Government of Nepal

Ministry of Physical Infrastructure and Transport

Department of Roads

Quality Research and Development Center

Chakupat, Lalitpur

Guideline for Design, Construction and Maintenance of Gravel Road

2024

(Final Draft)

FOREWORD

PREFACE

Gravel roads play a vital role in the transportation infrastructure of rural and less-developed areas, providing essential access to remote communities, agricultural zones, and natural resources. Despite the rise in more advanced paving technologies, gravel roads continue to be a practical and cost-effective solution in many parts of the world. The effective design, construction, and maintenance of these roads are crucial for ensuring their long-term sustainability, safety, and efficiency.

This Guideline for Design, Construction, and Maintenance of Gravel Roads is intended to serve as a comprehensive resource for DoR engineers, consultants, contractors, and local authorities involved in the development and upkeep of gravel road networks. It presents a structured approach that incorporates best practices, technical standards, and practical recommendations for each phase of the gravel road lifecycle.

The guidelines address key aspects such as proper site selection, material specifications, road geometry, construction techniques, and routine maintenance practices. By following these guidelines, stakeholders can enhance the performance of gravel roads, reduce maintenance costs, and ensure a higher standard of road quality that meets both local needs and sustainability goals.

Transport Research Laboratory (TRL) reports, IRC:SP:77-2008, Manual for design, Construction & Maintenance of Gravel roads, ILO Reports, Manual for low volume roads,Ghana and many more resources have been sighted while drafting the Guideline.

This Guideline will assist in developing optimal designs that use locally occurring natural resources, encourage the use of labour-based construction methods where appropriate and ensure value for money. It is for use as a point of reference for engineering and allied practitioners alike and serves as an excellent guide for the design of low volume roads.

It is our hope that this document will contribute to the creation of safer, more reliable, and environmentally responsible gravel roads that support the economic and social development of rural and underserved communities.

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… 2024

TABLE OF CONTENTS

1.0 GENERAL

1.1 Purpose of the Guideline

The guideline for Low Volume Roads (LVRs) promotes the rational, appropriate and affordable provision of LVRs in Nepal. It is intended for use by roads practitioners responsible for the design and construction of low traffic gravel roads. Gravel road pavements are generally utilized for roads where design traffic flow Annual Average Daily Traffic (AADT) is less than 200.

1.2 Application of appropriate standards

In keeping with the government policies, the application of appropriate design standards for LVRs aims to optimize construction and maintenance costs and meet the requirement to:

- improve the economic and social well-being of rural communities and their access to social and other services;
- lower road user costs and promote socio-economic development, poverty reduction, trade growth and wealth creation in rural areas;
- facilitate rural accessibility in a manner that is available and relevant to the needs of disadvantaged and different ethnic groups in society; while
- protecting and managing non-renewable natural resources and reducing import dependency.

1.3 Understanding the Gravel Road Cross Section

Everyone involved in gravel road construction and maintenance must understand the correct shape of the entire area within the road's right-of-way. Figure 1-1 shows a typical cross section of a gravel road.

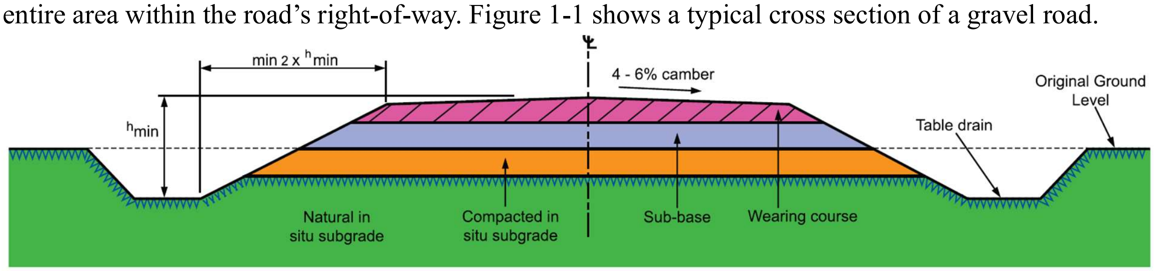


Figure 1-1: Roadway cross section.

In order to maintain a gravel road properly, operators must clearly understand the need for three basic elements:

1. A crowned driving surface,

2. A shoulder area that slopes directly away from the edge of the driving surface, and

3. A ditch.

The space for the shoulder area and the ditch of many gravel roads is often minimal. This is particularly true in regions with very narrow or confined rights-of-way. Regardless of the location, the basic shape of the cross section must be correct or a gravel road will not perform well, even under very low traffic.

1.4 Surface Performance

The performance of the gravel surface mainly depends on material quality, the location of the road, and the volume of traffic using the road. Gravel roads passing through populated areas in particular require materials that do not generate excessive dust in dry weather. Steep gradients place particular demands on gravel wearing course materials, which must not become slippery in wet weather or erode easily. Consideration should therefore be given to the type of gravel wearing course material to be used in particular locations such as towns or steep sections.

2.0 DESIGN OF GRAVEL ROADS

2.1 Geometric Design Standards

2.1.1 Roadway width: For the single-lane gravel roads, the roadway width shall be a minimum 7.5 m in plain and rolling terrain. However, where the traffic intensity is less than 100 motorised vehicles per day and where the traffic is not likely to increase due to situation, like dead end etc., the roadway width shall be reduced to 6.0 m. In the mountainous and steep terrain, the roadway width shall be 6.0 m.

2.1.2 Carriageway width: For the single-lane gravel roads, the carriageway width shall be a minimum 3.75 m. However, where the traffic intensity is less than 100 motorised vehicles per day and where the traffic is not likely to increase due to situations like dead end etc. or in difficult terrain condition, the carriageway width shall be reduced to 3.0 m.

2.1.3 Camber on carriageway: For gravel roads, the camber shall be 3.5% (1 in 30) for annual rainfall less than 1000 mm and 4.0% (1 in 25) for annual rainfall over 1000 mm. In some case, 6% camber can be adopted.

2.1.4 Crossfall on shoulders: On earthen shoulders, the crossfall should be 1% more than the camber for carriageway.

2.1.5 Longitudinal gradients: Due to the sizable proportion of slow-moving vehicles on gravel roads in rural areas and due to increased gravel loss on steeper gradients, it is necessary to impose restrictions on longitudinal gradients. In plain and rolling terrain, the ruling gradient shall be 3.5% and the limiting gradient of 5.0%, which can be relaxed upto 6%, where annual rainfall is less than 1000 mm. In mountainous and steep terrain, the ruling gradient shall be 5.0% and the limiting gradient of 6%.

2.1.6 Horizontal alignment: The requirements of minimum radii of horizontal curves, superelevation rates etc. for low-volume rural roads as contained in RC 073: Geometric Design Standards for Rural (Non-Urban) Highways shall be adopted for gravel roads. Due to the predominance of slow-moving animal drawn cart traffic on gravel roads in rural areas, the maximum superelevation shall be restricted to 0.07.

2.2 Design of Gravel Surface

2.2.1 Design Approach

The general approach to the pavement design of LVRs differs in a number of respects from that for High Volume Roads (HVRs). For example, conventional pavement designs are typically directed at relatively high levels of service and require multiple layers of selected materials. In the case of LVRs, significant reductions in the cost of the pavement can be achieved by reducing the number of pavement layers and/or layer thicknesses, by using local materials more extensively as well as at lower cost, and through the adoption of more appropriate surfacing options and construction techniques.

In addition, research has indicated that the road deterioration mechanisms of LVRs are significantly different to those of HVRs. Appropriate pavement design options need to be fully responsive to a range of factors that may collectively be referred to as the road environment.

The adoption of appropriate designs for LVRs does not necessarily mean an increased risk of failure. Rather, it requires a greater degree of pavement engineering knowledge, experience and judgement and the careful application of fundamental principles of pavement and material behaviour derived from local or regional research.

The challenge of good pavement design for LVRs is to provide a pavement that is appropriate to the road environment in which it operates, and which fulfils its function at minimum life cycle cost at an optimal level of service. However, positive action in the form of timely and appropriate maintenance will always be necessary in order to ensure that the assumptions of the design phase hold true over the design life.

An essential consideration in the design of gravel roads is to ensure all-weather access. This requirement places particular emphasis on the need for sufficient bearing capacity of the pavement structure and provision of drainage and sufficient earthworks in flood or problem soil areas (e.g. black cotton).

2.2.2 General considerations

A gravel road consists of a wearing course which covers the in situ material and, in some instances, a structural layer (sub-base) when the in situ subgrade has insufficient bearing capacity (in situ CBR < 8 %). The thickness of the wearing course will reduce with time under the influence of climate and traffic and therefore regravelling should take place before the wearing course thickness reduces to approximately 50 mm.

The performance of a gravel surfaced road depends on the quality of the materials, the location of the road (terrain and rainfall), and the traffic volume using the road. Where good quality in situ road building materials occur (in situ CBR ≥ 8%), they can provide a strong enough pavement structure to carry the expected traffic for many years with no additional structural layers being required. It is, however, a prerequisite that suitable drainage must be provided, and the road prism and carriageway must be properly shaped and compacted.

Roads described as gravel roads imply that a number of factors have been taken into account in their design and construction. These include:

- Material of a selected quality is used to provide an all-weather wearing course;
- The structure of the road and strength of the materials is such that the subgrade is protected from excessive strains under traffic loads;
- The shape of the road is designed to allow drainage of water (mainly precipitation) from the road surface and from alongside the road;
- The necessary cross and side drainage is installed; and
- The road is constructed to acceptable standards, including shape, compaction and finish.

Although an all-weather wearing course is provided, the road may not necessarily be passable at all times of the years as a result of low-level water crossings being flooded periodically. The critical aspect of gravel road design is the selection of the gravel wearing course material. The use of incorrect materials in the wearing course will result in roads that deform, corrugate, become slippery when wet, lose gravel rapidly and generate excessive dust.

Gravel roads that are likely to incur high maintenance costs in some circumstances, namely:

- When they carry relatively large traffic volumes (> 100 vpd);
- When the quality of the gravel is poor;
- Where no sources of gravel are available within a reasonable haul distance;
- On road gradients greater than about 6%; and
- In areas of high and/or intense rainfall.

In these circumstances spot improvements will almost certainly be justified. In some cases it may prove to be more economical to build a fully paved road at the outset.

2.2.3 Design period and Levels of Service

The road pavement is designed to carry the expected traffic loading over the selected design life of the road. The design period is therefore defined as the time span in years before the road pavement reaches a terminal condition of serviceability after which major rehabilitation or reconstruction would be required. It is conventional practice to specify this terminal condition in terms of an International Roughness Index (IRI) value which is limited to 11m/km.

The regravelling frequency, R is considered as design period, which is typically in the range 5-8 years. Regravelling should take place before the underlying layer is exposed.

2.2.4 Design Traffic

Only Trucks, Buses, Tractor-Tailors, with gross weight more than 3tons have to be accounted. The Classified traffic counts and Origin-Destination (OD) surveys need to be performed to obtain an estimate of the Annual Average Daily Traffic (AADT).

Guidance:

- Counting for seven consecutive days.
- On some days counting for a full 24 hours, preferably with one 24-hour count on a weekday and one during a weekend. On other days, 16-hour counts (typically 06.00 – 22.00 hours) should be made and expanded to 24-hour counts using a previously established 16:24 hour expansion ratio.
- For single day traffic counts, repeating the count to capture data both on a market and a non-market day. Especially in rural areas, this may demonstrate a higher demand on specific days of the week.
- Avoiding counting at times when road travel activity increases abnormally. For example, just after the payment of wages and salaries, or at harvest time, public holidays or any other occasion when traffic is abnormally high or low. However, if there is a harvest during the wet season, it is important to obtain an estimate of the additional traffic typically carried by the road on account of this during these periods.
- Care should be exercised in selecting appropriate locations for conducting the traffic counts to ensure a true reflection of the traffic using the road and to avoid under- or over-counting. Local knowledge should be used to help with this.
- If any junctions occur along the road length, counts should also be conducted before and after the junctions.
- Adjustments for seasonal factor

The design traffic is considered in terms of cumulative number of standard axles to be carried during the design life of the pavement. This can be computed as:

Design Traffic (AADT), $A = P(1 + r)^R$

P is the number of commercial vehicles as per the last traffic count;

r = growth rate of commercial vehicles a minimum annual growth rate of 5 percent can be used for commercial vehicles for estimating the design traffic.

2.2.5 The CBR design method

The CBR design procedure for new gravel roads consists of the following steps:

1. Determine the traffic volume and traffic loading.
2. Determine the strength of the subgrade at the appropriate moisture condition.

