure minimum cover to steel from soffits, walls and top surfaces (50 - 100mm)
- Ensure minimum overlaps between bars
- Ensure steel and shuttering is clean with no loose rust or contamination (slight corrosion assists bonding of concrete to reinforcement)
- Reinforcement should be cut to the specified lengths, bent cold and provided with the minimum laps specified. Overlapping and lapped bars should be bound tightly with binding wire at ALL points.

![Figure D.5.14: Reinforcement spacers](image)

The spacers supporting reinforcement should be securely fixed so that they will not move during concreting. Spacers can be made from mortar cubes with binding wire cast in. The amount of cover to the reinforcement (usually 50 mm in moderate conditions to 100 mm in extreme exposure conditions) is important for reinforced concrete durability.
5.4.9 Concrete work

The requirements of the specifications and guidelines elsewhere in this Manual should be followed. Water for concrete should be clean and free from contaminants such as salt, silt etc. Water with solids in suspension should be allowed to stand in barrels so that the sediments settle out. Water that is drinkable is usually fit for concrete works. Concreting is usually not permitted at ambient (shade) air temperatures below 3°C. Hot weather concreting must also be avoided as the uncured concrete will dry out too quickly. Usually concreting is not permitted in ambient (shade) temperatures above 32°C. In ambient temperatures well below this figure structures and aggregates in direct sunlight can rise to unacceptable temperatures. Shading and timing of concreting during cooler hours can be important countermeasures.

Concrete strength and durability depends particularly on the correct mix proportions as specified elsewhere in this Manual. Batching boxes or weighing methods should be used to ensure correct quantities. Volume batching should be carried out using batching or gauge boxes of volume equivalent to one 50kg bag of cement. A box of internal dimensions 400 x 300 x 300mm will have the correct unit volume of 0.036m³.

Hand or machine mixing of concrete is acceptable. Either method must ensure complete mixing of the components. For mechanical mixing the order of adding the materials to the drum should be: coarse aggregate, cement, fine aggregate, water. Water should be added at the specified water:cement ratio. Less water will not allow the materials to be properly mixed and placed. Too much water will lead to segregation and a weak concrete. If the aggregates are already wet, then adjustment of the quantity of added water will be necessary. The slump test should be used to check the water:cement ratio and workability of the wet concrete.
Wet concrete must not be transported long distances as segregation will occur. It must not be dropped more than 1.5 metres as this will also encourage segregation. Concrete should be vibrated with a mechanised immersion poker placed throughout the fresh wet concrete to agitate the particles into a compact matrix and expel the excess air. Over vibration must be avoided as this will result in segregation. The vibrator should be kept away from the formwork. For minor works and standard concrete grades it is acceptable to use lengths of reinforcing rods to agitate the concrete if a vibrating poker is not available. Good supervision is required to ensure a methodical process.

Finished concrete surfaces should be tamped and screeded with excess concrete removed and disposed of. Exposed surfaces should be finished smooth with a steel or wooden trowel. The finished surface of the concrete must be protected from rain within the first two hours after placing. Curing with water should commence three hours after casting. Concrete must be adequately cured for quality and durability and adequate arrangements must be made for this for at least the first 7 days after casting. Some types of cement require longer curing times.

Sacking or sand or other suitable material should be used to cover the concrete and retain the curing moisture/water. The surface of the concrete should be kept damp with repeated wetting during the curing period.

Formwork must not be removed until the concrete is strong enough to support its loading. Removal must be carried out carefully as point loads can damage “green” concrete. The rate of strength gain in concrete depends on the type of cement used.

**Supervision check box – Concreting**

- Permissible air temperatures for placing
- Clean water for concrete mix
- Correct mixing proportions (check especially that correct cement quantities used and that batches are weighed or gauge/batching boxes are used)
- Correct water:cement ratio (check workability with slump test)
- Concrete placed and compacted within 30 minutes of mixing
- Cure continuously (keep all surfaces damp) for at least 7 days for Ordinary Portland Cement (OPC) and 14 days for Pozzolanic Portland Cement (PPC).
5.4.10 Precast concrete

Where possible and where transport arrangements allow, precast units can be built at a central location (e.g. culvert pipes or reinforced concrete beams). This should allow the benefits of efficient production arrangements and greater quality control.

Precast culvert rings should be carefully lowered into position using ropes or straps to control the operation. Particular care must be taken to prepare the bed to ensure uniform support of the pipe. Final adjustment of position should be carried out with the aid of crowbars. Joints should be mortared and protected (for example with banana leaves) prior to backfilling. After backfilling the joints should be inspected internally and repaired if necessary. Precast box culvert deck slab units or even bridge deck beams may be cast on site and then placed in final position. Crane or heavy lifting and moving equipment will be required for precast deck beams.

5.4.11 Timber Stave Culverts

These pre-treated timber culverts may be transported in component form to the site. The efficiency of the system means than a number of culverts can be transported in one truck load. The timber culvert is assembled with its binding hoops at ground level alongside the culvert site. It is then gently lowered into its permanent location. Particular care must be taken to ensure that the culvert does not move during backfilling and compaction.

Plate D.5.4: Timber Stave Culvert

As with all precast unit systems, particular care is required to ensure a completely uniform bedding, surround and backfill operation to avoid later settlement or failure problems.

5.4.12 Masonry Work

In masonry work, the corners and ends should be constructed first, with particular attention to verticality and alignment. String lines can then be stretched between the initial work to guide and ensure smooth faces and coursing of the subsequent work. Adequate bonding should be ensured with vertical joints staggered. A timber template may be fabricated to assist with constructing irregular shapes (see Figure D.5.17 and Plate D.5.5). Mortar must be used within 30 minutes of mixing. Masonry work should be cured as concrete.
Supervision check box – Masonry

- Stone must be clean, sound and firm
- Vertical joints staggered
- Edges and corners true, and appropriate stones selected for these locations
- Faces true without irregularities, dishing or bulges
- All joints to be pointed to ensure effective load transfer and minimise water penetration
5.4.13 Timber Superstructure

Although timber may be used for bridge abutments and piers, its eventual replacement can involve considerable work when resources may not be readily available. Timber beams, decks and running boards are comparatively low cost and easy to replace, and are discussed in the following text.

Sawn timber or logs can be used for bridge deck beams or bearers. Timber plank decking or running boards can be fixed to the timber bearers or to steel beams. All timbers should be carefully treated prior to installation to achieve acceptable service life. A small diameter pole or timber can be used to launch the first main beams across the bridge span as shown in the diagram, using log rollers and ropes if necessary. Once two main beams are in place then these can be used as a platform to manhandle the remainder of the main beams into place (see Figure D.5.18).

Figure D.5.18: Timber beam launching

Log bearers should be selected which are as straight as possible and do not taper substantially over their length. Log bearers will not all be of exactly equal diameter. After all bearers are in place they should be levelled with string lines and spirit level so that all top faces are reasonably level. They should then be packed with stones/bricks and mortared into position at the abutments and piers (Figure D.5.19). The ends of the logs should be concreted or mortared to discourage insect access. If logs vary in diameter along their length, then adjacent logs should be laid with their thick sections at opposite ends of the deck to provide uniform deck stiffness and strength.

Figure D.5.19: Log packing
There will usually be high and low points on the log beams. These are either trimmed off with an axe or built up with packing to achieve a level area to which the deck planking can be fixed. Packing timbers should be at least 300mm long, treated and securely nailed to the bearers before the deck planking is laid.

Decking timbers are fixed by nailing or bolting at right angles to the main beams (even on a skew bridge). These timbers will spread the vehicle loads to the main beams. Each deck timber should be fixed to every beam as close to its centre as possible (Figure D.5.20).

If the timber is particularly hard the nail holes may need to be pre-drilled to a diameter slightly smaller than the nails to avoid the timber splitting yet achieve a secure fixing. Excess timber should be trimmed from the ends of the deck planking.

Running boards are fixed to the decking by nailing or bolting. Heads should be recessed to avoid damage to vehicle tyres. Running boards should be laid to form a running surface for each wheel of at least 1.1m wide for safety. Joints in running boards should be staggered and cut square. All board ends must bear on a decking timber and be securely fixed to it and trimmed (see Figure D.5.21). A threshold board should be fixed across the end of the running boards at each end of the bridge. This will absorb the initial impact of a vehicle and protect the running boards.
Kerb timbers should be fixed to the edges of the deck and parapets provided for pedestrian safety.

Figure D.5.22: Kerb timber fixing

5.4.14 Earthworks/Backfilling

Prior to backfilling, weep holes in masonry and concrete walls should be backed with a lean concrete plug. This will be porous to allow ground water drainage, but will prevent the backfill material from washing out.

Backfilling (Figure D.5.23) and compaction should be carefully and methodically carried out. Adjacent to structures it is usually not possible to use heavy compaction equipment; in confined spaces small plant or handtools must be used. The backfilled area adjacent to the structure is particularly susceptible to settlement in contrast to the relatively rigid structure. Good procedures and supervision are required to minimise the risk of later settlement so that particular care must be taken within 5 metres of the structure. The control of layer thicknesses is important.

Figure D.5.23: Backfilling

Control of compaction should either be by “end-product” specification, or “method” specification. Nuclear density testing is quick and convenient and avoids the need for laboratory testing and time delay using the sand replacement density method. Method specifications rely entirely on the presence and integrity of an inspector throughout the filling and compaction process.

Supervision check box – Backfilling
Backfill with selected suitable material in even layers of no more than 150mm thickness and thoroughly compacted. Material to be moistened if necessary to aid compaction.

No large stones or rocks to be placed directly against structure

5.4.15 Safety Measures

Markers, chevrons and/or reflectors should be installed at the ends of the bridges to clearly show the extent of the structure and the vehicle path. Kerbs and ends of the structure should be painted white. Warning signs should be installed on the bridge approaches in accordance with the local traffic sign recommendations.

5.5 Site Administration

The following activities will be required to be carried out in support of the site works. It is important to keep accurate records of the actual works carried out to compare to the planned progress, resource use and expenditure. This will help to ensure value for money. Any problems encountered should be recorded along with explanations of how they were overcome. This will assist in explaining any delays or cost over runs and help to improve future planning of structures.

Checklist of site administration tasks

- Set and review individual/gang task rates
- Daily muster-roll and work achievement record for site labour force
- Daily diary of works achieved; problems encountered and methods of solving them should be recorded
- Update work programme
- Daily checks on site stores, tools, materials, re-order as necessary
- Daily checks and service of site equipment
- Testing of materials, inspection and quality control
- Prepare payrolls
- Arrangements for payment of labour force
- Keep a careful record of all costs
- Reporting of progress to Employer/senior management
- Safety and first aid arrangements.

Weekly and daily programmes should be prepared based on the Bills of Quantities, the overall works programme and expected local productivities. Adjustments will be required to be made continuously based on actual experience. Weekly reports should be prepared for management monitoring purposes. Key indicators should be used to monitor the progress of the work, such as cement or worker days used, against the quantities planned.

For structures, ‘as-built’ drawings should be prepared; these should particularly record differences from the original design, and important details such as actual foundation levels and concrete strengths. If there are no changes, this is also valuable information.

A cost analysis of the completed structure should be carried out to enable cost estimating of future structures to be more accurate.