3. Establish the quality of the gravel that is to be used for the sub-base construction. If only very poor gravel is available, blending with another gravel or soil to improve its properties may be an option.
4. Determine the thickness of sub-base (consisting of min. CBR 15% quality material) that is necessary avoid excessive compressive stresses in the subgrade from Figure B.7.1 depending on the subgrade strength and traffic class.
5. Calculate the thickness of the wearing course based on the expected rate of gravel loss and a realistic choice of the frequency of regravelling.

Table 2-1: Suggested Capping Layer (CBR >15%) thickness for gravel roads[1]

Subgrade Strength Class (90-percentile value)	Traffic Load Class		
	TLC 0.01 (≤2 heavy vpd)	**TLC 0.3 (6-20 heavy vpd)**	**TLC 1.0 (>20 heavy vpd)**
S1 (CBR<3%)	Special treatment required (Sub-grade treatment)		
S3 (CBR 3-7%)	N/A	100	150
S7 (CBR 8-14%) & S15 (CBR≥15%)	Place GWC directly on prepared subgrade		

Where the in situ subgrade material has a soaked CBR < 3%, i.e. subgrade strength class SC1, realigning the road to avoid such material should be considered or if economically viable or for social considerations; the material shall be excavated and backfilled with competent selected subgrade material of minimum soaked CBR 15%.

2.2.6 Wearing course thickness design

The design of the gravel wearing course thickness must take into account the fact that gravel will be lost from the road continuously. Other than the relatively high road user costs, this is the single most important reason why, in whole life cost terms, gravel roads are expensive and often unsustainable especially when traffic levels increase.

Gravel loss (normally expressed in mm/year/100vpd) is a function of a number of factors including climate, traffic, material quality, road geometrics, maintenance frequency and type, etc. The appropriate wearing course thickness can be determined based on expected annual gravel loss, traffic and the number of years between regravelling operations.

Various studies and methods exist to estimate the expected rate of annual gravel loss. These include the HDM4 model, TRH20 model, ARRB model, and the Kenya Maintenance Study conducted by TRL. These models, however, often need regional calibration.

Case Study 1: the thickness of the wearing courses of the gravel test sections varied from 28 mm to 223 mm. Although gravel loss can be seen as a loss of the upper surfacing layer, any inherent weaknesses or strengths due to the varying depth of wearing course must influence the resistance of the road to deformation[2].

Case Study 2: For site with low plasticity wearing course, the rate of gravel loss was high, ranging from approximately 15mm/year for low trafficked roads (ADT<20) to 30mm/year for higher trafficked roads(ADT=100). For sites with higher plasticity wearing course, the rate of gravel loss approximately 10mm/year for low trafficked roads (ADT<20) to 15mm/year for higher trafficked roads(ADT=100)[3]

[1] Specification requirement of Clause 1004, STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE WORKS 2073 (latest version)

[2] The Kenya Maintenance Study on Unpaved Roads: Research on Deterioration (TRRL Laboratory Report 1111)

[3] Increase Application of Labour-based methods through appropriate engineering standards, Uganda Country Report, TRL-DFID-ILO, 2006

Case Study 3: For site with Plasticity Product (PP = PI x P0.075) < 225, the rate of adjusted gravel loss may be 20mm/year/100vpd having low trafficked roads(ADT<20) and 40mm/year/100vpd having high trafficked roads(ADT=100). For site with PP >370, the rate of adjusted gravel loss may be 10mm/year/100vpd having low trafficked roads(ADT<20) and 15mm/year/100vpd having high trafficked roads(ADT=100).[4]

Case Study 4: Studies have shown that as much as one ton of aggregate per mile is lost each year for each vehicle that passes over a road daily. This means that a road carrying 200 vehicles per day will have a loss of 200 tons of aggregate per mile each year.[5]

A more accurate indication of gravel loss for a particular section of road can be obtained from periodic measurement of the gravel layer thickness. The rates of gravel loss increase significantly on gradients greater than about 6% and in areas of high and intense rainfall. Spot improvements should be considered on these sections.

Adopted Formula for Gravel Loss for Design

Reference to TRL Laboratory Report 673, an estimate of the annual gravel loss is given by the following equation[6]:

GL = $f T^2 / (T^2 + 50) (4.2 + 0.092 T + 3.50 R^2 + 1.88V)$

Where
GL = the annual gravel loss measured in mm
T = the total traffic volume in the first year in both directions, measured in thousands of vehicles =365 x A/1000
R = the average annual rainfall measured in m
V = the total (rise + fall) as a percentage of the length of the road
f = 1.29 for lateritic gravels
= 1.51 for quartizitic gravels
= 1.38 for sandstone gravels

The optimum wearing course thickness = R×AGL

Where: R = regravelling frequency in years; and

AGL = expected annual gravel loss = typical gravel loss (mm/yr/100vpd) x ADT

The wearing course thickness should be kept within a range of 150 mm to 250 mm for construction practicality and maintenance purposes.

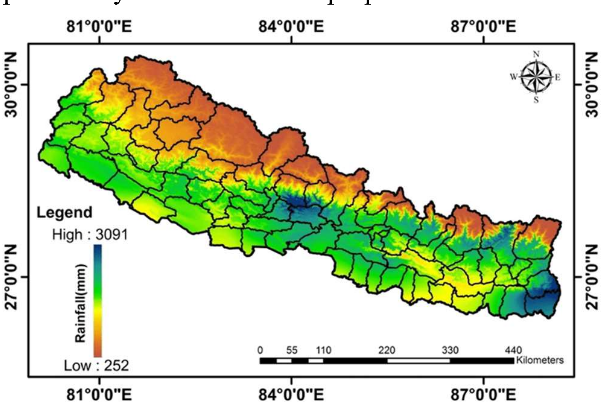


Figure 2-1: Annual mean rainfall map of Nepal (Reference only)[7]

[4] Manual for Low Volume Roads, Part B: Materials, Pavement Design and Construction-2019, Ghana

[5] Gravel Roads Maintenance and Design Manual,2015, U.S. Department of Transportation, FHWA

[6] The Kenya Maintenance Study on Unpaved Roads: Research on Deterioration (TRRL Laboratory Report 1111)

[7] Source: Modeling Earth Systems and Environment (2021) 7:169–179 https://doi.org/10.1007/s40808- 020-00922-7

2.2.7 Reference Design Template

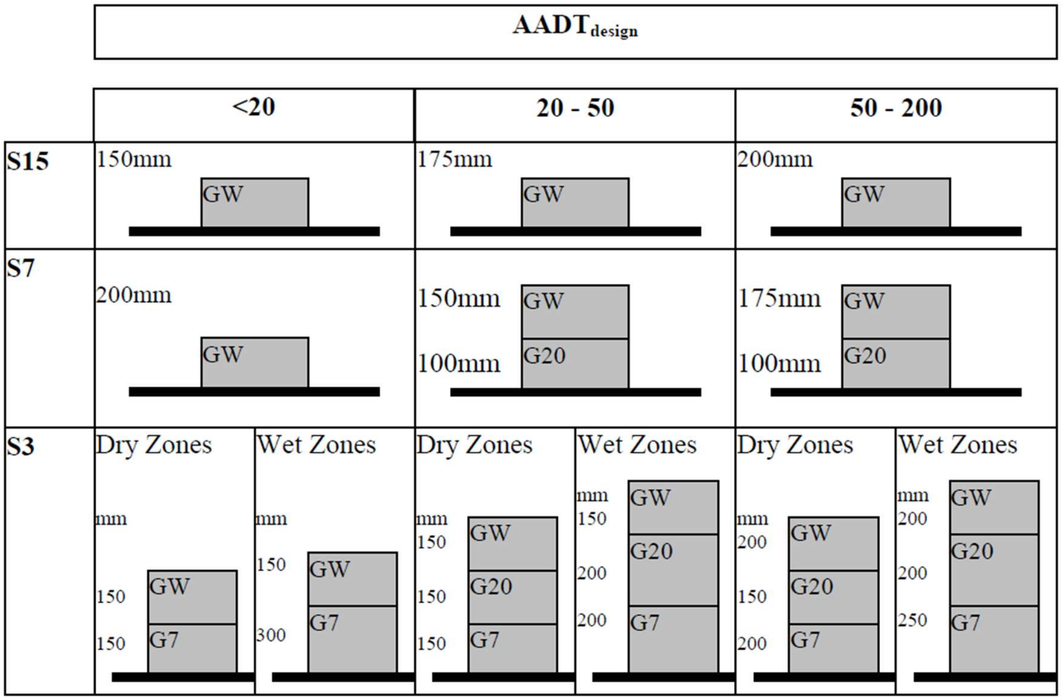


Figure 2-2: Pavement and Improved Subgrade for Gravel Roads for ADDTs < 200

G7 means capping layer of minimum 7% CBR

G20 means capping layer of minimum 20%, shall meet the specification requirement of Clause 1004, STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE WORKS 2073 (latest version)

2.3 Pavement on the High Gradient Section[8]

The high gradient sections on the earthen and gravel surface are the most vulnerable section on the road where the deterioration of the pavement takes place at the faster rates due to the high water run-off during the rainy season. In addition to the proper efficient drainage system, it is recommended that these high gradient sections (generally above 9% gradient) be treated with semi permanent type of pavement in view of keeping the maintenance cost to the minimum. This could be done with the selection of appropriate standards from the following alternatives on the basis of severity of the gradient and the level of traffic.

- 350 mm of gravelling (gravel with higher percentage of plastic fines) on the earthen surface
- 350 mm of stone soling and a cover of 200 mm of gravel with higher percentage of plastic fines
- 150mm gravel emulsion on the gavel surface
- 150mm gravel emulsion with one or two coat of surface dressing on the gravel surface.

[8] Departmental Policy Document Construction Guidelines For Low Cost Feeder Roads , December 1995

3.0 CONSTRUCTION OF GRAVEL

3.1 Materials

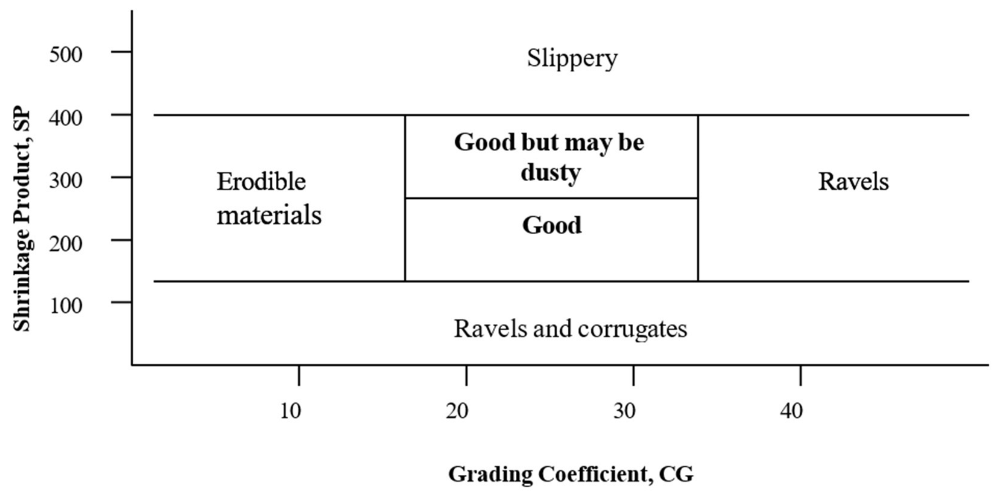
The materials for gravel wearing course should satisfy the following requirements that are often somewhat conflicting:

a) They should have sufficient cohesion to prevent ravelling and corrugating (especially in dry conditions)

b) The amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions.

Knowledge of past performance of locally occurring materials for gravel roads is essential. Material standards may be altered to take advantage of available gravel sources provided they have proved to give satisfactory performance under similar conditions.

Figure 3-1 illustrates the performance characteristics to be expected of materials that do not meet the requirements for gravel wearing course. Refinements and amendments of the standard material specification may be necessary to overcome problem areas such as towns (dust nuisance) or steep hills (slipperiness).



Note: SP = (Linear Shrinkage) x (% passing 0.425 mm)
GC = ((% passing 28 mm) - (% passing 2 mm)x (% passing 5 mm)/100

Figure 3-1: Expected Performance of Gravel Wearing Course Materials

Figure 3-1 shows the effect of the Shrinkage Product (SP) and Grading Coefficient (GC) on the expected performance of gravel wearing course materials. Excessive oversize material in the gravel wearing course affects the riding quality in service and makes effective shaping of the surface difficult at the time of maintenance.

3.1.1. Roadmaking gravels: Roadmaking gravel has been defined as 'a mix of stone, sand and fine-sized particles[9] used as surfacing on a road'. It is not always possible to find a suitable roadmaking gravel in a natural deposit and often the naturally occurring gravels have to be processed to meet the specified requirements for use in a gravel road. There are few natural deposits of material that have an ideal gradation without being processed.

[9] As per the IS Soil Classification System, 'Gravel is a coarse-grained soil (with more than half the total material coarser than 0.075 mm size), having more than half the 'coarse fraction' (larger than 0.075 mm), coarser than 4.75 mm. Sand is a coarse-grained soil with more than half the coarse fraction, finer than 4.75 mm. Silt and Clay are fine-grained soils with more than half the total material fine than 0.075 mm.

3.1.2. Grading requirements of Gravel Wearing Course[10]

Gravel for Wearing Courses is necessary well graded gravel.

Percent retained on IS 4.75 mm sieve and passing 80 mm in size (Percent Gravel) : 50-70%

Percent retained on IS Sieve 75 micron, and passing IS Sieve 4.75 mm (Percent Sand) : 25-40%

Percent passing IS Sieve 75 micron (Percent Slit and Clay): 8-15%

3.1.3. Plasticity characteristics of fines[11]

The requirements of plasticity characteristics of fines in surface/wearing courses depend on the climatic conditions of the area. The Requirements of Liquid Limit and Plasticity Index of fines are as under:-

Table 3-1: Atterberg Limits

Climate	Liquid Limit(Max)	Plasticity Index (Range)
Moist temperate and wet tropical	35%	4-9
Seasonal wet tropical	40%	6-15
Arid	55%	15-30

3.1.4 Aggregate Impact Value (AIV) & CBR

The maximum Aggregate Impact Value (AIV) for wearing course gravel materials is 45%

The minimum CBR value for wearing course gravel materials is 20%.

3.2. Materials sampling

It is most important to get a truly 'representative' sample to the Laboratory for testing. The main problem in getting a 'representative' sample of aggregate/gravel is the problem of segregation. At the stockpile, there will be a tendency for the bigger particles to roll down towards the base. It is, therefore necessary to collect samples close to the top, middle and bottom of the stockpile (Fig. 2.3) taking care that a wooden board should be shoved in before collecting the samples, to prevent further segregation. All the three samples thus collected should be mixed together and the final sample for laboratory testing, reduced by the process of 'Quartering'. Alternatively riffle box may be used to reduce total mixed sample to the 'representative' sample for laboratory testing.

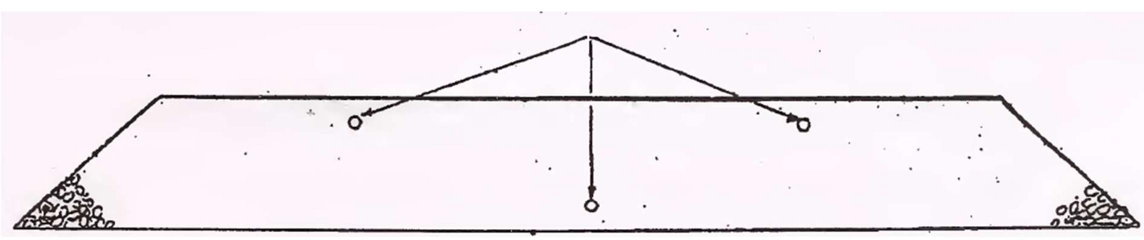


Figure 3-2: Sampling from Flat Stockpiles

3.3 Methods of testing

The standard tests commonly used to determine the suitability of a sample of gravel as a pavement material include the following:

(i) Particle size Distribution (18:2720 Part 4)

(ii) Plasticity Index (18:2720 Part 5)

[10] Source : Transportation Research Board, Compendium 7 'Road Gravels'

[11] Source : Low Cost Roads; UNESCO Publications. Butterworths

(iii) CBR Test(IS:2720Partl6)

(iv) Wet Aggregate Impact Value (18:2386 Part 4)

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 regravelled or constructed;
- Appropriate materials processing methods (if required); and
- The expected characteristics and uniformity of the processed materials. The recommended type and frequency of tests are shown in Table 3-2.

Table 3-2: Recommended Testing of Borrow Pit material

Tests	Frequency (every)	Comments
Atterberg Limits (PL, LL)	2,000 m3	Increase frequency if variable or marginal suitability
Grading Analyses	2,000 m3	Increase frequency if variable or marginal suitability
Compaction and CBR	4,000 – 6,000 m3	Dependent on uniformity of material
Particle Strength (AIV)	4,000 – 6,000 m3	Dependent on uniformity of material

3.4 Stockpiling

In order to avoid segregation in the borrow pit the following method is recommended (Figure 3-3). 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 (as well as 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.

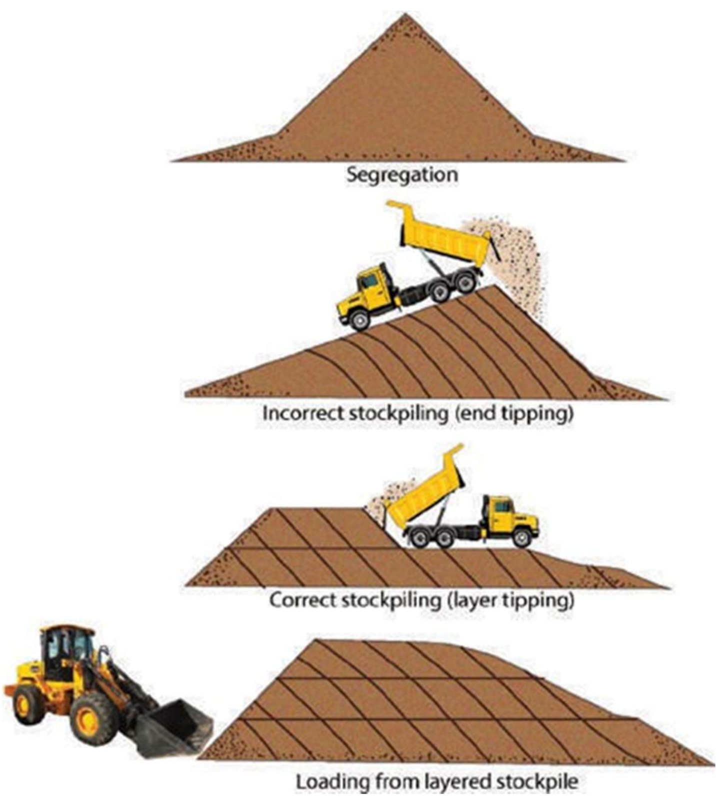


Figure 3-3: Correct stockpiling to avoid segregation [11]

Mechanical blending involves the mixing of two different materials to achieve a composition or grading that satisfies the intended end use that could not be achieved by using either material in isolation. It is often the most cost-effective option for increasing the quantity of an acceptable material. However, careful mixing of the various components being blended is essential. The commonly-used procedure shown in Figure 3-4 is seldom effective and is not recommended for a borrow pit.

Figure 3-4 Non-recommended method for blending in borrow pit [11]

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.

3.5 Handling gravel

From the time gravel is taken from the quarry, the following should be kept in view while handling gravel:

(i) Remove the topsoil or any vegetation from the surface of material source before beginning to process the materials.

(ii) Since variations in the layers of gravel are common, it is a good practice to remove the material by working a broad area of the face.

(iii) To avoid the problem of segregation, stockpiles should be constructed in layers.

(iv) Hauling and spreading gravel should be treated as a work zone and precautions shall be taken for safety of workers and road users.

(v) After gravel is dropped on the road, the grader operator should place it in a windrow.

(vi) For a new road, prior to laying gravel on a soil subgrade, the subgrade should be properly compacted and finished to the required profile.

3.6 Construction equipment

The choice of the most appropriate type of equipment for a particular project is normally dependent 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.

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.
- 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 are a flexible resource.
- Mixing on the road: Towed agricultural disc harrows drawn by a large tractor are very effective at mixing.
- Compaction: There are towed versions of vibrating, grid or tamping rollers. Vibrating rollers on labour- based works are often hand controlled self-propelled units that can be used effectively in relatively restricted spaces.
- Surface reparation: Towed mechanical brooms can be effective.

Figure 3-5: Tractor-towed grader

Bulldozers for stockpiling: These 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, excavating drains, filling, spreading and to some degree compacting 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 where more flexibility is required 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.

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).

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.

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.

Figure 3-6: Grid Roller

Pneumatic (rubber tired) rollers operated with tire pressures and wheel loads within the manufacturer's recommended range are the most common means of compaction. Pneumatic (rubber tired) rollers are most often used for compaction of gravel. Smooth steel drum rollers will work as well, but may cause problems if the gravel has high plasticity causing it to stick to the roller.

3.7 Roadbed preparation

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

After clearing and grubbing, any unsuitable materials (such as clays, black cotton soils, dispersive soils, etc.) should be removed to appropriate depths 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 entails 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 through density tests or by using DCP measurements.

Once the required compaction has been achieved, the same number of passes should be used thereafter for the rest of the roadbed compaction, provided soil conditions are homogeneous. Method specifications are very practical and time-saving and their use should be encouraged where appropriate

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 this, but the recommended methods are those that minimise the amount of water required by using heavy impact rollers or heavy vibrating rollers.

Where there is a hard (rock) stratum below the roadbed drainage problems can arise, particularly in cut areas. The choice of appropriate solution depends on a number of factors including the proximity of the stratum to the finished road level, the thickness/hardness of the stratum, and whether the road is in cut or fill. Remedial measures are:

- Relatively thin (≤ 1 m) 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 (> 1 m) stratum: Raising the road embankment and/or providing lined drains to minimise seepage of water under the road pavement

3.8 Compaction

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.

Compaction to refusal

When using natural gravels it is important 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 3-7. 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.

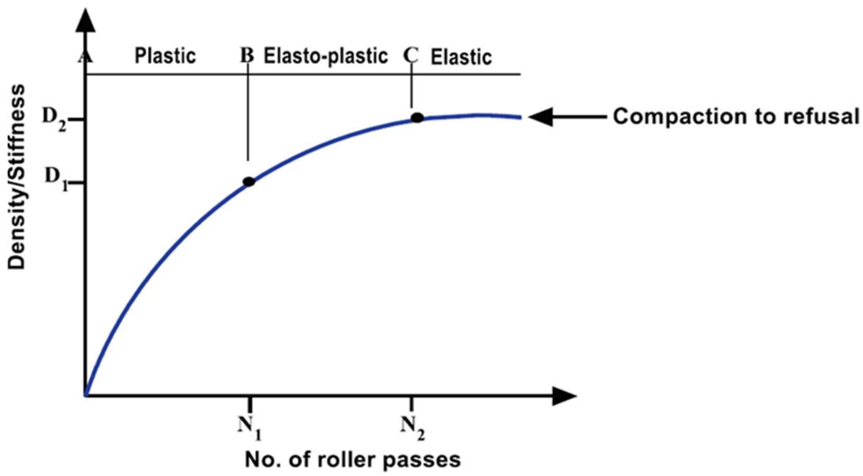


Figure 3-7: Illustration of concept of compaction to refusal

To ensure optimal performance from the road, a maximum allowable moisture content during construction should be specified and proper precautions taken for surface and sub-surface drainage (where required).

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. It is therefore 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.

3.9 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. There is therefore every benefit to achieving as high a density and related strength as economically possible in the subgrade.

3.10 Pavement layers compaction

Compaction of the pavement layers (and the subgrade) 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 described 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 its compaction. The higher the density in the underlying layer, the stiffer and more deeply balanced the pavement structure will be.

3.11 Moisture for compaction

Thorough mixing of water with soil over the full width and depth of the layer and at the OMC of the admixture is essential for achieving the required density and an even surface finish. The OMC determined in the laboratory is a good guide for determining 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.

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 large disc harrows (see Figure 3-8) greatly reduces the required time for mixing water into the material compared to blade mixing with grader, though blade mixing is more effective.

Figure 3-8 Use of disc harrow for effective mixing of water in material

3.12 Dealing with oversize material

3.12.1 Manual removal or breakage

The maximum aggregate size in a gravel wearing course should be no greater than about half the layer thickness, with two-thirds of the layer thickness generally the absolute limit specified. This ensures that all large particles can be bound tightly in an interlocking structure as shown in Figure 3-9. The presence of oversize material in unpaved roads results in rough roads that are difficult to maintain.