A final inspection of the completed structure should be carried out prior to handing over to the authority that will be responsible for its maintenance. The following chapter discusses maintenance arrangements. It is advisable for an independent performance audit to be carried out on a completed structure to review the works. This should verify the structure’s ‘fitness-for-purpose’ and value for money.
6.1 Introduction

6.1.1 Background

Good quality control/quality assurance (QC/QA) practices are essential to obtain satisfactory results on any road project. This is particularly the case for LVRs where naturally occurring, inherently variable materials are being used and it is essential that the underlying design assumptions are achieved on site. This includes critical factors such as use of materials of acceptable quality and attainment of the minimum compaction requirements and pavement layer thicknesses specified. Unless these, and other specified requirements are met, such as an adequate quality surfacing to waterproof the pavement structure, and effective internal and external drainage, then premature failure of the LVR is likely.

In developing a QC/QA system, it should be borne in mind that LVR projects in Ethiopia are often relatively small in size and widely scattered in remote areas with limited facilities. Moreover, the speed of construction is relatively slow and the available resources as well as skills with small contractors are at a relatively low level. It is therefore necessary that while developing a suitable QC/QA system for construction, such constraints are borne in mind. Thus, the types of quality control and their frequency must be judiciously selected so as to be achievable under the prevailing conditions.

6.1.2 Purpose and Scope

The purpose of this chapter is to set out a simplified approach to QA/QC to achieve an acceptable end product in a typical rural environment with the resources that are likely to be available for constructing a LVR. The inherent compromise in this approach will often require innovative solutions and a focus on a robust, but simple, QA/QC system to achieve optimal results.

This chapter covers the general approach to QA/QC that is typically adopted in the construction of a LVR. It then focuses on the manner of undertaking QC with reduced resources and the priority that should be placed on QA. Consideration is also given to QC of gravel wearing courses for unpaved roads which is supplemented by an Annex on Material Selection and Quality Assurance. The Annex provides in-depth guidance regarding material selection, testing and control of the construction process for labour-based unsealed road projects.

6.2 Approach to QA/QC

6.2.1 General

There are various means of ensuring that an acceptable quality of the final LVR is achieved. Each is separate and each has an important role to play. Together they consist of a suite of procedures that work together to ensure good quality but they are often not fully understood. A clear distinction should be drawn between the following:

- Quality Plan (QP)
- Quality Assurance (QA)
- Quality Control (QC)
- Production Control (PC)
- Acceptance Control (AC).

The differences and functions of each component of the Total Quality Management System (TQMS) are explained below.
Components of a TQMS

Quality Plan (QP)
This refers to a written plan submitted by the contractor, which is reviewed and approved by the client/supervising engineer. This document clearly demonstrates how the contractor will control the processes used during construction in order to meet the requirements set out in the technical specifications. The QP will typically include the sequence of tests (QC tests) to be performed on the materials intended for use at a prescribed frequency, with the objective of demonstrating that the intent of the specification is being satisfied.

The tender documents should include the requirement that the contractor must present his project Quality Plan that he/she intends to follow during the working process.

Quality Assurance (QA)
Quality Assurance refers to the component of the TQMS and associated work procedures within the construction site that help to ensure that correct quality of the final road is attained. The QA system comprises the documentation required to show that the contractor is following the QC plan. It incorporates standard procedures and standard methodologies and applies to all site activities. The QA Plan should be followed by everyone on site and checked by both the construction supervisor and the contractor. QA activities are determined before construction work begins and the activities are performed throughout construction. Components of a QA system include process checklists, project audits and construction methodology (contractor's work plan).

The tender documents should include the requirement that the contractor must present his project Quality Assurance Plan that he/she intends to follow during the working process.

Quality Control (QC)
Quality Control refers to measured quality-related attributes associated with the construction of various aspects of the project. QC is generally concerned with measuring properties and checking that specifications have been met consistently throughout the project. It does not in itself create higher quality. Examples of quality control activities include site inspections, field and laboratory testing. Such activities are performed after the work has been completed.

Production control
Production control is carried out by the contractor for the purpose of satisfying himself that chosen methods and materials meet the specified standards. Production control serves as an early warning for the contractor and helps reduce his risk of failure and associated additional cost to himself of remedial work. The contractor may be obliged to submit results from the production control to the supervising engineer and may in some cases these may be taken as part of the acceptance control.

Acceptance control
Acceptance control is carried out by the supervising engineer to check compliance with the specified standards and to enable payments to be made. Acceptance control makes use of confirmed QA and QC testing. Results from acceptance control will normally form part of the as-built data which provides the basis of the road inventory kept by the responsible road agency.

Quality control supervision therefore comprises two principal elements namely site inspection and laboratory and in-situ testing. A large component of the latter is compaction control and testing.

Site Inspection
The works are inspected visually to detect any deviation from the specified requirements. Visual assessment is an essential element of pavement layer approval, particularly in the identification of oversize material in lower pavement layers or in a gravel wearing course. Physical measurements of thickness, widths and crossfall are an essential element of this assessment. This activity is supplemented by simple in-situ
checking of specified procedures; for example, temperature of bitumen and spray rates, concrete slump, etc.

**Laboratory and in situ testing**

Materials as well as the finished product are subject to laboratory testing for such characteristics as density and strength. On larger projects it may be possible for the contractor to set up and maintain a basic field laboratory for routine tests for quality control testing required on a day to day basis. The field laboratory will normally have test equipment that does not require an electric power supply and is relevant to the project specifications. There are also portable field test kits, such as the Gravel Test Kit supplied by CSIR of South Africa, which includes simple equipment for basic control tests.

**Field compaction control**

One of the most critical quality control activities is the field density compaction tests, the outcome of which could have a significant bearing on the performance of the road. The Sand Replacement Test, sometimes used in conjunction with Nuclear Density testing, is commonly used for compaction control on LVR projects. However, on a practical level, these tests are time consuming. They may be replaced for quality control purpose by the easier-to-perform DCP test, initially in conjunction with in situ density testing and moisture content testing for correlation purposes.

Compaction control is typically based on absolute requirements and spot tests. However, the number of such tests is often too low for a high level of statistical reliability and therefore does not necessarily ensure a well-defined quality of the product. It is for this reason that a statistical approach to quality control should be adopted, particularly for the larger LVR projects. Works and materials are accepted or rejected based on the requirements given in the ERA Standard Specification and Method of Measurement for Road Works.

**6.2.3 Benefits of operating a TQMS**

The operation of a TQMS offers the following major potential advantages:

- Ensures that the work to be done correctly the first time,
- Achieves quality by focusing on preventing problems or errors rather than reacting to them,
- Ensure that errors are detected and corrected as early as possible. Therefore, quality controls, which include checking and back-checking procedures, must be implemented during all phases of the work,
- Eliminate the causes of the errors as well as the errors themselves. By removing the cause and by improving the quality application process,
- Streamlines the inspection and release process for acceptance of qualification of constructed projects for maintenance.

**6.3 Quality Control Issues**

**6.3.1 General**

The resources available for quality control in construction of LVRs are sometimes limited, depending upon the size of the contract. Use is also made of new and emerging contractors with little experience. It is therefore important to utilise whatever means are available as efficiently as possible and to combine conventional control methods with other practical procedures as described below.

- **Stockpiling** as a means of selecting qualities and ensuring known quality of the materials being used (stockpiling carried out preferably in the borrow pit rather than on the road)
- **Good management procedures** to ensure that materials are used to their full potential and to prevent rejection of material after transportation to the road
- **Control by observation** of construction procedures by an experienced practitioner
- **Proof rolling** (e.g. with loaded trucks) to test the stability of layers before proceeding with further construction
- Use of methods for **direct strength measurements** by correlation with known parameters (e.g. probing methods such as DCP and others)
- Laboratory testing for ‘calibration’ of method specifications
- Laboratory testing of typical material sources for ‘calibration’ of visual observations.

In addition to the above, the following quality control activities are not expensive to undertake and can make a significant difference to the quality of the constructed LVR:

**Bituminous surfacing:**
- Visual inspection of all surfacing equipment.
- Check that spray nozzles are not blocked.
- Check that bitumen spray temperature is correct.
- Ensure that spray rate is correct.
- Ensure that sheets for start and end points are in place.
- Ensure that longitudinal joint is correctly done.
- Ensure that rolling is timely and correctly carried out.

**Base finishing:**
- Ensure that base is not too rough and/or too open.
- Ensure that biscuit’ layers are not present. The use of a geological hammer/pick can be used to identify such flaws.
- When priming is carried out ensure light watering take place prior to spraying prime.

**Pavement layers and subgrade:**
- Test stockpile prior to transporting material to site.
- Ensure that the tested stockpile(s) are the only one used.
- Prepare a method specification for compaction control using i.e. a DCP.
- Prepare a watering plan for adding water to the material.

**6.3.2 Frequency of Laboratory Testing**

The frequency of testing of borrow pits needs to strike a balance between cost and time and statistical validity of the results. Such frequency will depend on the variability of the material: the more homogeneous the material the less the amount of testing necessary for statistical validity of the results. Table D.6.1 provides guidance on the typical frequency of carrying out various laboratory tests on samples collected after stockpiling of the material in the borrow pit to verify the quality of the material which will be hauled and used on site.
### Table D.6.1: Typical frequency of materials sampling and laboratory testing

<table>
<thead>
<tr>
<th>Material</th>
<th>Frequency of the sampling and testing requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tests on Soils</strong></td>
<td>▪ Samples shall be collected from each stockpile.</td>
</tr>
<tr>
<td></td>
<td>▪ Collect 5 samples from different parts of each stockpile.</td>
</tr>
<tr>
<td></td>
<td>▪ Each sample shall be 50kg or more.</td>
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<tr>
<td></td>
<td>▪ Collect 2 samples per stockpile if the material is sand.</td>
</tr>
<tr>
<td>Grading tests</td>
<td>▪ Two sieve analyses per material source.</td>
</tr>
<tr>
<td>Atterberg limits</td>
<td>▪ 2 tests for each sample.</td>
</tr>
<tr>
<td>Determination of laboratory dry density and optimum moisture content</td>
<td>▪ Mix the material for each stockpile and carry out at least 2 similar tests, separate tests on the mixed material to check for accuracy of the test results.</td>
</tr>
<tr>
<td>Determination of CBR or DN value (soaked, OMC and 0.75 OMC (optional))</td>
<td>▪ Carry out 2 similar tests on the mixed samples for each stockpile.</td>
</tr>
<tr>
<td><strong>Tests for concrete</strong></td>
<td></td>
</tr>
<tr>
<td>Slump test on fresh concrete</td>
<td>▪ One test for every 3 batch mixes.</td>
</tr>
<tr>
<td>Cube strength tests</td>
<td>▪ Six cubes for every pour (every lift or continuous pour).</td>
</tr>
<tr>
<td>Test on aggregate in the laboratory</td>
<td>▪ Samples shall be collected from 3 or more different positions in the truck or stockpile and the samples shall be tested separately.</td>
</tr>
<tr>
<td>Grading</td>
<td>▪ Minimum of 3 tests and plot a grading envelop for each delivery on site.</td>
</tr>
<tr>
<td>ACV</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td>10% FACT</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td>Water absorption</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td><strong>Bitumen tests</strong></td>
<td></td>
</tr>
<tr>
<td>Penetration (suitable for straight run and cutback bitumen, 60/70 pen, 80/100 pen, 150/200 pen, MC3000, MC800)</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td>Softening point (suitable for straight run and cutback bitumen, 60/70 pen, 80/100 pen, 150/200 pen, MC3000, MC800)</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td>Viscosity tests (suitable for straight run and cutback bitumen, 60/70 pen, 80/100 pen, 150/200 pen, MC3000, MC800)</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
<tr>
<td>Bitumen content (suitable emulsions SS60, SS70)</td>
<td>▪ Minimum of 3 tests and record and take an average of the values.</td>
</tr>
</tbody>
</table>
6.3.3 Compaction Quality Control

General

Compaction is a crucially important aspect of road construction as it substantially influences the long-term durability and performance of the pavement structure and, hence, the whole-life cost of the road. Thus, this aspect of the construction process must therefore be carefully controlled on site to ensure that the specified densities are met in a consistent manner. The main aspects that need to be considered, other than routine material control testing, are the field density attained, the layer thickness and surface finish.