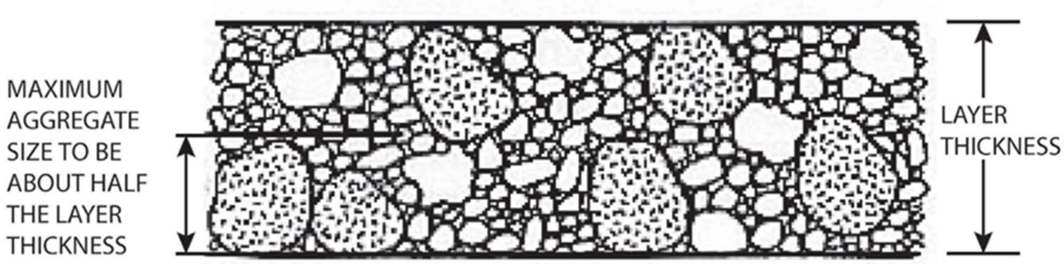


Figure 3-9: Maximum aggregate size within layer [11]

The various methods of dealing with oversize material either in the borrow pit or on the road (during material placement) are shown in Figure 3-10. Each method is briefly reviewed below.

Where the proportion of oversize material is relatively small it may be treated effectively by manual removal or crushing either at the borrow pit or on the road. It may be beneficial to crush the oversize material and add it to the stockpile to optimise material usage and minimise wastage and spoil.

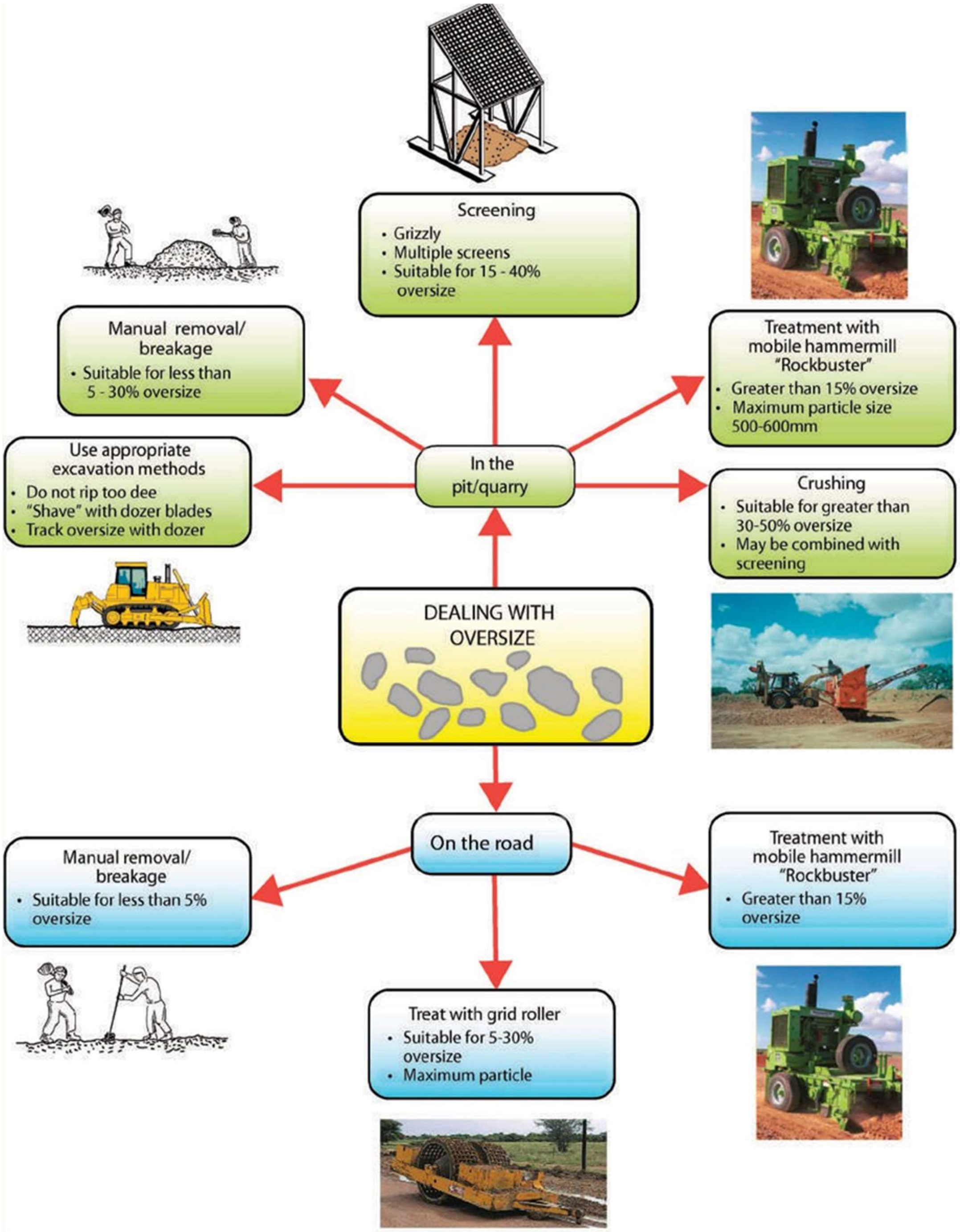


Figure 3-10 Dealing with oversize material [11]

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 at 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.

3.12.2 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 3-11 illustrates the various types of simple screens.

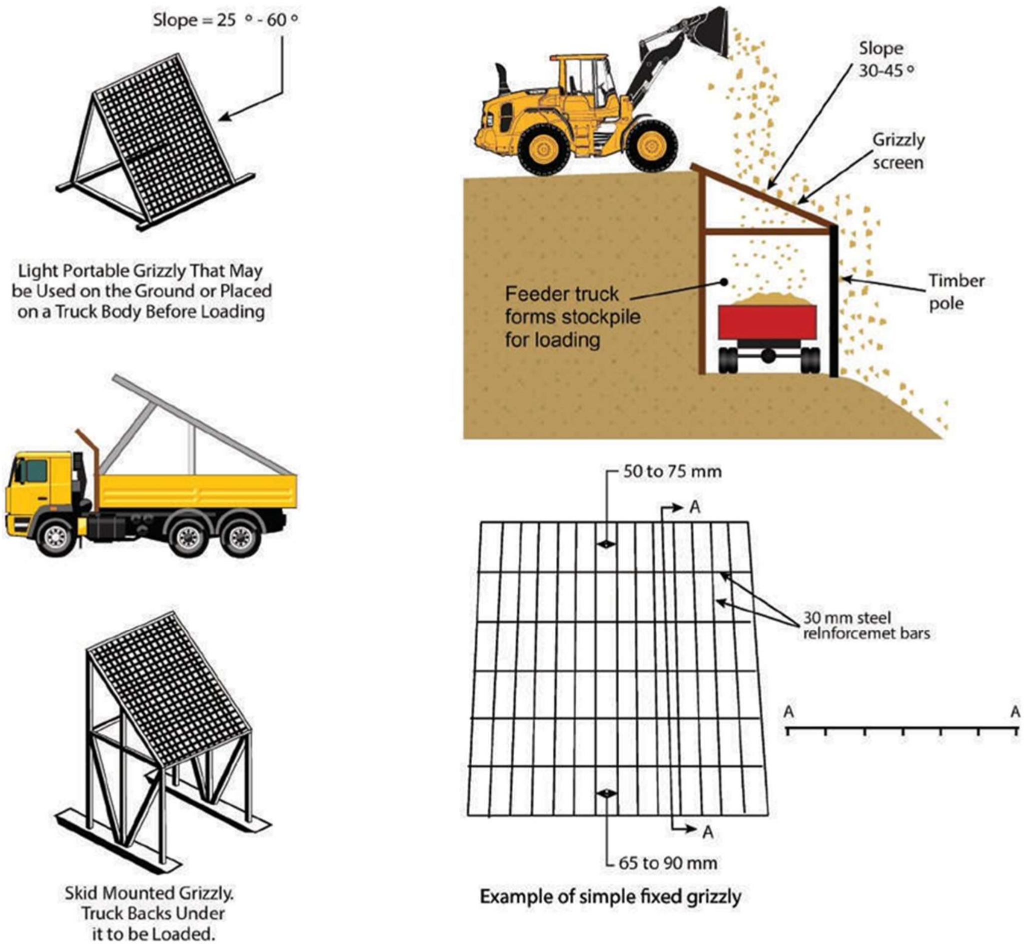


Figure 3-10 Examples of simple fixed grizzly screen [11]

3.12.4 Crushing

Crushing of oversize aggregate is expensive so is normally reserved for surfacing and concrete works and not used for gravelling or pavement layer construction. 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, only the large-scale production of high value crushed gravel road surfacing materials may be viable. Factors that should be considered before committing to the production of crushed aggregates include the:

- 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 material; and
- use of mobile crushers, which can be very effective.

In steeply sloping ground with high rainfall, such as occurs in many parts of Nepal, well-graded angular gravels stand up well to scour and traffic abrasion, because of the higher friction associated with particle interlock. Hence, the use of crushed river gravel, as opposed to rounded river 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, unless blended.

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.

3.13 Water usage, evaporation and temperature variations

Before deciding upon the required moisture content, the in situ moisture content must be determined. If evaporation is taken into account, then the water investigations should aim to provide at least 50% more water than the amount required to compact all materials at OMC, particularly in dry areas.

High daytime temperatures can result in an extremely high evaporation rates leading to excessive loss of water. In order to prevent such losses it is prudent to programme watering and mixing activities very early in the morning or late in the afternoon.

3.14 Single and multi-layer construction

Single layer construction is usually specified for pavement layers upto 200 mm thick. The most common layer thickness is 150 mm. However, when a pavement layer is specified at a thickness greater than 200 mm it will be necessary to compact it in more than one layer of the same thickness in order to achieve uniform specified density throughout. The maximum allowable size of any constituent layer is 2/3 of the total layer thickness.

3.15 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).

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 winning process;
- processing of stockpiled material; and
- quality control and assurance.

4.0 MAITENANCE OF GRAVEL ROAD

4.1 General

Timely and proper maintenance of Gravel Roads can lead to significant economic benefits. These include reduction in level of future maintenance and rehabilitation costs, improved safety and reduction in road closures, reduction in vehicle operating costs and accident costs.

While proper maintenance of all types of road pavements is important, it is a matter of crucial importance for the satisfactory performance of Gravel Roads. Even though Gravel Roads require more frequent maintenance interventions than black-topped roads, these interventions are relatively inexpensive and simple, within the available resources and skills in rural areas. Specially designed studies as well as experiences all over the World show that for low volumes of traffic upto about 200 vehicles per day, the maintenance costs of gravel roads work out to be lower than for black-topped roads, while for higher volumes of traffic, it is the other way round. With simple inexpensive maintenance interventions, gravel roads can be easily maintained in good condition.

Good gravel road maintenance or rehabilitation depends on two basic principles: proper use of a motorgrader (or other grading device) and use of good surface gravel. The use of the grader to properly shape the road is obvious to almost everyone, but the quality, volume, and size distribution of gravel needed is not as well understood. It seems that most gravel maintenance or rehabilitation problems are blamed on the grader operator when the actual problem is often material related. This is particularly true when dealing with the problem of corrugation or “washboarding” as it is often called in the field. This problem is often perceived as being caused by the grader, but it is primarily caused by the material itself.

4.2 Maintenance operations

The performance level should not be allowed to fall below a PCI of 2.0. If, however, proper maintenance has been neglected, the following guidelines may be followed for rehabilitation:

PCI	Rehabilitation Measures
1	Reconstruct Immediately
1 to 2	Regravel Immediately; Routine maintenance to continue
2 to 3	Regravel within 1 year; Routine maintenance to continue
>3	Routine Maintenance

(a) The various maintenance operations on gravel roads can be broadly classified into the following categories:-

(i) Routine maintenance, comprising patch repairs; dragging, grading, maintenance of shoulders and repairs to roadside drains, road signs, culverts etc., and collection of data such as road condition and traffic surveys, which are required to be carried out by the maintenance staff once or twice every year.

(ii) Periodic maintenance, which consists of work items such as 'Regravelling' to be carried out periodically every 5-8 years.

(iii) Special repairs, and flood and rain damage repairs, which consist of repairs to the embankment, pavement, culverts, road furniture, etc. necessitated by landslides, earthquakes, cyclones, heavy rains/cloud bursts, floods etc; the nature and extent of such repair works could not be foreseen or predicted.

(b) Before starting with the work, it should be ensured that adequate arrangements (like erection of barriers, signs and red flags/light/reflectors) are made for the safety of traffic, workmen, pedestrians, cattle etc. The work should be planned in such a way that inconvenience caused to the traffic is minimal. Wherever possible, the work should be confined to half the pavement width at a time, leaving the other half to traffic.

4.3 Surface & Structural Defects on Gravel Roads

The defects observed on Gravel Roads are essentially the result of complex interactions between the materials used, traffic type and volume, climatic conditions, construction methods and quality control exercised. Broadly, the various defects can be classified as:

(a) Surface defects, observed in the upper layers of the pavement are due to factors like poor compaction, unsatisfactory grading, climatic conditions, poor quality of materials, inadequate drainage, neglect of routine and preventive maintenance measures etc. or a combination of these. The surface defects result in poor riding quality. The more common surface defects are Corrugations, Potholes, Rutting, Ravelling/Loose Material, Surface Erosion/Dust Generation/Loss of Surface Material, Slippery Surface, Soft Spots.

(b) Structural Defects, are deep seated problems caused by overstressing of the subgrade and/or the pavement. One of the common causes is lack of drainage, other causes being substandard materials used and inadequate thickness of the pavement for the design traffic. These defects are often characterized by shear failure in form of large settlements and upheavals.

Surface defects can be removed by grading or planning the surface. However, gravel roads with structural defects would require a more detailed investigation and treatment including rehabilitation.

During the Condition Survey of any Gravel Road, it is necessary to make an assessment of the severity of surface defects in terms of the severity being 'High', 'Medium' or 'Low'. Such an assessment can be accomplished as under:

(a) Surface Roughness/Riding Quality

An assessment shall be made in terms of the 'Pavement Condition Index' (PCI) on a rating scale of 5 to 1 as under:

Normal Safe Driving Speed (km/h)	PCI
Over 35	5
25-35	4
15-25	3
10-15	2
Less than 10	1

(b) Corrugations

A visual assessment of the corrugations shall be made by the bumps experienced while travelling on the gravel road in a jeep or passenger car as under:

(i) Bumps can be felt and heard and significant reduction in speed is required: High severity

(ii) Bumps can be felt and heard and some reduction in speed is required: Medium severity

(iii) Bumps can be felt and heard but no reduction in speed is required: Low severity

(c) Potholes

A visual assessment of the severity of' Potholing' shall be carried out as under:

(i) Depth of pothole more than 50 mm: High severity

(ii) Depth of pothole in the range 25 to 50m: Medium severity

(iii) Depth of pothole less than 25 m: Low severity

(d) Rutting

The ruts or depressions of the surface in the wheel tracks shall be measured in mm and an assessment of the severity level made as under:

(i) Depth of rutting more than 50 mm: High severity

(ii) Depth of rutting 25 to 50 mm: Medium severity

(iii) Depth of rutting less than 25 mm: Low severity

(e) Ravelling

An assessment of the percentage area of the ravelled surface shall be made and severity level recorded as under:

(i) Percentage area of ravelled surface over 50: High severity

(ii) Percentage area of ravelled surface 25 to 50: Medium severity

(iii) Percentage area of ravelled surface < 25: Low severity

(f) Surface Erosion

Gravel roads are susceptible to longitudinal/transverse erosion by flow of water over the road surface. An assessment of the severity level can be made by the bumpiness experienced while driving in a car or jeep over the eroded surface, as under:

(i) Bumps can be felt and heard and significant reduction in speed is required: High severity

(ii) Bumps can be felt and heard and significant reduction in speed is required: Medium severity

(iii) Bumps can be felt and heard and significant reduction in speed is required: Low severity

(g) Dust Generation

An assessment of the dust nuisance shall be made by driving in a car/jeep at a speed of 30-40 km/h and taking observations as under:

(i) Dangerous loss of visibility- significant discomfort: High severity

(ii) Some loss of visibility- no discomfort: Medium severity

(iii) No loss of visibility: Low severity

4.4. Maintenance of Gravel Roads

The maintenance methods commonly adopted for Gravel Roads are Grading, Dragging, Patching, Regravelling and use of Dust Palliatives.

4.4.1 Grading

It is a matter of vital importance that a good camber is always maintained on a gravel road surface to enable the water to shed off readily. Such a maintenance effort can be accomplished by regular 'Grading'.

For Gravel Roads, the 'Grading' is also needed to restore gravel from the shoulders which has been lost from the Gravel Road surface and the gravel thus restored can be used to fill potholes and corrugations etc. Grading can be used to correct the following defects:- loss of shape, ruts potholes, corrugations, erosion gullies, silted or blocked ditches.

Grading is a 'Routine Maintenance' activity and can be carried out by tractor towed graders. The gravel road surface to be graded should first be prepared by patching of large potholes or depressions and draining out areas of standing water etc. It may be necessary to scarify the existing surface to cut to the bottom of any surface defects and loosen the material for reshaping. The process of grading can be carried out by tractor-towed grader. Grading can be of three types, as under:

- Light Grading : When the gravel surface crust is not broken and it is a matter of only spreading or raking back loose surface material to provide a "running course" as protection of the surface crust. Alight Grader or Drag can serve the purpose.
- Normal Grading : This is done when the surface crust is cut and it is necessary to remove surface defects such as corrugations, ruts or potholes. In this case a 8-10 tonne Grader is suitable.
- Heavy Grading : This is required when the road is out of shape and in the process of repair, and fairly heavy scarifying is required. This reshaping operation requires a Grader in the 10-12 tonne mass range.

Operating speed in blading operations must not be excessive. It is virtually impossible to do good work above a top speed of 3 to 5 mph in most conditions. Higher speeds have caused problems on many roads. When the machine begins to “lope” or bounce, it will cut depressions and leave ridges in the road surface. Conditions including moisture, material quality, and subgrade stability vary; therefore, assigning a maximum speed for good maintenance is a challenge. Operating speed must be slow enough to be sure the machine remains stable.

The Grader works on one side of the road at a time and works in passes about 200 metres long to convenient and safe turning points. Light Grading will normally require 4 passes to reshape the road (Figure 4-1,left). Heavy Grading will require additional passes to achieve the required camber. Work should be completed on one side of the road at a time. An even number of passes should be used to avoid a flat finished crown. The initial passes cut to the bottom of the surface irregularity and deposit a windrow just beyond the centre line. If required, water should be sprayed over the windrow. In order to avoid flattening the centre, the final pass should not be made down the centre of the road with the grader blade horizontal (Figure 4-1,right).

On sections where grading has been completed, the road roller should follow. Normally about 8 passes of the roller are required to achieve full compaction, working towards the centre. Shoulders should be treated as part of the running surface. Camber should be checked with a Camber Board at about 100mintervals. On bends, the surface should be straight at 4 to 6 % from shoulder to shoulder. The shape of the road over the culverts should be maintained to avoid a hump (Figure 4-2). Where required, material should be brought from either side of the culvert to maintain the required cover to the top of the culvert.

The angle of the moldboard is also critical for good maintenance. This angle is fixed on some grading devices, but on motor graders it can be easily adjusted. It is important to keep the angle somewhere between 30 and 45 degrees. It is a challenge to recover loose aggregate from the shoulder of the roadway without spilling material around the leading edge (toe) of the moldboard. Operating without enough angle is a primary cause of this spilling not allow enough material to be carried for good maintenance.

Along with correct angle, it is important to understand proper pitch or “tilt” of a moldboard. If the moldboard is pitched back too far, the material will tend to build up in front of the moldboard and will not fall forward and move along to the discharge end, or heel, of the blade. This also causes excess material loss from the toe of the moldboard. It also reduces the mixing action that is desirable when recovering material from the shoulder and moving it across the roadway, leveling and smoothing it in the process. This mixing action is part of routine maintenance.

The number of times during the year each Gravel Road will need grading will depend upon the amount of traffic using the road, climatic conditions in the area, local topography and other physical features. In the absence of adequate experience in the area, the Grading Frequency Chart developed by the TRRL of UK (Figure 4-3) may be used.

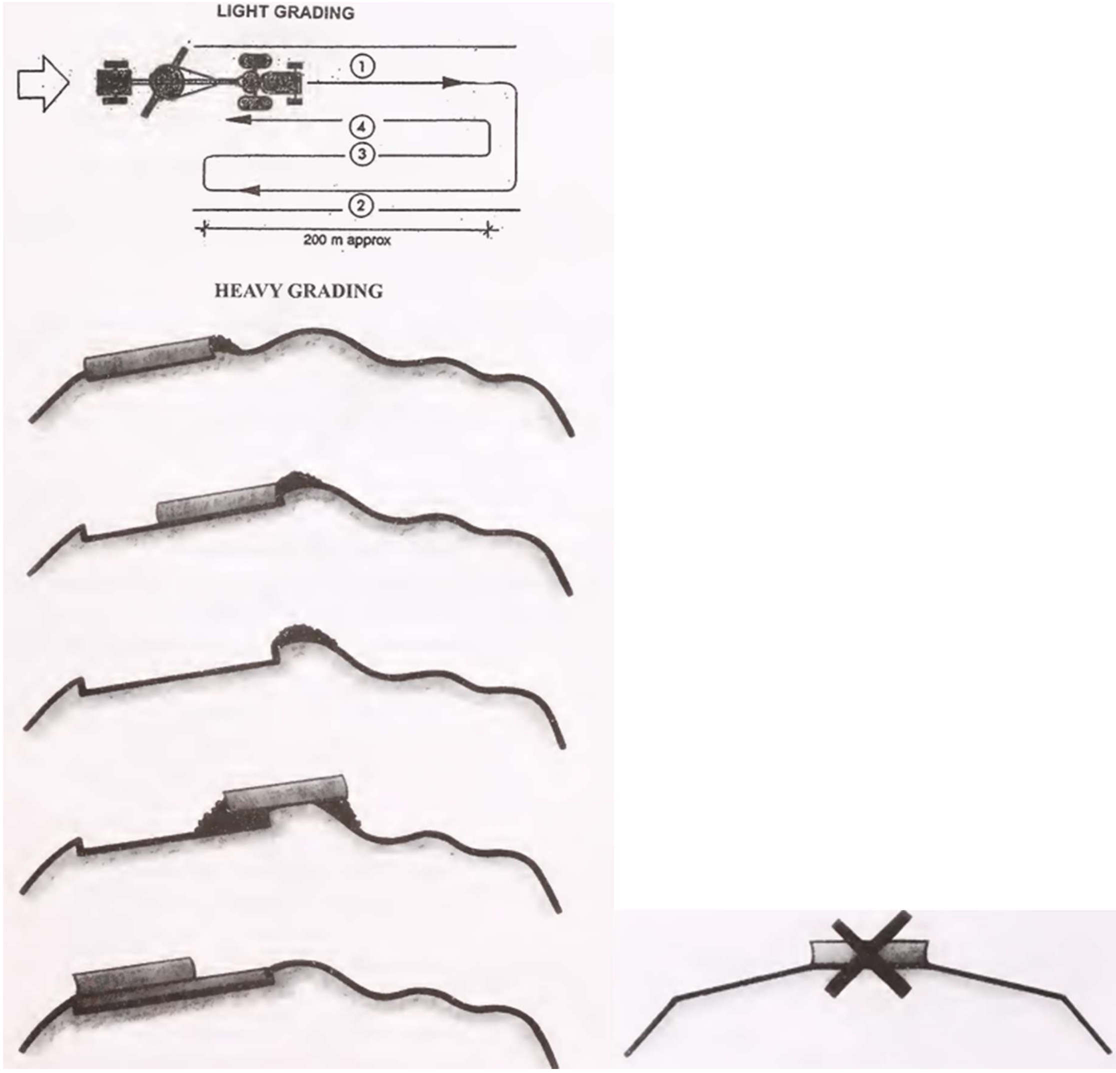


Figure 4-1: Light and Heavy Grading (Left) & Avoid Flattening at the Centre(Right) (Source: International Road Maintenance Hand Book Vol. II, Maintenance of Unpaved Roads, PIARC, Published by the TRRL, UK)

Figure 4-2: Avoid Hump at Culvert (Source: International Road Maintenance Hand Book Vol. II, Maintenance of Unpaved Roads, PIARC, Published by the TRRL, UK)