Compaction control

The pavement layers (or gravel wearing course) should be compacted preferably to refusal or to the minimum specified density assumed in the pavement design. This requires that the materials be processed at or about Optimum Moisture Content and rollers of adequate mass are used. Trial sections should be constructed using the materials and plant that will be used on site, and density increase monitored for each pass of the roller. Compaction control can make use of any density determination method (nuclear, sand replacement, etc.) but the most practical method is to use a DCP which is quick and easy to carry out and which will provide adequate assurance that satisfactory compaction has been achieved.

Compaction trial using the DCP: Provided the material is tested at or close to OMC, a reliable Target DCP DN value can be obtained from the compaction trial for the subsequent compaction control of the road works. This Target DN value can be determined as follows:

1. Following completion of the first 3 roller passes, undertake 3 No. DCP measurements after every successive pass of the roller up to about 8 passes.
2. Calculate the average DN value after each successive pass of the roller.
3. Plot the average DN values against the number of roller passes as shown in Figure D.6.1.
The average DN value will normally decrease with an increase in the number of roller passes until the curves flattens out to a point where the decrease in DN value becomes negligible, in this illustrative example after 6 passes. This DN value becomes the Target DN for compaction control, as described below. It is also necessary to correlate the Target DN value with the density obtained using the traditional density determination method (Sand Replacement of nuclear gauge) to ascertain whether the specified density has been achieved in the field.

Compaction control procedure using the DCP: The procedure is as follows:

1. Determine from a compaction trial the optimum number of roller passes and Target DN value (which is deemed to be at “compaction to refusal” at or close to OMC (+1%/-2%) as described above.
2. For each lot do a minimum of 10 DCP tests in a staggered pattern illustrated as illustrated in Figure D.6.2 with 3 tests on each side and 4 tests along the centre line.
3. The offset from CL for the LHS/RHS tests shall be varied and no tests shall be done closer to the start/ end and to the outer edge of the lot than 0.2 m.

Evaluation procedure: Figure D.6.3 illustrates the evaluation procedure and criteria for compaction quality control using the DCP. Further details may be obtained from the AFCAP Guideline for Compaction Quality Control on Low Volume Roads Using the DCP (2015).
6.3.4 Thickness control

It is important that the required thicknesses of material are placed. Layers that are too thin will require premature regraveling and those that are too thick will lead to an increased cost and possibly a lack of compaction in the lower part of the layer. Layer thickness can be easily controlled using a simple tool as shown in Figure D.6.4. This tool can be easily made and is pushed into the ground until an obvious change in resistance is felt (the underlying, usually dried out layer). The thickness of the layer is then read off the scale. The tool can also be used to assess the uncompacted thickness before rolling, which together with knowledge of the bulking factor, can indicate whether the loose material is adequately thick. The layer should be slightly thicker than required as some thickness will be lost during final trimming and shaping, particularly developing the camber as discussed below.
6.3.5 Final finish

The final finish is critical as this will affect the riding quality (and thus the vehicle operating costs) as well as the drainage from the road surface. Good shape of the road is essential with a central crown and a cross-fall of between 4% and 5%. In order to ensure this, proper control using stakes and string-lines must be carried out during construction.

In addition, it is essential to ensure that all oversize material has been removed. Any oversize material near the surface will be plucked during the final trimming and dragged along the surface leaving grooves. An excess of these grooves indicates that the oversize material has not been removed properly and the layer should be reconstructed after removing the large particles. Failure to remove them will result in excessive roughness, difficult, expensive and ineffective maintenance and excessive vehicle operating costs.

6.4 Bibliography

7.1 Introduction

7.1.1 Background

The management and financing of Ethiopia’s road infrastructure is currently undertaken in a much more commercialized and business-like manner than previously. The key organizations involved in the roads sector – ERA and the Road Fund - operate under performance contracts within their respective ministries. Both these organizations have a primary responsibility to ensure that the funds provided for road provision are used effectively and efficiently and that the providers of these funds, and ultimately the Government of Ethiopia and its people, receive value for money.

In the prevailing commercialized environment in which Ethiopia’s roads agencies operate, it is essential that the professional services provided by all parties to the contract are carried to acceptable standards in an efficient and cost effective manner. Therefore, ways and means must be found to regulate the construction industry and its service providers to ensure that the required standards are not compromised. One of the ways of doing this is by carrying out regular technical auditing of road projects. The primary aim of these audits is to check compliance with the requirements of the contract during all stages of the project cycle and, ultimately, to ensure that the Employer receives value for money.

The primary responsibility for undertaking technical audits resides with the roads agencies in Ethiopia that are responsible for executing road projects. Such audits are quite separate from the more broadly based ones that may be conducted by the Ethiopia Road Fund or other agencies after the project has been completed to verify such aspects as the manner of procurement and management of the works.

7.1.2 Purpose and Scope

The main purpose of this chapter is to outline the scope of a typical technical audit and to indicate the appropriate requirements and techniques to be employed for such audits that cover all stages of the project cycle. The primary aim of these audits is to verify that the road is planned, designed and constructed to the prescribed specifications and that the contractor performs and is paid as per the contract conditions.

The chapter covers auditing of projects related to the following five main stages of the project cycle, namely: Planning, Preparation, Contract Award, Implementation and Monitoring and Evaluation. The procedures described should be amended, where necessary, to comply with general government requirements and procedures.

7.2 Fundamentals of Technical Audits

7.2.1 What is a Technical Audit? Definition

A technical audit may be defined as a formal, systematic procedure for undertaking an independent, objective, assessment of a project to determine the extent to which it has complied with various prescribed procedures, standards and specifications set down in the project documents.

Technical auditing versus supervision/quality control

A clear distinction should be drawn between technical auditing and supervision/quality control which are not synonymous terms. The difference between these terms is both legal, in relation to the roles and responsibilities of the key parties to the contract, and technical in terms of the roles and responsibilities of the technical audit team and the degree of detail applied when auditing the project. It is therefore critically important that the technical audit process is kept well apart from the supervision process prescribed in the conditions of contract.
7.2.2 Why Undertake a Technical Audit?

An appropriately formulated technical audit can detect and predict problems arising during the various stages of the road provision cycle, thereby enabling the Employer to respond. The audit process should commence as early as possible in the project period. There is little benefit in initiating a technical audit either during construction or when a problem is suspected or realized as the findings of such audits cannot influence the outcome of quality of the work.

Typical problems that can be detected by a technical audit include:

**Human errors**

Human beings are prone to making errors in any undertaking in which they engage. Neither Employers, consultants nor contractors are immune from this human failing. These errors can occur during any of the stages of the project cycle, and end up being very costly during project implementation. If an appropriate experienced independent verifier is engaged at the right time, these errors could be detected early and corrective action taken. Moreover, designers, supervisors and contractors are likely to be more diligent in their work if they are aware that it will be subjected to external review or evaluation.

**Incompetence**

The designer or supervisor of the engineering project may be incompetent and an auditor will be able to establish this before costly mistakes are made. Employers, either out of ignorance or with the intention of “saving money” sometimes engage incompetent persons to carry out design or supervision of complex engineering projects. On the other hand, contractors are often guilty of the same short-coming - failure to engage competent personnel to implement the works.

**Corruption**

Contractors, sometimes in collusion with supervisors, may take shortcuts during project implementation. For instance, inadequate or wrong reinforcement in structures may be used, inadequate compaction in road construction is allowed, or concrete may not be allowed to cure as required before proceeding with further construction. A technical auditor will pick this up at an early stage and raise a red flag.

**Poor quality control**

Effective quality control is extremely important during project implementation. If this is lacking or there is laxity in implementing the required quality control, the technical auditor will raise the matter with the auditee and alert the Employer.

**Professional ethics**

There are, unfortunately, some professionals who do not adhere to a code of professional ethics and who undertake projects for which they are ill-qualified. Others may deliberately over-design an Engineering facility to inflate its cost, while others may fail to carry out adequate field investigations. As a consequence, their designs may be based on inadequate data and could lead to under- or over - design. An audit of such projects would reduce the likelihood of such shoddy practice occurring.

7.2.3 Typical types of road audits

There are basically four types of road audits that may be considered. These are outlined in Table D.7.1. This chapter deals primarily with Technical Audits although aspects of Procedural Audits, Road Safety Audits and Environmental Audits can be applied at the various stages of the process.
### Table D.7.1: Types of road audits

<table>
<thead>
<tr>
<th>Procedural Audit</th>
<th>Technical Audit</th>
<th>Road Safety Audit</th>
<th>Environmental Audit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deals with administrative and financial procedures. Reviews and checks if Government regulations are followed in the use of financial resources.</td>
<td>Deals with the road project cycle for maintenance, upgrading and new construction. Aims to determine the extent to which the road has been planned, designed and constructed to the prescribed specifications and that the contractor performs and is paid as per the contract conditions.</td>
<td>Deals with the safety aspects of a new or an existing project to ascertain if the project in any way would worsen the road safety situation. Detailed recommendations are put forward in cases where standards are not achieved as intended.</td>
<td>Deals with the environmental and social aspects of a project. Assumes that an ESIA has been carried out prior to the execution of the project and that the end result can be compared with what was intended. Recommendations for improvements are put forward.</td>
</tr>
</tbody>
</table>

#### 7.2.4 Benefits of Technical Auditing

The benefits of technical auditing include:

- Identifying potential problems early in the course of the project cycle (planning, investigation, design, procurement, construction stages).
- Instilling a sense of greater diligence in the attitude of all parties to the contract.
- Reducing the scope for corruption, particularly at the contract award and implementation stages of the project.
- Detecting misinterpretations of data, inaccurate reporting, departures from planning directives or project objectives.
- Confirming the implementation of prescribed requirements such as quality assurance, quality control and work plans;
- Minimising the risk and severity of failures that may occur as a result of design deficiencies in the road project.
- Minimising the need for re-work and physical remedial works caused by design or construction deficiencies by taking early corrective action.
- Benefiting from any lessons learnt for application to other projects.
- Enabling the Employer to ascertain whether the parties involved in the contract (including the Employer) have provided the Government and people of Ethiopia with value for money.

The cost of a technical audit is normally significantly less than the cost of changing a design or the cost of remedial works after the contract has been awarded and construction started. The cost of the audit is a small price to pay for upholding the highest possible standards that all parties to a contract are expected to attain, not only to ensure compliance with prescribed standards, but also to enhance the quality of their work.