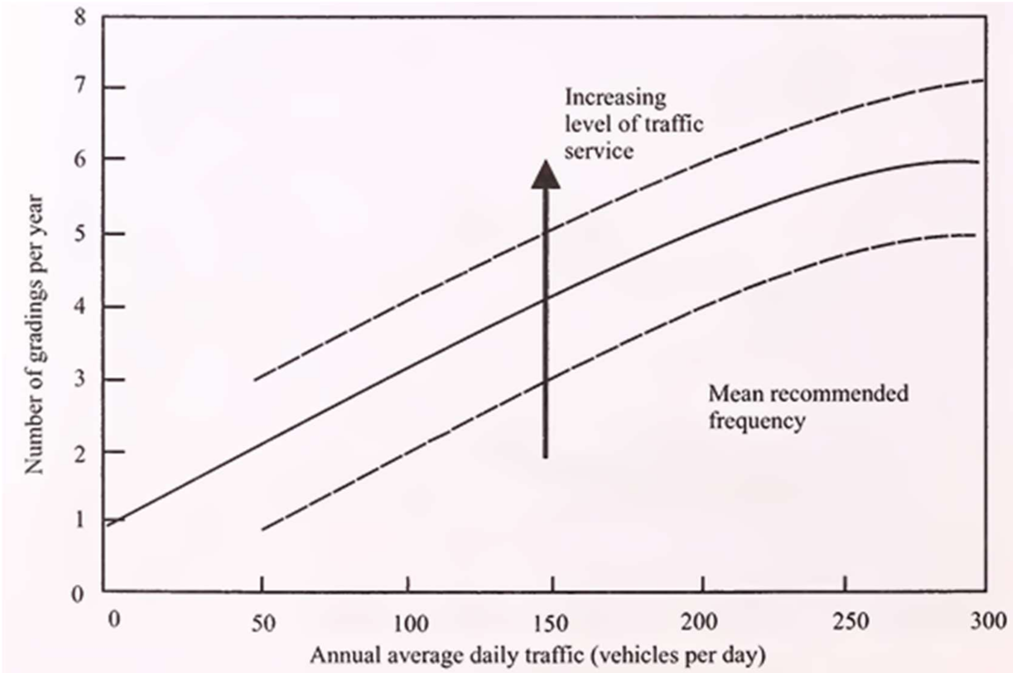


Figure 4-3: Grading Frequency Chart

4.4.2. Dragging

Dragging is normally a Routine Maintenance task used to improve the gravel road surface. Regular Dragging smoothens out minor defects in the road surface and removes loose material from the surface. Where a running course of sand/gravel is used to cover the base material for protection from traffic wear, frequent dragging is used to redistribute the running course material disturbed by traffic plying overthe surface.

Specially made drags towed by agricultural tractors can be used for Dragging. Where the traffic plying on a rural road is of a low order, frequent dragging can reduce the need for Grading. It is generally after a number of dragging operations that Grading is required. Dragging will not remove corrugations once they are formed, nor will it restore camber or lost material.

Dragging may be considered suitable only when development of road has been carried out to a level when the pavement is structurally sound and where the loose running course is less than 25 to 30 mm in depth.

Table 4-1: For various road conditions, the recommended plants

Road Condition	Recommended Plant
Roads with depths of loose material in excess of20 mm	Broom drag Cutting drag using old grader blades. Towed grader or light power grader.
Roads with roughness levels* less than 6000 mm/km with no appreciable loose material	Timber framed drag or broom drag Light grader or planer
Roads with roughness levels greater than 6000 mm/km	Cutting drag using old grader blades. Light grader, planer or medium grade

* Roughness measured using Bump Integrator

Drags should not be towed at speeds above 10 km/h and preferably should be towed at 5km/h. A broom drag and roller can be seen in Figure 4-4, while a typical tractor and timber drag are shown in Figure 4-5. In Figure 4-6, it can be seen how a drag can be used to shift material from different parts of the pavement.

It must be emphasised that Drags must be used at frequent enough intervals to smoothen the road surface. Drags should not be used on roads which have deteriorated, due to lack of frequent maintenance interventions, to a level where only heavy grading or reshaping is the answer. Figure 4-7 shows a multi-purpose tractor-towed equipment enabling an operator to carry out a wide range of maintenance activities.

Figure 4-4: A Broom Drag

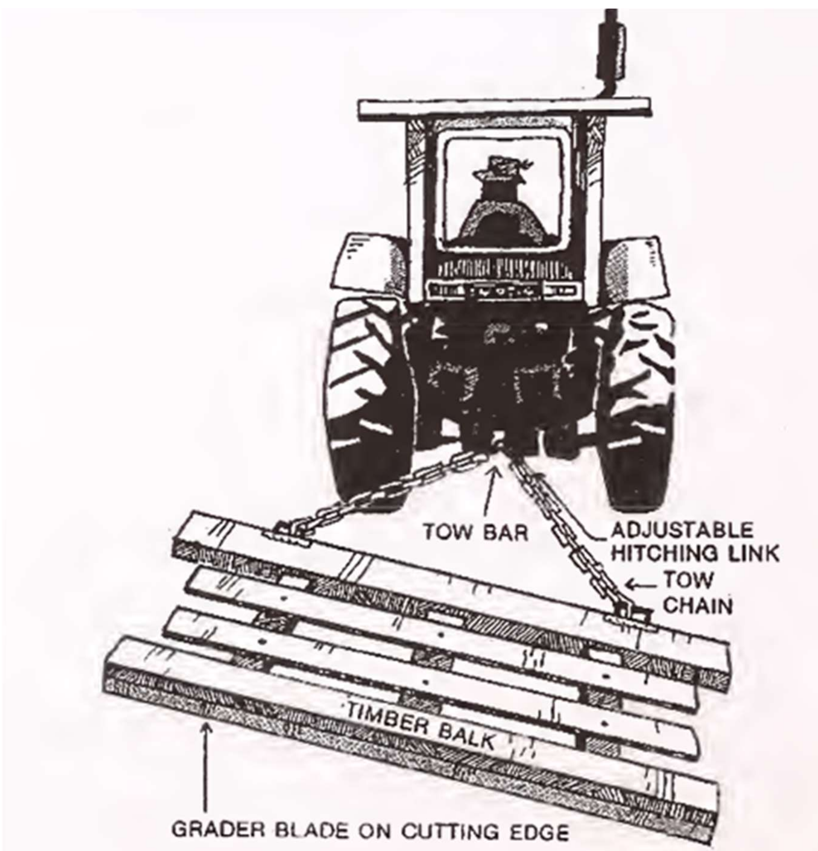


Figure 4-5: Typical Tractor Towed Drag (Source: Unsealed Roads : A Manual of Repair and Maintenance for Pavements, National Roads Board, New Zealand)

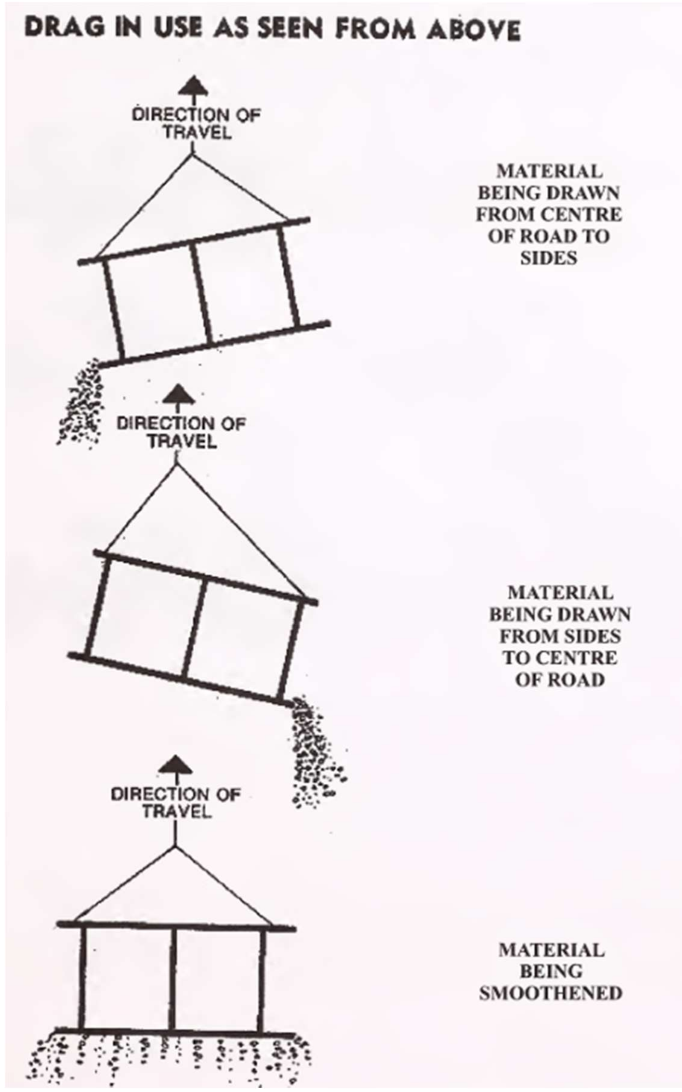


Figure 4-6: Use of Drag in Drawing Material from Different Parts of Pavements (Source: Unsealed Roads : A Manual of Repair and Maintenance for Pavements, National Roads Board, New Zealand)

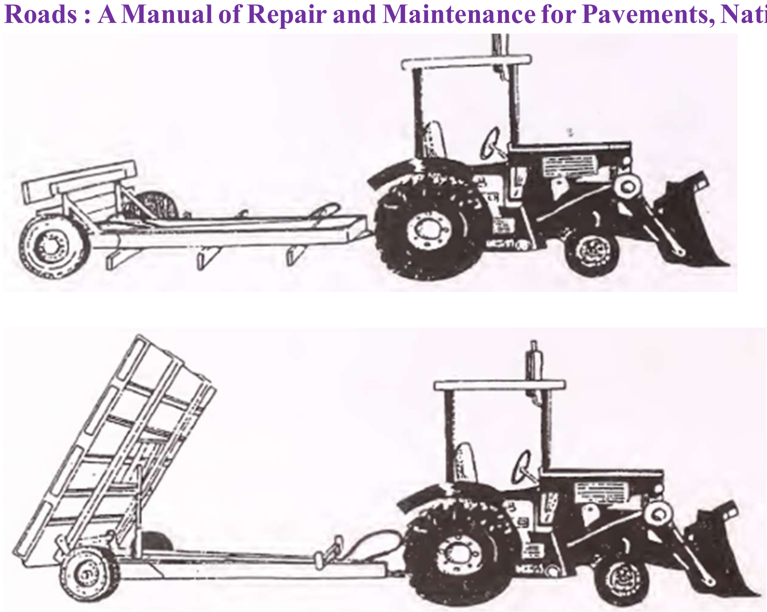


Figure 4-7: A Tractor-Towed Equipment Enabling the Operator to Carry out a Variety of Maintenance Operations (Source: Unsealed Roads: A Manual of Repair and Maintenance for Pavements, National Roads Board, New Zealand)

4.4.3 Patching

Where potholes or depressions on the gravel road are large, patching is required before grading. Sometimes, patching is required between grading or reshaping operations. Patching can be used to repair eroded areas or can be used to restore areas which become soft when wet. When the work involves material less than a truck or two, the repair work is termed patching, while for large scale work, it is termed Spot Gravelling or Regravelling. Patching cannot be used for repairing Corrugations but can be used to correct Erosion Gullies.

Where the potholes are large in numbers, scarifying will be needed with a grader and possibly Regravelling.

Gravel to be used for patching should be dumped by the road side where it is required to be used. The quality of gravel should be at least as good as the gravel already used in the road surfacing. The gravel should be dumped on the shoulder (Figure 4-8) adjacent to the location where the patching work is to be carried out. Care must be taken to see that the material should not be dumped on the road surface.

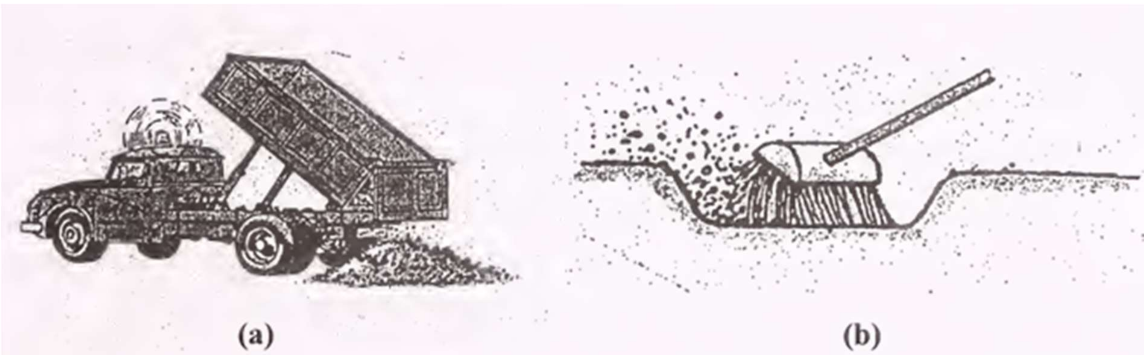


Figure 4-8:(a) Dump the material on the shoulder adjacent to location of patching work (b) Brush out any loose material or standing water (Source: International Road Maintenance Hand Book Vol. II, Maintenance of Unpaved Roads, PIARC, Published by the TRRL, UK)

In the pothole or rut, where patching work is to be carried out, any loose material or standing water should be brushed out (Figure 4-8). Where the potholes are large in size or are very deep, the sides should be cutback to be vertical.

Check the moisture content of the material. If it is dry, the area to be patched should be sprinkled with water and also water should be added to the material to be used for patching. The area should be filled with gravel to a depth of about 100 mm. If the material is dry, it should be sprinkled with water to assist compaction.

The 100 mm layer at a water content close to OMC, should be compacted using a roller or a hand rammer. In this manner, patching is built up in layers. The patched area is thus filled up with gravel to about 30 mm proud of the surface level and is spread and raked to the correct shape. The patch is compacted by a roller if the area is large and by hand rammer if the area is small. Even for large areas, hand rammers will be required for the short edges and comers.

4.4.4. Regravelling

Regravelling is a periodic maintenance operation. Well before any significant reduction in base thickness takes place and before the PCI rating reduces to the terminal PCI of 2.0, the task of 'Regravelling' must be accomplished. Regravelling can be carried out to correct the following defects:- Loss of shape Ruts- Potholes- Erosion Gullies Grading or Reshaping should be carried out before the regravelling operation.

Gravel obtained from a quarry or gravel pit must meet the specified quality requirements and the needed approval obtained before commencement of the work. The sections where Regravelling is required should be marked at the site. The existing road surface must be graded to provide a firm regular surface and the edges should be boxed to provide lateral support for the fresh gravel. The graded surface should be watered to have the water content close to OMC and roller compacted. The camber should be checked with a Camber Board and it should fall within the specified range.

The Drainage System should be checked and repaired where necessary. The excavated gravel should be stockpiled in low heaps to prevent segregation. After the initial grading of the road is complete, the gravel should be transported to the regravelling site. The dumping of gravel should start at the far end of the site so that the gravel heaps do not come in the way of trucks delivering later loads. Materials should be dumped at correct spacing on one side of the road only. A Weekly Gravelling Plan should be prepared to indicate hauling distance etc.

Spreading of the gravel can start when there is a working length of at least 200 m of dumped material. Initially the road is sprayed with water. The Regravelling material is then spread across the road using the grader. The material is then alternately spread by the grader and watered until its moisture content is close to OMC. The material is then graded to produce the specified camber. The camber should be checked with the Camber Board at approx. 100 m intervals along the road. If the desired camber is not achieved, the process of grading should be repeated. After the correct camber has been achieved, rolling can start, commencing at the edge towards the centre. The roller should progress section to section at the same rate as the Grader. About 8passes are generally required to achieve full compaction.

4.4.5 Use of dust palliatives

The main disadvantage being cited against gravel roads, is the dust generation, considered as a safety hazard and pollutant to the environment. Besides being a safety hazard, a very significant implication of dust generation is the loss of fines from the surface gravel which leads to increased gravel loss and consequently more frequent maintenance. If, however, the generation of dust can be controlled, the expenditure on gravel road maintenance can be significantly reduced.

There is a wide variety of dust palliatives available which can be divided into 7 basic categories, as under:

(a) Water

(b) Water absorbing products (hygroscopic)- Calcium Chloride brine and flakes- Magnesium Chloride brine- Sodium Chloride (Salt)

(c) Organic Petroleum Products- Asphalt emulsion, Cutback Asphalt(Liquid Asphalt), Dust oils- Modified Asphalt Emulsions

(d)Organic Nonpetroleum Products- Animal Fats, Lignosulphonate, Molasses/Sugar Bee, Tail Oil Emulsions, Vegetable Oils

(e) Electrochemical Products- Enzymes- Ionic Products- Sulphonated Oils

(f) Synthetic Polymer Products- Polyvinyl Acetate, VinylAcrylic

(g) Clay Additives- Bentonite, Montmorillonite

The selection of type has to be based on the quantity of fines in the surface material, climatic conditions and traffic volume. The following four categories of dust palliatives appear suitable for Indian conditions:
(i) Water

(ii) Water absorbing products (hygroscopic)

(iii) Organic petroleum products

(iv) Clay additives

Prior to applying dust palliatives, all the surface defects should be removed, gravel added to provide the correct shape/camber/super elevation and the surface compacted. The surface should be dampened (except when non-emulsified petroleum products are used). The dust palliative should then be applied uniformly over the surface. After light compaction, traffic may be allowed if chlorides are used while for other products, sometime may be required for the product to get absorbed before allowing traffic. Field trial sections need to be laid and their performance monitored to evaluate the efficacy of a product.

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ANNEX

ANNEX-A: ANALYTICAL MODAL FOR GRAVEL LOSS ESTIMATION

HDM-4 Modal: Gravel Loss

The HDM-4 relationship for predicting the annual quantity of gravel loss is a function of monthly rainfall, traffic volume, road geometry and characteristics of the gravel and is given below.

$GL = K_{gl} \times 3.65 \times [3.46 + 0.246(MMP/1000)(RF) + (KT)(AADT)]$

where

$KT = K_{kt} \max[0, 0.022 + 0.969(HC/57300) + 0.00342(MMP/1000)(P075) - 0.0092 (MMP/1000)(PI) - 0.101(MMP/1000)]$

and

GL = annual material loss, in mm/year

KT = traffic-induced material whip-off coefficient

AADT = annual average daily traffic, in vpd

MMP= mean monthly precipitation, in mm/month

RF= average rise plus fall of the road, in m/km

HC= average horizontal curvature of the road, in deg/km

P075= amount of material passing the 0.075 mm sieve, in % by mass

PI= plasticity index of the material, in %

K_{gl}= calibration factor for material loss (default value 1.2[12])

> HDM4 calibration factors for gravel loss (Kgl) and an overall calibration factor of 1.5 is recommended, with 2.4 for low plasticity wearing course material and 0.85 for high plasticity wearing course material[13].

K_{kt}= calibration factor for traffic-induced material whip-off coefficient

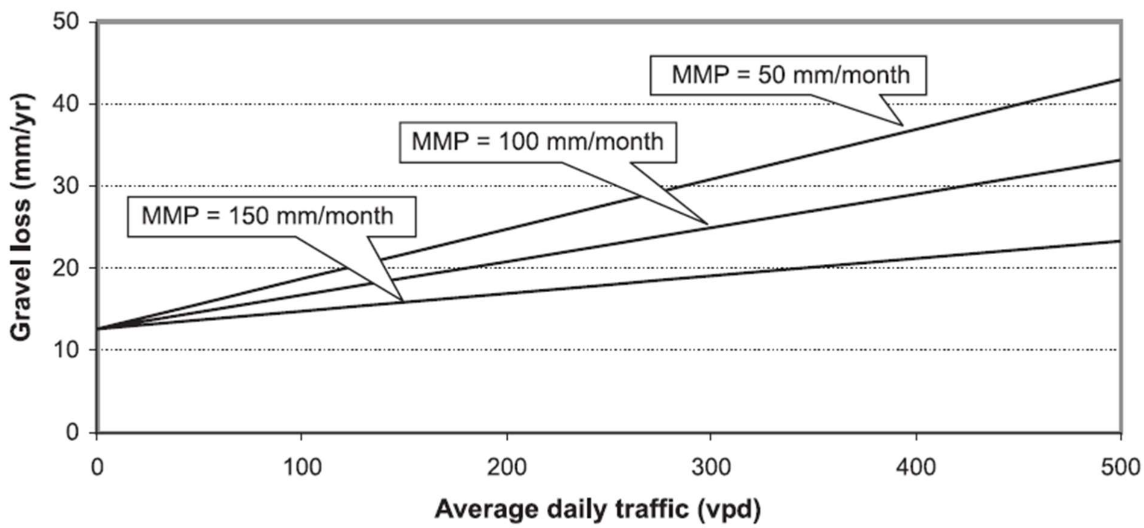

Figure A-1: HDM-4 predicted rates of gravel loss[11]

[12] Increase Application of Labour-based methods through appropriate engineering standards, Uganda Country Report, TRL-DFID-ILO, 2006

[13] Manual for Low Volume Roads, Part B: Materials, Pavement Design and Construction-2019, Ghana

ANNEX-B: MATERIAL DEPTH

It is of critical importance that the nominal subgrade strength is available to a reasonable depth in order that the pavement structure performs satisfactorily. The concept of "material depth" is used to denote the depth below the finished level of the road to which soil characteristics have a significant effect on pavement behaviour. In addition, the moisture regime may need to be controlled by, for example, the provision of adequate subsurface drainage and/or surface drainage. Below the material depth the strength and density of the soils are assumed to have a negligible effect on the pavement. Figure B-1 shows the material depth in relation to the main structural components of the road pavement.

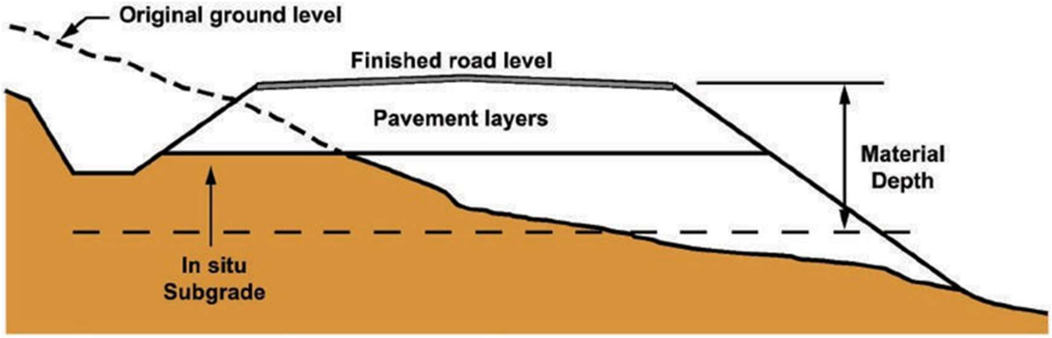

Figure B-1: Material depth [11]

The material depth approximates to the cover required over in situ subgrade material less than 3% soaked CBR (i.e. Subgrade Class S1). Table B-1 specifies typical material depths to be used for the different Traffic Load Classes for paved LVR's with a non-structural surfacing. It should be noted that the material depth is not necessarily the same as the thickness of the imported pavement layers. In certain special cases where "problem soils" occur , the recommended material depth may still be insufficient, meaning that subgrade cover requirements need to be specifically checked.

Table B-1 Recommended material depth for LVR's by Traffic Load Class

Traffic Load Class	Material Depth (mm)
TLC 1.0	700
TLC 0.3	600
TLC 0.01	450

The material depths indicated are not depths to which re-compaction and reworking is necessarily required. Rather, they are the depths to which the Engineer should confirm that the nominal subgrade strength is available. In general, unnecessary working of the subgrade should be avoided and limited to rolling prior to constructing overlying layers.

For the stronger subgrades, especially Class S3 and higher, the depth check is to ensure that there is no underlying weaker material at shallow depths that could lead to detrimental performance.

It is recommended that the Dynamic Cone Penetrometer (DCP) be used during construction to monitor the uniformity of subgrade support to the recommended minimum material depths.

ANNEX-C: IMPROVED SUBGRADE LAYERS

If the in situ subgrade is of class S1 – S3, subgrade improvement is generally required for paved roads. Only when the in situ subgrade is of Class SC4 can the upper pavement layers be placed directly on the in situ subgrade. For Subgrade Class S7 and S15 the subgrade would only need to be prepared as roadbed, i.e. reworking to a minimum depth of 150 mm, shaping and compacting to 93% of mod AASHTO Density, provided that the requirements in terms of material depth described Annex-B are met. Subgrade improvement requirements for unpaved roads are less stringent and is generally only required on very poor subgrades of Class S1.

There are many advantages to improving the strength of the in situ subgrade by constructing one or more improved layers. In principle, where a sufficient thickness of improved subgrade is placed, the overall subgrade bearing strength is increased to that of a higher class and the upper pavement layer thickness may be reduced accordingly. This often results in an economic advantage, as sub-base and base standard materials are generally more expensive than fill materials.

The use of improved subgrade layers also provides several other advantages, including:

- Provision of uniform subgrade strength;
- Protection of underlying earthworks;
- Improved compaction of layers above subgrade level;
- Provision of a more balanced pavement structure; and
- Provision of a running surface for the traffic during construction;

An improved subgrade placed on soils of any particular class must be made of a material of a higher standard than the underlying material. The decision to consider the use of an improved subgrade generally depends on the respective costs of sub-base and improved subgrade materials.