#### 7.2.5 Types of Road Projects Which May Be Audited

In principle, technical audits are applicable to all types of activities in the road sector, on all types of roads. The main categories of road projects include the following:
Construction and Rehabilitation

- New construction.
- Upgrading (including geometric improvements).
- Rehabilitation (including pavement reconstruction and structural overlays).

Maintenance

- Routine and preventative maintenance.
- Periodic maintenance (including regravelling, reshaping, resealing, rejuvenation and regulating overlays).

Construction and rehabilitation projects tend to be more complex and costly to undertake than maintenance projects. Thus, although maintenance projects can be audited, it is more usual to focus auditing attention on construction and rehabilitation projects.

7.2.6 When to Undertake a Technical Audit

Technical audits can be undertaken at any or all of the main discrete stages of the project cycle. The various stages of technical auditing should not be seen as rigid as all projects are not the same in terms of size, complexity and type. For example, a large, new road construction project may well entail all six stages of technical auditing whereas a minor routine maintenance project may warrant only a 5-Stage audit. For projects that are constructed in sections, a technical audit may be conducted at the completion of each section of construction.

7.2.7 Who Should Undertake a Technical Audit?

Criteria

A technical audit is best carried out by a team of people who are independent of the Employer, consultant or contractor so that the audit process is undertaken with fresh eyes in an unbiased manner. The Employer has the ultimate responsibility for accepting that the level of independence is adequate and credible. To avoid an inappropriate “culture” of the consultant or contractor being incorporated, members of the audit team should be commissioned from organizations with no ties to the Employer’s, consultant’s or contractor’s organisations.

Size of the audit team

The most appropriate size of a technical audit team depends on the complexity of the audit task. There is no optimum number of people suggested, although teams of more than four people can be unmanageable. The benefits of having an audit team, rather than a single person, include:

- The diverse backgrounds, experience, knowledge and approaches of different people
- The cross-fertilization of ideas through discussion
- Simply having more pairs of eyes.

While skills in road engineering are the most crucial attribute, technical audit teams should possess balanced skills appropriate to individual projects. Avoid having a one-person team just to reduce costs in undertaking an audit. The cost of undertaking an audit is small relative to its potential benefits.

Appointment of audit team

The Employer should appoint the audit team in accordance with any over-arching requirements of the Government. A list of potential auditors compiled by the Employer that includes their skills and experience can assist with the selection process. To avoid potential conflict of interest, it is desirable to appoint independent auditors, i.e. persons not involved themselves in the types of activities that they are required to audit.

For each technical audit, one person in the audit team should be appointed as the audit team leader, to manage the team and process.
Skills of audit team

While continuity within core audit teams through the stages is desirable, audits at the different stages may require different skills as follows:

Stage 1 – Identification: Requires consideration of the country’s development strategy and sectoral objective requirements - issues with political connotations that may best addressed by government personnel rather than by an external auditor.

Stage 2 – Planning and Appraisal: The issues to be examined are quite different (broader and often more conceptual) than for later stages. Thus, a big picture view, taking in the potential for wider implications to all road users is important. It would be desirable to include team’s members with planning and economic appraisal skills.

Stage 3 – Preparation: Include team members who are familiar with the types of details required at the design stage of the project, for example, with experience in road construction materials, design and preparation of contract documents.

Stage 4 – Contract Award: Include team members who are familiar with the types of details required at the tendering stage of the project, for example, with experience in preparation of tender documents and tender evaluation procedures.

Stage 5 – Implementation: Include team members who are familiar with the types of details required at the construction stage of the project, for example, with experience in quality control, quality assurance, construction practice, specifications for road and bridge works.

Stage 6 – Evaluation: Include team members who are familiar with the types of details required at the evaluation stage of the project, for example, with experience in pavement investigations including visual and road condition surveys, sampling techniques, interpretation of test results.

Attributes of audit team

The experience and skills of the audit team should be broadly as follows:

Team leader: The Team Leader should:

- Be an appropriately qualified professional engineer with wide-ranging experience covering feasibility studies, highway design, construction and contract management.
- Have demonstrated management and reporting skills.
- Have up-to-date professional experience.

Team members: The other members of the team may be more varied in their backgrounds than the Team Leader and should have experience that achieves the balance required for the audit. These team members could be, for example:

Materials and/or Pavement Engineer: Should be an appropriately qualified professional engineer with appropriate experience in pavement engineering/materials. If only one of these engineers is preferred, then they should have an in-depth knowledge of the other field. For instance, the Pavement Engineer would be required to have an in-depth knowledge of materials and the Materials Engineer would be required to have a sound knowledge of pavement engineering.

Engineers with experience in drainage, structures/bridges and geometric design could form part of the team where necessary, depending on the complexity of the project. They should be appropriately qualified professional engineers in their respective fields.

Observers: Can be included in the technical audit for a variety of reasons, such as a training exercise in order to be considered as future audit team members, or simply to observe the process.

Appointment of audit team

The Terms of Reference for the appointment of an audit team are always project specific and, as a minimum, should contain the following details:

- Background to the project, indicating clearly the stage(s) of the project to be audited.
Overall objective of the audit.

Detailed scope of the works, which could include:
- particular aspects of the work to be audited;
- detailed work programme for the assignment indicating expected submission dates for the various reports;
- minimum professional qualifications and experience of the personnel;
- standards and specifications for the project;
- available data and information including feasibility studies, design documents, programme of works and periodic progress reports;
- specific areas of focus depending on the Employer’s concerns;
- help that the audit team can expect from the Employer.

### 7.2.8 The Parties to a Technical Audit

The parties to a technical audit are:
- **Employer**: The organisation ultimately responsible for the project.
- **Consultant**: The team undertaking the investigation, and/or the design, and/or the supervision of construction of the project.
- **Contractor**: The team engaged by the Employer to construct the project.
- **Auditor**: An independent person or team appointed by the Employer to undertake the audit.

### 7.2.9 Relationship of Audit Team with Main Parties to a Contract

The audit team is appointed by the Employer to whom it reports directly. Under no circumstances may any member of the audit team advise or issue instructions to the contractor or supervising consultant. Communication should be focused on seeking clarification or information regarding the project, and should avoid any interference with smooth implementation of the project. The consultant, contractor and Employer must make available to the Auditor any document, as and when required by him/her. Relevant clauses in the tender documentation and/or letters of appointment should make provision for this.

The relationship between the Auditor and the Employer must be clearly described in the Auditor’s agreement with the Employer. The Auditor can review actions of the Employer during the project and any deficiencies or lack of performance should be noted in the audit report. This ensures that the audit process is transparent and may assist to improve internal practices within the Employer organisation.

### 7.2.10 Limitations of Technical Audits

Auditing of engineering projects has a number of limitations that Employer should be aware of as follows:
- In many forms of contract, an auditor has no role and is not contractually recognised. The contract is usually between an employer and a contractor. The roles of the engineer or his representative are usually spelt out in the contract.
- Auditees do not always give the assistance and cooperation expected. The Auditor’s role is often seen as investigative and some auditees do not therefore feel obliged to co-operate.
- The Auditor may be a competitor to the auditee in other areas and the report prepared after the audit exercise is therefore not taken to be impartial.
- One of the major issues faced by auditing firms is the need to provide auditing services while maintaining a business relationship with the audited entity. Often, it is difficult to maintain the balance without compromising on professional ethics.

Most, if not all, of the potential limitations of technical audits highlighted above can be overcome by undertaking the audit process in a well-structured manner in which clearly defined procedures are followed by each party in an objective and transparent manner. This process is considered in the next section.
7.2.11 Reporting

The reporting of the outcome of a technical audit is a critical aspect of the auditing process. In many cases, such a report could be the most important document affecting the outcome of arbitration or legal proceedings.

All aspects of the audit carried out at any or all stages of the project cycle should be carefully reported and should be comprehensive without being excessively lengthy. The format of the audit report needs to be carefully considered and strict confidentiality of its contents should be observed.

7.3 Audit Process

7.3.1 Main Steps in Process

Figure D.7.1 shows the general steps to be followed in performing an audit in terms of the sequence of activities and responsibilities of the parties to the audit. For a particular project that has been chosen by the Employer to be audited, the audit process starts off with the selection and appointment of the audit team and ends with the implementation of changes decided by the Employer.

Once selected and appointed, the audit team will work through the various steps of the audit process shown in Figure D.7.1. The specific activities undertaken at each step of the process depend on the stage of the project cycle being audited.
Details of Each Step in Audit Process

1. Select category and number projects to be audited

Objective: To select the category and number of road projects to be audited. Much as it may be desirable to audit all projects in all road categories under the responsibility of the roads agency, this may not be possible due to funding and/or capacity constraints. Thus, a manageable and representative number of projects in each road category will need to be chosen from amongst a much larger number.

Responsibility: Employer.

Procedure: As for any typical contract.

2. Decide on type of audit to be carried out

Objective: To decide what particular aspect (stage) of the project cycle should be audited. This is to ensure that appropriate attention is given to the most critical issues of the project. For example, a large, new road construction project which is donor funded may well require that all six stages are audited whereas a minor routine maintenance project that is carried out in-house may warrant only a Stage 5 audit, i.e. an audit that focuses on the implementation of the maintenance works and the supervision thereof.

Responsibility: Employer.

Procedure:
- Consider the type, complexity and cost of the project.
- Consider the most common type(s) of problem(s) that have arisen on similar projects in the past.
- On the basis of the above, decide on the type of audit to be carried out.

3. Develop Terms of Reference (ToR) for Auditor

Objective: To define clearly the scope of the audit to be performed and its objectives as well as the individual tasks to be carried out. The ToR will vary in relation to the type of audit being carried out (Stage 1, Stage 2, etc.) and the type of project being audited (new construction, periodic maintenance, etc.).

Responsibility: Employer.

Procedure: As for any typical contract.

4. Request for proposals for auditing services, and evaluate proposals, select and appoint Auditor

Objective: To procure the services of an auditor. Such services can be procured on a competitive tendering basis or by direct appointment, with the latter option being the more typical one employed in a commercialized roads agency where transparency in the procurement of professional services is an important factor.

Responsibility: Employer.

Procedure: As for any typical contract.

5. Provide project information to Auditor

Objective: To provide the Auditor with all the information required to undertake the audit. This will entail obtaining project information from either in-house staff involved in the project, from the consultants involved in any of the stages of the project cycle or the contractor. Such information will simplify and speed up the process of the audit and enable the Auditor to focus on the most important issues. The type of information to be provided to the Auditor will depend on the type of audit being carried out (Stage 1, Stage 2, etc.) and could include:
- Feasibility Study report
- Design report
- Tender Documents
Construction Progress Reports (for on-going or post construction audit)

Relevant ad hoc reports or special reports (for on-going or post construction audit).

**Responsibility:** Employer

**Procedure:**
- Write to in-house staff involved in the project or the consultant(s) or the contractor informing them about the audit and enclosing the ToR for the audit, listing the information required from them and the time by which the information is needed.
- List the information received and provide it to the Auditor at least two weeks before the commencement of the audit.

6. **Assess project documents**

**Objective:** To provide the first opportunity for the Auditor to review the project documents in detail. This allows the Auditor to assess the adequacy of the information received and to identify any action required prior to the commencement of the audit. In this phase, specific tasks may be allocated to various team members and an audit questionnaire may be prepared prior to commencing the audit.

**Responsibility:** Auditor

**Procedure:**
- Review in detail all project documents provided by the Employer
- Request any additional information or documents considered necessary
- Prepare programme and introduction for entry meeting.

7. **Hold entry meeting**

**Objective:** To provide an opportunity for all parties to the audit to meet prior to the commencement of construction. Such a meeting provides an opportunity:
- To establish lines of communication during the execution of the audit
- For the Employer, and/or consultant and/or contractor to brief the Auditor on issues, constraints and specific areas that are relevant to the audit
- For the Auditor to seek additional data, if necessary, and to discuss any initial observations or seek clarification arising from prior perusal of the background information provided
- To discuss the programme for completion of the audit and delivery of the report
- To determine the protocol for delivery of the audit reports.

**Responsibility:** Employer/consultant/contractor/auditor

**Procedure:**
- Provide background to, and objectives for, the audit
- Agree on documents to be examined by the Auditor
- Agree on programme and methodology for undertaking audit
- Summarise key issues discussed which will serve as an official record of the inaugural briefing meeting.

8. **Prepare audit questionnaire**

**Objective:** To facilitate more efficient interviews and site visits with the auditees. Such a questionnaire serves the purpose of obtaining information that might not otherwise be volunteered by the auditee as well as bringing about in-depth discussion on particular aspects of the project that are of particular interest to the Auditor.

**Responsibility:** Auditor
9. Undertake site inspection(s)

**Objective:** To allow the Auditor to familiarize himself with details of the project and to collect the necessary information and data on site for completing the audit.

**Responsibility:** Auditor

**Procedure:**
- Focus on aspects of the project that have been highlighted in the ToR
- Review in detail those components that have caused contractual or other disputes
- Refer to master checklist and fill in details as appropriate
- Measure/investigate specific features as necessary
- For maintenance projects, give priority to most critical components of the road (drainage, surfacing) as well as quality of materials and workmanship
- For new construction, rehabilitation or upgrading projects, pay particular attention to quality of materials, quality of supervision and construction methods
- Prepare field inspection notes as an official record of this aspect of the audit.

10. Hold exit meeting

**Objective:** To provide an opportunity for the Auditor to present and discuss his preliminary findings and conclusions to the auditees prior to writing up of the audit report. Such a meeting also provides an opportunity to agree on procedures for:
- Identifying and resolving misunderstandings or errors of fact
- Informally discussing possible solutions for addressing the problems
- Providing the basis for preparing the draft audit report
- Formalising the basis for the minutes of the exit meeting incorporating all issues discussed and recorded.

**Responsibility:** Employer/auditees/auditor

**Procedure:**
Provide feedback on preliminary findings of audit, covering all major issues identified in ToR and summarize key issues discussed, which will serve as an official record of the exit meeting.

11. Complete audit report and submit to Employer

**Objective:** To act as a formal record of the audit as seen from the Auditor’s perspective. The audit report also provides the basis for the auditees to present their comments.

**Responsibility:** Auditor

**Procedure:**
- Prepare the first draft report based on the exit meeting notes and other information collected during all stages of the audit
Guidance on preparing the audit report

General

The audit report should succinctly report on aspects of the project that are of concern to the audit team and to make recommendations for corrective actions. Recommendations may indicate the nature or direction of a solution but they do not specify the details of how to solve the concern. Responsibility for this rests with the supervising consultant and/or contractor.

Ranking system for concern

All concerns identified in the report should be of sufficient importance to require action. To assist the Employer and consultant to gauge the relevant importance of the concerns raised, a simple ranking system is desirable along the lines indicated below:

- **Serious concern**: A major concern that should be addressed and requires changes to the project to avoid serious technical problems.
- **Significant concern**: A significant concern that requires consideration of changes to improve the technical shortcomings of the project.
- **Minor concern**: A concern of lesser significance, but which should be addressed as it may improve the overall performance of the project.
- **Comment**: A concern or an action that may be outside the scope of the technical audit, but which may improve the overall design or be of wider significance.

The ranking system used should be defined in the report, and should take into account the risk of a problem occurring, and the outcome.

By their nature, technical audit reports appear to be negative documents as they typically raise only concerns. Positive design elements are not necessarily mentioned, as the assumption is that all designs contain good elements. However, a notable or excellent element which improves the performance of the project should be mentioned if appropriate.

Contractual implications

In assessing a project, the Auditor will be working within the framework of two contracts - one between the Employer and the engineer and another between the Employer and the contractor. Both contracts should be in the possession of the Auditor. The contract between the Employer and the engineer for professional services requires the contract administration to be done with due care and diligence. The contract between the Employer and the contractor is more clearly defined in the general and special conditions of contract.

Where the audit leads to the conclusion that either the engineer or the contractor has been in breach of their respective contracts and that this will lead to under performance of the final product, then the audit report should refer to the contracts and where possible the specific terms and clauses. The Employer will then be guided by the result of the audit in his decision as to whether or not to take appropriate action in terms of the contracts.

Contents of Report

In general, technical audit reports tend to contain large quantities of information but should not repeat contract data. To ensure that they are optimally utilised, they should be carefully structured. It is suggested that as much background and supporting information as possible is included in appendices or referred as separate documentation and that the audit reports themselves concentrate only on the critical issues and their implications.

Typical Table of Contents for Technical Audit Report

1. Preface
2. Executive Summary
3. Introduction
   - Background
   - Terms of Reference
   - Audit format
4. Available Information
   - A list of drawings and documents made available for the audit
   - Other supporting information used
   - Plans which identify the extent of work
5. Technical Audit
   - Introduction
   - History of Project
   - Audit Process
   - Findings, conclusions and recommendations
   - Cost Implications
6. Procedural Issues

A draft report should be circulated to the audit team members for comment, corrections and agreement. As the technical audit team has a position of independence, a draft report does not have to be provided to the Employer or consultant for their comments before it is formally provided to them.

The follow-up to the submission of the audit report to the Employer would typically be as follows:

1. Employer request to auditees to comment on draft audit report
   **Objective:** To provide an opportunity for the auditees to comment on the Auditor’s draft audit report.
   **Responsibility:** Employer
   **Procedure:** Issue the draft report to the auditees requesting their comments within two weeks on the findings, conclusions and recommendations.

2. Auditee’s comments on audit report to Employer
   **Objective:** To obtain the auditee’s comments on the draft audit report. In this regard, the auditee’s response to the Employer will:
   - Recommend whether or not each audit recommendation should be adopted
   - Document the reasons for their views
   - Indicate the cost and implications of implementing each audit recommendation.
   **Responsibility:** Auditees
   **Procedure:**
   - Prepare response to draft audit report
   - Send specified number of draft reports directly to the Employer.

3. Employer decisions on audit recommendations
   **Objective:** For the Employer to make his final decisions on the Auditor’s recommendations and to advise the auditees and the Auditor accordingly. It is the Employer who decides finally whether the recommendations of the Auditor are to be adopted. The Employer may decide to seek specialist advice in arriving at his final decisions. Where a recommendation is not adopted, the reasons should be documented by the Employer.
Responsibility: Employer

Procedure:
1. Complete the Decision Tracking Form documenting:
   • The Auditor’s recommendations
   • The auditee’s response
   • The Employer decisions.
2. Prepare brief on feedback advice including Decision Tracking Form
3. Send the brief on feedback advice to the Auditees and the Auditor.

4. Implement changes

Objective: To implement the audit recommendations decided by the Employer.

Responsibility: Employer

Procedure: Instruct the consultant or contractor to implement the recommendations as listed in the Decision Tracking Form.

Bibliography
# DECISION TRACKING FORM

**Project Title:** Assela – Dodola Road, Oromia Region  
**Type of Audit:** Stage 5 (On-going construction)  
**Employer:** ERA  
**Auditee:** Premier Contractors  
**Auditor:** PQ Consultants

<table>
<thead>
<tr>
<th>Recommendation*</th>
<th>Report Ref.</th>
<th>Auditee Comments</th>
<th>Employer Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Raise finished road level between km 20.00 and km 20+800</td>
<td>ERA/PQ-1/3</td>
<td>Will delay completion of project by 70 days. Estimated additional cost of Birr 120,000 based on tendered rates.</td>
<td>Auditor’s recommendation upheld. Contractor to raise finished road as recommended by Auditor. Additional costs and project prolongation estimated by the Contractor is accepted by the Employer.</td>
</tr>
</tbody>
</table>
| **Reason:** Road likely to be overtopped during rainy season.  
**Cost:** Estimated at Birr100,000  
**Implications:** Prolongation of project by approx. 60 days.  
**Ranking:** Serious concern. |
| 2. Base course layer between km 30+000 and km 30+200 to be removed and replaced with appropriate quality material. | ERA/PQ-1/3 | Supervising Consultant did not condemn the use of the material. | Auditor’s recommendation upheld. Contractor to comply with Auditor’s recommendation at no additional cost to Employer. Contractor has a primary obligation to the Employer to comply with the Contract specification. |
| **Reason:** Material not compliant with Contract specification.  
**Cost:** N/A.  
**Implications:** None.  
**Ranking:** Significant concern. |
| 3. Supervising Consultant to verify quantities certified for prime coat. | ERA/PQ-1/5 | None. | Auditor’s recommendation upheld. Supervising Consultant to verify quantities. |
| **Cost:** None.  
**Reason:** Quantities over-estimated by 25%.  
**Implications:** Possible need to adjust next payment certificate  
**Ranking:** Significant concern. |
APPENDIX D.1: Material selection and quality assurance for labour-based unsealed road projects

Contents

1. Material specifications
2. Borrow material testing
3. Construction quality assurance testing
4. Contents of CSIR testing kit
5. References

Acknowledgements

This annex is based on ASIST Information Service Technical Brief No 9 published by International Labour Organisation in 1998. It was produced by ASIST Information Service with financial support from the Swiss Agency for Development and Cooperation (SDC). The original work was undertaken by Dr P Paige-Green of the Division of Roads and Transport Technology (Transportek) of the CSIR in Pretoria. Transportek also put together a Gravel Road Test Kit for use with this brief.
List of abbreviations and definitions

**AASHTO**
American Association of State Highway and Transportation Officials. This association adopted a test proposed by the US War Department in 1943, to cater for larger earth moving and compaction equipment. It is now referred to as the AASHTO test.

**ASIST**
Advisory Support, Information Services and Training for labour-based technology.

**Atterberg limits**
Atterberg limits are measured for soil materials passing the No. 40 sieve: the shrinkage limit (SL) is the maximum water content at which a reduction in water content will not cause a decrease in the volume of the soil mass. This defines the arbitrary limit between the solid and semisolid states. The plastic limit (PL) is the water content corresponding to an arbitrary limit between the plastic and semisolid states of consistency of a soil. The liquid limit (LL) is the water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil.

**BLS**
Bar linear shrinkage.

**BS**
British Standard.

**BS 1377**
Defines the British Standard compaction test, introduced by R. R. Proctor in 1933. It used a compactive effort which roughly corresponded to that available in the field at the time.

**CBR**
California Bearing Ratio. A measure of soil strength, determined from the load required to penetrate the surface of the compacted soil, expressed as a percentage of a standard value.

**Clegg Hammer**
A simple device utilising a decelerometer, installed in a modified Proctor compaction hammer, to evaluate the stiffness of a material by measuring the deceleration encountered when the falling hammer meets the material.

**DCP**
Dynamic Cone Penetrometer. Apparatus for estimating the in situ shear strength of a material by dynamically driving a standard cone through the material. In situ CBR and layer types may be estimated using the DCP.

**Grading Coefficient (Gc)**
A measure of the potential for particle interlock defined by the product of the gravel component of the material (the percentage retained between the 26.5 and 2 mm sieves) and the percentage passing the 4.75 mm sieve. \( G_c = (\% \text{ passing } 26.5\text{mm} - \% \text{ passing } 2\text{mm}) \times \% \text{ passing } 4.75\text{mm}/100 \)

**Maximum dry density (MDD)**
The maximum dry density which can be achieved under a specified compaction effort at the optimum moisture content.

**Optimum moisture content (OMC)**
The moisture content at which the maximum dry density for any combination of material and compaction effort is obtained. The importance of this is particularly relevant to labour-based projects as the compaction effort using small pedestrian rollers can seldom be equated to the traditional AASHTO and BS compaction efforts. Higher OMCs will often be necessary to achieve maximum density for these efforts.
**Oversize index (Io)**
The stoniness as defined by the percentage of material larger than 37.5 mm.

**Proctor**
Mr. R. R. Proctor was the author of the original BS compaction standard. The compactive effort is supplied by a 2.5 kg hammer with a 50 mm diameter head falling freely from 300 mm above the top of the soil sample.

**Rapid Compaction Control Device (RCCD)**
A simple impact penetrometer which injects a small cone into the material to estimate the shear strength of the material.

**Ravelling**
A process where the surface material of a road is broken down by traffic to form loose material (e.g. gravel). The process is likely to occur where there is a deficiency of fine material, low cohesion between particles, poor particle size distribution, and inadequate compaction.

**Shrinkage Product (Sp)**
A measure of the plasticity of the soil defined by the product of the bar linear shrinkage and the percentage passing the 0.425 mm sieve.

**vpd**
Vehicles per day. That is, a count of the number of vehicles passing along a road in one day.
1. MATERIAL SPECIFICATIONS

The performance of any unsealed road is primarily a function of the materials from which the road is constructed. It is therefore essential that the best available materials which comply with, or are as close as possible to, the appropriate material requirements be used for construction. These material requirements need, of necessity, to be simply and rapidly determined at low cost to allow sufficient samples to be tested prior to use on the road.

Numerous material specifications have been developed and utilised over time in various countries, which take into account the local material and environmental conditions. Most specifications, however, have been derived from the original AASHTO requirements which are primarily based on theoretical considerations for maximum particle packing of low plasticity materials (the dominant material derived from glacial tills in the northern United States). Experience has shown that materials with low plasticity lack adequate cohesion to resist ravelling, or the formation of corrugations, under traffic.

Regional specifications were subsequently adapted to allow for slightly higher plasticities, but in very few cases was the lower limit for plasticity specified. For this reason, variable success was obtained using the available specifications.

Various projects to determine performance-related specifications for unsealed road materials were therefore carried out in South Africa and Namibia during the 1980s and early 1990s (see References 1, 2, 3, and 4). These specifications were evaluated in a number of regions and countries and generally found to be more appropriate than those previously used (and in many cases more appropriate than even those currently used).

The traditional properties used in existing material specifications for unsealed roads are particle size distribution, Atterberg limits, remoulded strength, and aggregate hardness. These are similar to those found by local research to be necessary. All these parameters are critical to the performance of materials in unsealed roads, but the traditional methods of defining and evaluating them are considered to be inappropriate for labour-based projects.

The material specifications recommended for the selection of borrow materials for wearing courses for unsealed roads using labour-based construction methods are given in Table 1.1. These should be the desired specifications for a project. Testing of all potential borrow materials for compliance with these should optimally be carried out during the borrow pit or initial materials evaluation. This should be done by a central laboratory for a Public Authority, or by a commercial laboratory, using traditional test methods, e.g. those contained in TMH 1 (see References 6 and 7).

If no central laboratory is available, or if the results from the laboratory are delayed, all the above testing except the soaked CBR can be determined in a simple field ‘laboratory’ using minimal equipment. If full testing facilities do not exist and if the road is likely to carry less than 50 vehicles per day with less than 10 per cent heavy vehicles, the Shrinkage Product and Grading Coefficient alone can be taken as the preliminary acceptance criteria. The material strength (CBR) can be evaluated during proof rolling trials as discussed in Chapter 3. Full test methods are provided in Chapter 3.
Table 1: Material specifications for labour-based road projects

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum size (mm)</td>
<td>37.5</td>
</tr>
<tr>
<td>Oversize Index (Io)</td>
<td>5 %</td>
</tr>
<tr>
<td>Shrinkage product (Sp)</td>
<td>100 – 365</td>
</tr>
<tr>
<td>Grading coefficient (Gc)</td>
<td>16 – 34</td>
</tr>
<tr>
<td>Soaked CBR (%)</td>
<td>15 at 95 % Modified AASHTO density</td>
</tr>
<tr>
<td>Treton Impact value (%)</td>
<td>20 – 65</td>
</tr>
</tbody>
</table>

Io = Percentage retained on 37.5 mm sieve  
Sp = Bar Linear shrinkage × per cent passing 0.425 mm sieve  
Gc = (Per cent passing 26.5 mm − per cent passing 2.0 mm) × per cent passing 4.75 mm/100

The relationship between the Shrinkage Product and the Grading Coefficient is directly related to the performance as shown in Figure 1, with Zone E being the recommended area for best performance. This Figure shows the predicted performance and the implications (potential problems) of using material not falling within the specified limits.

2. BORROW MATERIAL TESTING

2.1 General

It is essential that, during the initial proposal stage for any project, suitable borrow pits are located, the materials are adequately tested for compliance with the specifications given in Chapter 1, and the suitable borrow areas are carefully delineated in the field. In most cases, this should be carried out by the regional soils laboratory, as far as possible using traditional test methods and equipment as discussed in Chapter 1. Problems have, however, been encountered in the past, with the test results often only becoming available after construction has commenced. The following methods are proposed for control testing of materials during construction, but could also be used to replace or complement the initial borrow investigations where problems with obtaining results in time are encountered.

2.2 Test Requirements

Traditional test techniques have been developed, based on the assumption that various basic services and facilities are available. On many labour-based projects, certain simple assumptions, such as that electricity and running water will be available, are invalid. As far as possible, solar energy, local water
(preferably potable), and unsophisticated equipment are utilised. It is assumed that everyday objects such as batteries are available.

The specifications discussed in the previous chapter are mostly based on simple tests which can be carried out rapidly on site using minimal equipment. The following parameters should be evaluated:

- Grading
- Shrinkage
- Aggregate hardness
- Material strength.

2.2.1 Grading

The grading requirements for the characterisation of material for unpaved roads are based on only five sieve sizes, that is 37.5 mm, 26.5 mm, 4.75 mm, 2 mm, and 0.425 mm. For the testing, the material needs first to be dried, the mass determined, and then the material sieved (manual shaking) through the recommended sieves above with a soft brush being used where necessary. Air drying in direct sunlight is adequate for most materials which are potentially suitable, although the use of a solar oven is recommended. The mass of each portion is determined. The oversize index, grading coefficient and percentage passing the 0.425 mm sieve can then be determined. It should be noted that the influence of the hygroscopic moisture content on the parameters determined is negligible. The fraction passing the 0.425 mm sieve should be retained for shrinkage testing.

2.2.2 Shrinkage

The bar linear shrinkage test is carried out on the fraction passing the 0.425 mm sieve. The material should be moistened until it is at or very near the liquid limit (this can be checked with a simple fall-cone device (see Section 2.4)), placed in the mould, and oven-dried at 105°C until all shrinkage has stopped. The length of the sample is then measured and the percentage shrinkage calculated. It is recommended that the sample is dried for at least 12 hours (overnight if not done in a solar oven), but experience has shown that this can take as little as four or five hours, depending on the soil. The length of time necessary can be checked by drying to constant mass. However, preliminary research has shown that air-drying of samples is not effective for repeatable results.

2.2.3 Aggregate hardness

Aggregate hardness measurements are necessary to identify those materials which will disintegrate under rolling or traffic, as well as those which are excessively hard and will result in a rough road if too much of this type of material is included. The Treton test is used to determine this. The Treton impact value is determined by means of a simple impact hammer action on a single sized sample (obtained during the sieve analysis). This test is unnecessary if the road is unlikely to carry many buses or heavy vehicles (more than two per day) or if the material lacks a significant proportion of medium to coarse gravel (< 15 per cent retained on a 16 mm sieve).

2.2.4 Material strength

Material strength is an indication of the capacity of the material to support the wheel loads of the traffic using the road. The traditional method for determining this property is the soaked California Bearing Ratio (CBR) test. This test is routinely carried out in a central or typical site laboratory but is expensive to set up, requires a large amount of equipment, and is relatively time consuming.

As an alternative, it is considered more practical to first carefully compact a sample of the material, at the estimated optimum moisture content, to the required thickness on a subgrade prepared to the same standard as that which will be used in construction. Then to measure the resistance to penetration with a Dynamic Cone Penetrometer (DCP) (see Figure 2), a Rapid Compaction Control Device (RCCD) (see Figure 3) or a Clegg Hammer. The moisture content at the time of testing (assumed to be at or about OMC) should be taken into account. Acceptable values of penetration for the DCP and RCCD are given in Table 2.
Table 2: Penetration rates of DCP and RCCD for equivalent soaked CBR values of 15 % (tested at OMC)

<table>
<thead>
<tr>
<th>Apparatus</th>
<th>Penetration rate (mm/blow)</th>
<th>Penetration (3 blows) (mm)</th>
<th>Penetration (20 blows) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCP</td>
<td>5</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>RCCD</td>
<td>9</td>
<td>27</td>
<td>—</td>
</tr>
</tbody>
</table>

Figure 2: DCP test apparatus
The RCCD is recommended for use since the test is simpler and quicker. The apparatus is more robust (only periodic calibration of the spring is necessary), but less bulky than that required for the other two methods of control, and it has less operator variability. More tests per job lot (day’s production) can be carried out more economically with the RCCD than with the other methods. However, the DCP penetration rates given in Table 2 can also be used for material characterisation and control purposes.

Selection of materials based on the specified Gc and Sp will in most cases exclude those which are likely to have insufficient CBR strength.

2.3 Frequency of Laboratory Testing

The frequency of testing of borrow pits needs to strike a balance between cost and time and statistical validity of the results. It is proposed that, even for labour-based projects, the location of borrow materials and borrow-pit testing should preferably be done according to traditional methods. If full laboratory facilities are not available, the methods described in this report can be substituted.

The frequency of testing will depend on the variability of the material: the more homogeneous the material the less the amount of testing necessary for statistical validity of the results. Unless proper testing of the borrow materials is carried out prior to commencement of the project, it is usually not possible to quantify the variability in advance of construction. For projects of this nature it is thus necessary to test samples from at least five locations per borrow pit (covering the full depth of the layer to be used) in order to quantify the variability. The sample locations should be randomly selected within the pit. This variability is used as an indication of the variation to be expected within the borrow pit, and for a simple process control technique during the construction operation.
It is recommended that at least ten RCCD or DCP tests (at least two per square metre) be carried out at points selected in a stratified random pattern when compaction is tested during proof rolling.

2.4 FULL TEST METHODS

2.4.1 Sieve analysis for grading coefficient

SCOPE
In this method, a soil, sand or gravel sample is separated by dry sieving for determination of the grading coefficient and to prepare fine material for the bar linear shrinkage test.

APPARATUS
- Sheet of canvas 1 metre by 1 metre for coning and quartering of the material
- The following test sieves: 37.5 mm, 26.5 mm, 4.75 mm, 2 mm and 0.425 mm with pan and cover
- Balance with pan, accurate to 1 g, to weigh up to 5 kg
- Various pans of 250 to 300 mm diameter and 20 mm deep
- Drying oven (Solar) to maintain a temperature between 105 and 110°C
- Various stiff brushes
- Thermometer (0 to 120°C)

METHOD
Size of sample. The size of the test sample should be such that at least 100 g of material passes the 0.425 mm sieve, but not less than 2 kg in all. This should be prepared from a bulk sample of at least 5 kg by coning and quartering on the canvas sheet.

Preparation of the sample. Air-dry the sample until it is friable and particles separate with ease. If the sample is still too wet, it should be dried in an oven at a temperature not exceeding 50°C.

Dry sieving. Dry sieve the material as follows: shake the material through each sieve in turn, starting at the 37.5 mm sieve, until further shaking results in minimal additional material passing each sieve. The larger particles (> 4.75 mm) should be brushed with a stiff bristle brush to remove all fines adhering to them. Determine the mass of the soil fines (< 0.425 mm) and transfer these to a marked paper bag. It is recommended that they are dried in a solar oven prior to being weighed but, if this will delay the testing, this step may be omitted since the use of air-dried weights will not affect the results unduly.

Determination of the particle size distribution. The masses of the individual fractions retained on each sieve should be determined (preferably after being oven-dried but after air-drying if necessary). The masses of these fractions should be determined to the nearest 1 g. Record the masses retained on each sieve and that of the material passing the 0.425 mm sieve.

CALCULATIONS
1. Calculate the total mass of material as the sum of the masses retained on the individual sieves as well as of that passing the 0.425 mm sieve.
2. Calculate the cumulative percentages passing each sieve (by mass of the total dry sample) accurately to the nearest 1 per cent. All results should be normalised to 100 per cent passing the 37.5 mm sieve by multiplying the percentage passing each sieve by the percentage passing the 37.5 mm sieve (P37) divided by 100. If 100 per cent passes the 37.5 mm sieve, this step is not necessary.
3. Calculate the grading coefficient. This is the percentage material passing the 26.5 mm sieve and retained on the 2 mm sieve, multiplied by the percentage passing the 4.75 mm sieve, as follows:

   \[ G_c = \frac{(P_{26} - P_2) \times P_{475}}{100} \]
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Where \( P_{26} \) = cumulative percentage passing the 26.5 mm sieve \( P_2 \) = cumulative percentage passing the 2 mm sieve \( P_{4.75} \) = cumulative percentage passing the 4.75 mm sieve.

The oversize index is defined as the percentage of the total material retained on the 37.5 mm sieve.

**INTERPRETATION**

The limits for the grading coefficient are shown in Figure 1 and should be between 16 and 34. A maximum oversize index of 5 per cent is permitted to retain a good riding quality over time.

### 2.4.2 Determination of the linear shrinkage of soils

**SCOPE**

This method covers the determination of the linear shrinkage of soil when it is dried from a moisture content equivalent to the liquid limit to the oven-dry state.

Definition: The linear shrinkage of a soil, for the moisture content equivalent to the liquid limit, is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.

**APPARATUS**

- A shrinkage mould made from 10 mm stainless steel bar with internal dimensions of 150 mm ± 0.25 mm long x 10 mm ± 0.25 mm wide x 10 mm ± 0.25 mm deep, and open on two sides (see Figure 4)
- A stainless steel plate to fit under the shrinkage mould
- A small thick-bristle paint brush, about 5 mm wide
- Silicone lubricant spray (e.g. Q20 or WD40)
- A spatula with a slightly flexible blade about 100 mm long and 20 mm wide
- A solar drying oven
- A pair of dividers and a millimetre scale
- A standard cup, drop cone and guide-tube for estimating the liquid limit
- A thermometer (0 to 120 °C).

**METHOD**

**Waxing the mould.** The interior of a clean, dry shrinkage mould is sprayed evenly with the silicone lubricant

**Filling the mould.** The moisture content at which the test is carried out must be as close to the liquid limit as practically possible. A simplified drop-cone device based on the British Standard liquid limit method...
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is used to ensure that the moisture content is correct. Sufficient material to fill the cup provided should be mixed up and placed evenly in the cup to a level between 2 and 5 mm below the rim of the cup. The cone should be placed in the guide tube on the surface of the soil in the cup and allowed to penetrate for five seconds. The cone should penetrate to a depth of 20 mm, equivalent to the calibration mark on the cone. If the penetration is below this mark, the material is too dry and additional water is required. The material would then need thorough re-mixing before the penetration test is repeated. If the penetration is too high (i.e. the cone sinks into the material to a depth above the calibration mark), the material is too wet and needs to be dried out by mixing in sunlight until repetition of the penetration test gives a result within the defined limits.

The lubricated mould should be placed on the plate provided, and one half should be filled with the moist soil by taking small pieces of soil on the spatula and pressing the soil down against one end of the mould. Then work along the mould until the whole side is filled and the soil forms a diagonal surface from the top of one side to the bottom of the opposite side (see Figure 5(a)).

The mould is now turned round and the other portion is filled in the same manner (see Figure 5(b)). The hollow along the top of the mould is now filled so that the soil is raised slightly above the sides of the mould (see Figure 5(c)). The excess material is removed by drawing the blade of the spatula once only from one end of the mould to the other. The index finger is pressed down on the blade so that the blade moves along the sides of the mould (see Figure 5(d)). During this process the wet soil may pull away from the end of the mould, in which case it should be pushed back gently with the spatula.

NB: The soil surface should on no account be smoothed or finished off with a wet spatula.

![Figure 5: Preparation of material for shrinkage test](image)

Drying the wet material, the mould with wet material is now placed in the solar oven and dried at a temperature of between 105 and 110°C (the lid may need to be partially opened to maintain a reasonably constant temperature) until no further shrinkage can be detected. As a rule, the material is dried out for 12 hours, although three hours should be sufficient time in the oven. The mould (with the material) is taken out of the oven and allowed to cool in the air.

Measuring the shrinkage, it may be found that the ends of the dry soil bar have a slight lip or projecting piece at the top. These lips must be removed by abrading with a sharp, narrow spatula, so that the end of the soil bar is parallel to the end of the mould (see Figure 5(e)). If the soil bar is curved, it should be pressed back into the mould with the fingertips so as to make the top surface as level as possible.

The loose dust and sand removed from the ends, as well as any loose material between cracks, should be emptied out of the mould by carefully inverting it whilst the material is held in position with the fingers.
The soil bar is then pressed tightly against one end of the mould. It will be noticed that the soil bar fits better at one end than at the other end. The bar should be pressed tightly against the end at which there is a better fit. The distance between the other end of the soil bar and the respective end of the mould, is measured by means of a good pair of dividers, measuring on a millimetre scale, to the nearest 0.5 mm, and recorded.

**CALCULATIONS**

The bar linear shrinkage (BLS) is calculated as follows:

\[
\text{BLS} = \text{LS} \times 0.67 \, (\%)
\]

where \( \text{LS} \) = linear shrinkage in mm.

**NOTES**

After being tested, the soil bar should be examined to ensure that the corners of the mould were filled properly and that no air pockets were contained in the soil bar. If there are air pockets, the test should be repeated.

**INTERPRETATION**

A value for the shrinkage product in excess of 100 is required but it should not exceed 365, otherwise slipperiness will result when the material is wet.

### 2.3.1 The determination of the compacted strength of material

**SCOPE**

The objective of this procedure is to ensure that the compacted strength of the borrowed material as placed in the field complies with the acceptance testing carried out on the borrow material. Secondary objectives of this procedure are to identify the limit to be used for control testing after compaction and to identify the number of roller passes for optimum compaction.

**APPARATUS**

- Compactor equivalent to that proposed for use
- DCP or RCCD apparatus.

**METHOD**

**STEP 1** A sufficient quantity of the proposed material (between 4.0 and 4.5 cubic metres) should be dumped on a section of the proposed subgrade prepared to the same standard as that of the proposed road. Water should be added to bring this material to its estimated optimum moisture content.

**STEP 2** The moist material should be spread to a thickness which will provide a compacted thickness equivalent to the design thickness of the layer.

**STEP 3** Using the compaction method and plant which will be used during full construction, a complete roller pass should be given to the layer. The strength of the layer is then determined using a DCP or RCCD and the results recorded on the field test data form provided.

**STEP 4** Repeat Step 3, plotting the penetration rate obtained from testing against the number of roller passes until no further strengthening of the material occurs (i.e. until the measured penetration rate reaches a minimum). This identifies both the number of passes above which no additional benefit from rolling is obtained, and the final maximum strength of the material at compaction moisture content.

**INTERPRETATION**

The maximum strength of the material should comply with the requirements given in Table 2‘
STEP 5 If the strength requirements are not met, either the material has inadequate strength to resist deformation or to avoid becoming slippery when wet, or additional compaction energy is required in order to achieve a higher density and increase the strength of the material.

A minimum soaked equivalent CBR strength of 15 per cent is required for acceptable passability and trafficability. This is related to the DCP and RCCD results as indicated in the Table 2.

2.4.3 The determination of the Treton impact value of aggregate

SCOPE

The Treton value is an indication of the resistance of aggregate to impact. The aggregate is subjected to ten blows of a falling hammer and the resulting disintegration is measured in terms of the quantity passing the 2 mm sieve, which is then expressed as a percentage of the mass of the test sample. This is called the Treton value.

APPARATUS

- A Treton apparatus consisting of a base plate, anvil, cylinder, and a hammer weighing 15 kg ± 50 g (see Figure 6). The base plate should be placed on a firm concrete block.
- The following test sieves, all 200 mm in diameter: 19.0 mm, 16.0 mm and 2 mm. The bigger sieves should be made of perforated plate and the 2 mm sieve of wire mesh.
- A balance to weigh up to 200 g, accurate to 1 g.

METHOD

From the field sample, screen out a sufficient quantity (at least 200 g) of the fraction between 19 mm and 16 mm (see Note (i)). Select a sample of 15 to 20 of the most cubical pieces, so that their total mass (in grams) will be as close as possible to 50 times the relative density of the aggregate in grams (it is not necessary to determine the relative density. An estimate will be satisfactory (2.65 for granitic and sedimentary materials and 2.9 for dark basaltic and metamorphic materials)). Weigh the sample accurately to 1 g, and place the particles as evenly spaced as possible on the anvil in such a manner that their tops are approximately in the same horizontal plane.

Place the cylinder over the anvil and tighten the clamp screws. Place the hammer in the cylinder so that the top of the hammer is level with the top of the cylinder and let it drop ten times from this position. Remove the cylinder, and sieve all the aggregate on the anvil and base plate thoroughly through a 2 mm sieve. Weigh the aggregate retained on the sieve to the nearest 1 g, and record the mass. The test should be carried out in triplicate (see Note (ii)).

CALCULATIONS

Calculate the Treton value to the first decimal place as follows and report to the nearest whole number:

\[
\text{Treton value} = \frac{A - B}{A} \times 100
\]

Where

- \( A \) = the mass of the stone particles before tamping (g)
- \( B \) = the mass of the stone particles retained on the 2 mm sieve after tamping (g).

NOTES

i. If the aggregate is noticeably variable as regards type or hardness, each type should be tested and reported separately. In this case an estimate should be made of the percentage of each type and a weighted average determined.

ii. The Treton value, as reported, should be the average of three determinations. If any individual result differs from the others by more than five units, further tests should be carried out.
iii. INTERPRETATION

Recommended Treton impact values should lie between 20 and 65. Materials with values less than 20 will be too hard and cause excessive roughness whilst those with values higher than 65 will be too soft and break down under traffic.

Figure 6: Treton apparatus
3. CONSTRUCTION QUALITY ASSURANCE TESTING

3.1 Material Testing and Control

The properties of the material should be tested on a regular basis during construction to ensure that they do not differ from the accepted specification. For control testing purposes, only the grading coefficient and shrinkage product need be tested.

This testing shall be done daily to ensure that the material to be used for the following job lot complies with the specifications. It is recommended that samples of the material to be used the next day (or for the next job lot if a weekend follows) be taken during the morning and tested so that the material can be approved first thing in the morning before use. The test techniques are such that this is possible. The individual results of the borrow pit testing should be plotted on Figure 1 with the mean and standard deviations of the two parameters which can be used to define a rectangle. At least 90 per cent of the routine daily test results should plot in this rectangle as work in the borrow pit progresses. The test results should be plotted on this figure on an ongoing basis. If there is a trend to move out of the rectangle towards the limits of the E block (in Figure 1), this would be indicative of a change in the material properties. Additional testing should then be carried out to determine the cause of this and to identify remedial action, e.g. blending of different materials, redefinition of the boundaries of the borrow pit, or adjustment of the depth of excavation, etc.

3.2 Construction Quality Assurance

A number of factors should be controlled during construction. These include:

- Moisture content
- Thickness
- Compaction
- General finish.

3.2.1 Moisture content

One of the principal factors in the construction process, and which affects the final compaction, is the moisture content. In most soil materials the natural variation in optimum moisture content (OMC) is wider than the limits around OMC permitted for successful compaction. In addition, the actual process of adding and mixing water to soil materials, particularly in labour-based projects, often leads to significant variation of the moisture content within the material. In addition, most moisture content determinations are slow (except for nuclear methods, but these are often unreliable for moisture contents of natural gravels) and the results are frequently only available after compaction is completed. For this reason, the manual control of the moisture after laboratory calibration of the “feel” of the material at various moisture contents at and around optimum is considered the most practical and effective solution.

In most cases, the test techniques for moisture content render the results practically meaningless in the context of labour-based construction. The process of moistening the material, (whether this is done in the borrow-pit or on the road) is not discussed here.

The control of moisture during construction should be carried out visually by squeezing a sample of the material as tightly as possible in the hand. The material should be moist enough to stick together when squeezed without any visible sign of free water on the surface. If the material disintegrates, it is too dry for compaction. If free water is ejected or if the soil sticks to the hand, it is too wet. If the “sausage” formed by squeezing in the hand is squeezed diametrically between the thumb and forefinger, it should break with some crumbling. It should not break by deformation under the finger pressure, nor should there be excessive crumbling. It should be noted that non-cohesive soils behave differently, but that all materials for wearing courses should have some cohesion. The above technique is considered most practical and suitable for the purpose. If possible, this method should be practised in the laboratory with material at various known moisture contents, and correlated with the laboratory determined optimum moisture content to “get the feel” prior to commencement of compaction.
It is currently difficult to correct the field strength for any deviation from the expected moisture content at the time of testing. The following approximate model is based on the combination of various parameters (soaked CBR (CBRs) and optimum moisture content (OMC)) and models. It has been developed to assist with evaluating whether the results are in the right range for the DCP and RCCD penetration rates (\(D_{nc}\) and \(RCCD_{nc}\)) immediately after compaction at compaction moisture content (CMC):

\[
D_{nc} = 0.144 \left( e^{\frac{-1.33 \times \text{OMC}}{\text{OMC}}} \right)^{CBR \times 0.46}^{0.787}
\]

\[
RCCD_{nc} = 0.075 \left( e^{\frac{-1.33 \times \text{OMC}}{\text{OMC}}} \right)^{CBR \times 0.46}^{0.775}
\]

### 3.2.2 Thickness

It is important that the thickness of the material be closely controlled. This should be controlled prior to compaction, with allowance for the bulking factor. Spreading of the material should be as consistent as possible to ensure that all material is placed at a similar loose density. The bulking factor is usually between 25 and 35 per cent, depending on the gradation of the material and on the compaction effort, but this should be determined accurately during the initial proof rolling of the material.

Control of the thickness during construction is carried out by inserting a calibrated probe (Figure 7) through the uncompacted material to confirm that the thickness prior to compaction is equivalent to the required final layer thickness plus a correction for bulking. The bulking factor should be determined during the proof rolling by measurement of the thickness before and after rolling. It can also be estimated by comparison of the mass of a known volume (best done in a large measuring cylinder) with the maximum dry density of the material determined in the laboratory. In most cases a bulking value of 30 to 35 per cent may be assumed. One advantage of knowing the bulking factor accurately is that this can be used to ensure that adequate compaction has been achieved by monitoring the initial and final thickness of the layer.

Thickness before compaction = design thickness \(\times (1 + BF \% / 100)\),

where BF is the percentage bulking factor for the material.

### 3.2.3 Compaction

The compaction achieved in the field is arguably the most important aspect of the construction process. It is neither economically nor practically possible to determine sufficient densities on labour-based projects for construction quality control, to take into account the natural variability of the material. It is thus recommended that a simple device such as the Rapid Compaction Control Device (RCCD) or DCP be used for this purpose. Both tests are quick and repeatable and many tests can be done at little cost.

If the test results show up areas which are unacceptable, the reasons for this should be investigated. Poor results can be attributed to the use of material that is too wet, material that has not received adequate compaction effort, or to the presence of a pocket of poor quality material. The actual cause should be identified and corrective action taken. This may involve scarifying and drying out prior to recompaction if the material is too wet, additional compaction if necessary, or replacement of poor material where appropriate.

A simple method of sand replacement density determination can be carried out, but it is difficult to relate this to a standard for the evaluation of relative compaction in highly variable natural materials. To determine relative compaction, the density in the road should be compared with the actual laboratory maximum dry density (MDD) for that material. This would require an MDD test to be done on the identical material tested in situ. This is neither practical nor economical.
3.2.4 Visual inspection

It is imperative that supervisors are trained to carry out a comprehensive visual inspection of the completed layer prior to excessive drying out of the material. This inspection should be carried out during the latter part of the shift prior to demobilization of staff and plant for the day. It should be extremely thorough and should cover the total job lot completed in the shift. During this inspection, large stones, excessively moist areas, poorly compacted areas, bumps and depressions, areas of thin material, material segregation, etc. should be located and the appropriate remedial action taken.

4. CONTENTS OF CSIR TESTING KIT

The following are the basic contents of the CSIR field testing kit. Certain items (e.g. balance and oven), which are necessary in one test, are not repeated in the requirements for subsequent tests.

Grading
- Sheets of canvas 1 metre by 1 metre for coning and quartering material.
- Test sieves: 37.5 mm, 26.5 mm, 4.75 mm, 2 mm and 0.425 mm with pan and cover.
- Balance with pan, accurate to 1 g, to weigh up to 5 kg.
- Various pans of 250 to 300 mm diameter and 20 mm deep.
- Drying oven (Solar) to maintain a temperature between 105 and 110°C.
- Various stiff brushes.
- Electronic calculator (Solar powered).
- Wind shield for balance.
- Levelling platform for balance.
- Thermometer (0 to 120°C).

Linear shrinkage
- Shrinkage moulds with internal dimensions of 150 ± 0.25 mm long x 10 ± 0.25 mm wide x 10 ± 0.25 mm deep and made of 10 mm thick stainless steel bar, open on two sides.
- A steel plate to fit underneath the shrinkage moulds.
- Silicone lubricant spray (e.g. Q20 or WD40).
- A spatula with a slightly flexible blade about 100 mm long and 20 mm wide.
- A pair of dividers and a millimetre scale.
- A standard drop cone and calibrated tube for estimating the liquid limit.

Material strength
- RCCD or DCP test apparatus.

Aggregate strength (Treton)
- A Treton apparatus consisting of a base plate, anvil, cylinder and a hammer weighing 15 kg ± 50 g. The baseplate should be placed on a firm concrete block.
- The following test sieves, 200 mm in diameter: 19.0 mm, 16.0 mm and 2 mm. The larger sieves should be made of perforated plate and the 2 mm sieve of wire mesh.

Thickness
- Thickness probe.

Forms
The following forms are recommended for use in recording the test results.
LABORATORY TEST RESULTS

PROJECT: ___________________________ DATE: ___________________________

SAMPLE NUMBER: _________________________ OVEN DRIED: YES [ ] NO [ ]

SAMPLE LOCATION: __________________________________________________

GRADING ANALYSIS

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Mass retained (g)</th>
<th>% of total retained</th>
<th>Cumulative % passing</th>
<th>Normalised cumulative % passing</th>
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<tbody>
<tr>
<td>37.5</td>
<td></td>
<td></td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>26.5</td>
<td></td>
<td></td>
<td>A</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>0.425</td>
<td></td>
<td></td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>&lt; 0.425</td>
<td></td>
<td></td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

\[ G_c = (A - B) \times \frac{C}{100} = (........ - ........) \times (......./100) = ............... \]

\[ I_o = 100 - D = (100 - .......) = ............. \]

LINEAR SHRINKAGE

<table>
<thead>
<tr>
<th>Mould Number</th>
<th>Linear shrinkage (LS) mm</th>
<th>Bar linear shrinkage (BLS)* mm</th>
<th>Shrinkage product (SP)**</th>
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</thead>
<tbody>
<tr>
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</tbody>
</table>

* BLS = LS x 0.67

** SP = Mean BLS x Percent passing 0.425 mm

TRETON IMPACT VALUE

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Total Mass (A) g</th>
<th>Mass Retained on 2 mm Sieve (B) g</th>
<th>Treton value*</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

* Treton value = \((A - B)/A\) x 100

Operator: ___________________________
FIELD TEST RESULTS

PROJECT: __________________________________________ DATE: ______________________

TEST NUMBER: _______________________________________________________________________

TEST LOCATION: _____________________________________________________________________

COMPACTED STRENGTH

<table>
<thead>
<tr>
<th>Pass number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCCD reading (3 blows)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DCP penetration (mm/blow)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

THICKNESS

(25 readings in mm from the probe per job lot)

Operator: __________________________________________
5. REFERENCES


5. Secondary and feeder road development programme. Final report. 1995. Swedish National Road Administration (SweRoad), Solna, Sweden.