Table C-1 presents recommended actions for the different subgrade classes for paved roads only.

Table C-1 Subgrade improvement actions for paved roads

Subgrade Class	Possible improvement actions
SC1	Chemical / Mechanical stabilisation; or Remove and import new material; or Add additional cover to place poor quality material below material depth; or Use of geosynthetics
S3,S7, S15	The subgrade improvement action is dependent on the traffic class and in situ subgrade strength.

ANNEX-D: PROBLEM SOILS AND MITIGATION MEASURES

D1. Definition

The cost of a road is integrally linked with subgrade conditions. The poorer and more problematic the conditions, the greater the thickness required to support the design loads. Sometimes certain special problems may arise in the subgrade below the material depth which requires individual treatment. Some of the common problems which need to be considered include:

- The excessive volume changes that occur in some soils as a result of moisture change (i.e. expansive soils and soils with a collapsible structure);
- The non-uniform support that results from wide variations in soil types over the road length;
- The presence of soluble salts which, under unfavourable conditions, may migrate upwards leading to several problems, including cracking of the surfacing; and
- The excessive deflection and rebound of highly resilient soils during and after the passage of a load (e.g. micaceous soils).

By virtue of their unfavourable properties, some subgrade materials fall into the category of "Problem Soils". When encountered, they would normally require special treatment before acceptance in the pavement foundation. This category of soils includes:

- Low-strength soils;
- Expansive clays;
- Collapsible sands;
- Dispersive / Erodible soils;
- Micaceous soils.

D2. Low-strength Soils

Soils with a soaked CBR of less than 3 % (< 2 % in dry climates) are described as low-strength soils. These soils may be extremely soft in their natural state or become extremely soft on soaking. They occur particularly in low-lying, swampy areas. They are easy to identify whether in situ, during site inspections or through laboratory testing of their soaked strengths. Typical treatment measures for such soils include:

- Removal and replacement with suitable material;
- Stabilisation – chemical modification with lime, or through mechanical means;
- Use of geo-synthetic products to provide mechanical stabilisation; and
- Raising of the vertical alignment to increase soil cover and thereby redefine the design depth within the pavement structure.

A method of treatment for low-strength soils needs to be established at the design stage. The appropriate measure depends on soil properties, site conditions, available equipment, available materials, experience from other sites with similar conditions and cost.

D3. Expansive soils

Expansive soils, e.g. black cotton soils, are those which exhibit particularly large volumetric changes (swell and shrinkage) following variations in moisture contents. In the dry season they shrink and crack, becoming dusty. They are highly expansive and become very sticky when wet.

The mechanism of expansion illustrated in Figure D-1 is that of seasonal wetting and drying, with consequent movement of the water table. Soils at the edge of the road wet up and dry out at a different rate than do those under a paved surface, thus bringing about differential movement. It is this movement rather than the low soil strength (most expansive soils are often relatively strong at their equilibrium moisture content) which brings about failure. Such failure typically takes the form of associated longitudinal crack development, occurring first in the shoulder area and developing subsequently in the carriageway, as well as general unevenness of the pavement surface, arcuate cracking and settlement near trees and transverse humps and cracks at culvert sites (Figure D-2 and Figure D-3).

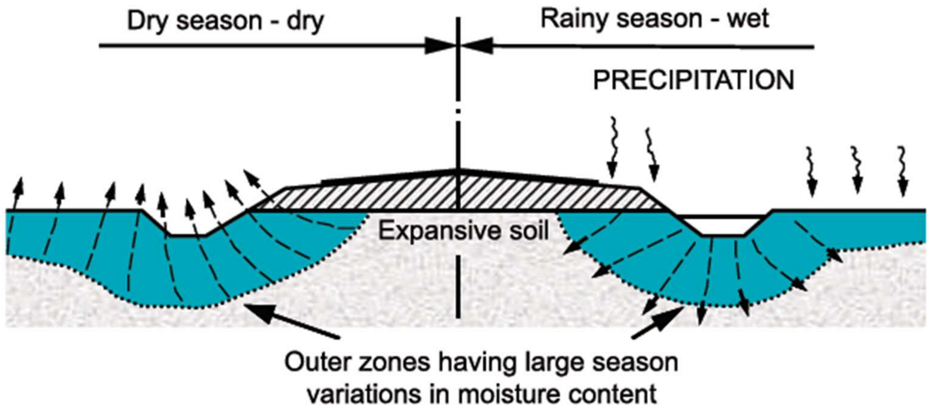

Figure D-1: Moisture movements in expansive soils under a paved road [11]

Figure D-2: Expansive soil exhibiting wide shrinkage cracks [11]

Figure D-3: Longitudinal cracking and deformation caused by expansive subgrade [11]

Generally, all of the following conditions must be satisfied before significant movement occurs:

- The soil must be active; and
- The changes in moisture content must be sufficiently great; and
- The confining stresses must be sufficiently low.

When dry, some expansive soils present a sand-like texture and are prone to erosion to a much greater extent than what would be normally expected from their plasticity and clay content.

Countermeasures for dealing with expansive soils:

Expansive soils are often thick and laterally widespread which makes the implementation of countermeasures costly, particularly for LVRs. Measures for dealing with such soils need to strike a balance between the costs involved and the benefits to be derived over the design life of the road. Traditional countermeasures typically include one or more of the following elements:

- Placing an uncompacted pioneer layer(s) of sand, gravel or rock fill over the clay and wetting up, either naturally by precipitation or by irrigation;
- Pre-wetting (2-3 months) to induce attainment of the equilibrium moisture content before constructing the pavement;
- Partially or completely removing the expansive soil and replacing it with inert material;
- Modifying or stabilising the expansive soil with lime to change its properties;
- Increasing the height of the fill (surcharge) to suppress heave; and
- Minimizing or preventing moisture change using waterproofing membranes (Weston, 1980) and/ or vertical moisture barriers (Evans and McManus, 1999).

The choice of Countermeasure Option should be based on a life-cycle cost analysis of the options presented.

Table D-1: Countermeasures for dealing with expansive soils

Expansiveness of soil	Alternative design and construction measures over expansive soils	
	Design Traffic TLC 0.01 and TLC 0.3	Design Traffic TLC 1.0
Low & Medium	Countermeasure A	Countermeasure A
High	Countermeasure A	Countermeasure B
Very high	Countermeasure B	Countermeasure C1 or C2

NOTE: Countermeasures C1 and C2 are normally not appropriate on unpaved roads.

Countermeasure A

General good construction practice for all LVRs on expansive soils adds little, if any, additional cost to construction works. Where possible:

- Remove vegetation during the dry season as long as possible in advance of construction.
- Construct any cuttings necessary, however shallow.
- Undertake construction when the in situ material is at equilibrium moisture content (i.e. at the end of the rainy season). If construction takes place in the dry season, the roadbed should be watered to saturation immediately prior to the placing of the backfill material.
- Extend side slopes of the embankment to 1:4 (TLC 0.3 roads) or 1:6 (TLC 1.0 roads). Utilize excavated material to flatten the side slopes of the embankment.
- Do not provide side drains unless this is necessary due to site conditions, in which case locate them 4 m from the toe of the embankment for TLC 0.3 roads or 6 m for TLC 1.0 roads as shown in Figure D-4
- Seal the shoulders with an appropriate impermeable surfacing. (For low expansive soils, sealing shoulders is uneconomical and not recommended as a countermeasure for both traffic groups; sealing of shoulders does not apply to unpaved roads).
- Remove/do not plant trees within a distance of 1.5 times their mature height from the edge of the shoulder.

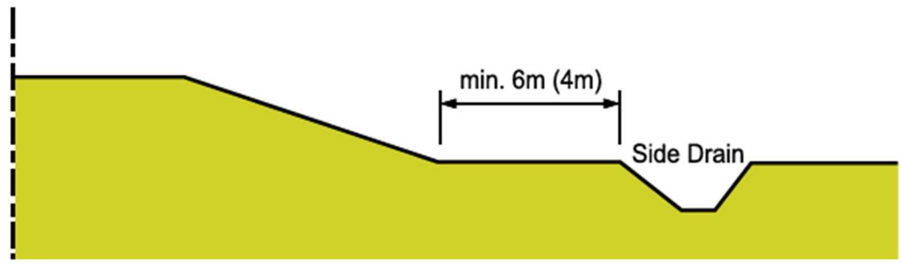

Figure D-4: Location of side drains in expansive soils [11]

Countermeasure B (Pioneer layer)

These measures are recommended for the higher class of TLC 1.0 roads. They typically entail the use of a 'pioneer" layer (Figure D-5) as follows:

- Adopt countermeasures listed for Countermeasure A.
- Place a loose layer "pioneer" layer (about 100-200 mm in thickness) of permeable sand, gravel or rock fill over the clay to cover the full width of construction. It is essential that this layer should remain loose and permeable and must therefore not be compacted or trafficked.
- Allow the "pioneer" layer to stand through one full rainy season in order to pre-wet the roadbed as much as possible through the elimination of evapotranspiration, and the collection of rainwater. Prevent localised ponding of water.
- Compact the "pioneer" layer in advance of construction during the following dry season and utilize it as the first layer of fill.
- Ensure minimum earthworks cover of 0.6 m.
- Do not use active clay as fill.
- Replace clay under culverts to a depth equivalent to the reduction of surcharge caused by the culvert.
- Waterproof culvert joints.
- Prevent ponding of water at culvert inlets and outfalls and adjacent to road.

If it is not possible to apply the "pioneer" layer technique, the vegetation should be removed as far in advance of construction as is feasible. If the roadbed is to stand open during the rainy season, it will be advantageous to plough or scarify it to a depth of about 150 mm to promote the collection and ingress of rainwater.

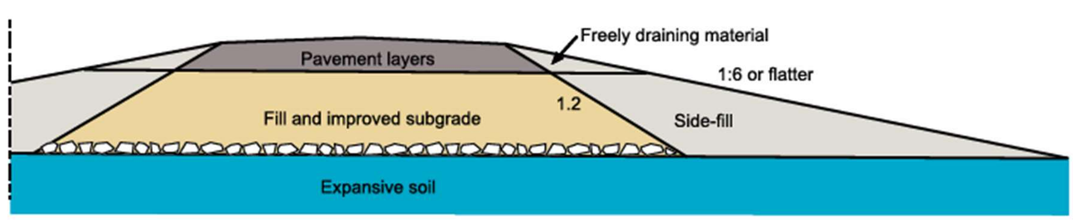

Figure D-5: Construction on expansive soils (use of Pioneer layer) [11]

Countermeasure C1 (embankment height < 2 m)

These measures are recommended for TLC 1.0 roads on soils with very high expansiveness and embankment height < 2 m. They typically entail partial excavation of the road bed as follows:

- Adopt countermeasures listed for Measure A.
- Excavate expansive soil over width to toe 1:2 side slope and to depth of 0.6 m.
- Stockpile excavated material at sides for eventual grading on to fill side slopes.

- Backfill excavation with non-expansive fill. Ensure minimum earthworks cover of 0.6 m.
- Fill above ground level to be constructed with 1:2 side slopes.
- Grade and spread excavated expansive soil on fill side slopes to lengthen their slope to 1:6 or flatter, thereby extending the distance of the road over which transpiration will be reduced.
- Expansive material must not be used for the shoulder slope to the pavement – these must be constructed as wedges of permeable material as shown in Figure D-6.

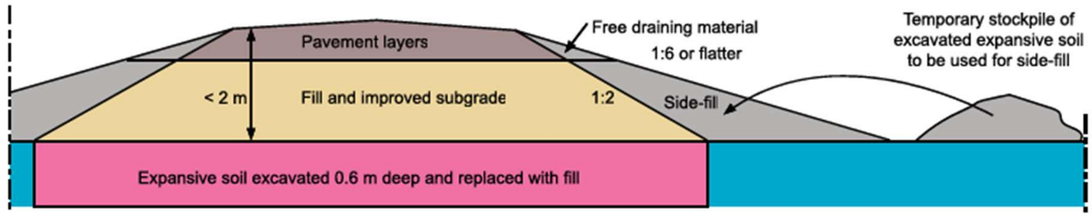

Figure D-6: Construction on expansive soils (embankment height < 2m) [11]

Countermeasure C2 (embankment height ≥ 2 m)

These measures are recommended for TLC 1.0 roads on soils with very high expansiveness and embankment height ≥ 2 m. They typically entail partial excavation of the road bed. The same countermeasures as for Measure C1 are adopted except for the following:

- Excavate expansive soil only under the width of the 1:2 (or 1:1.5) side slopes (Figure D-7)

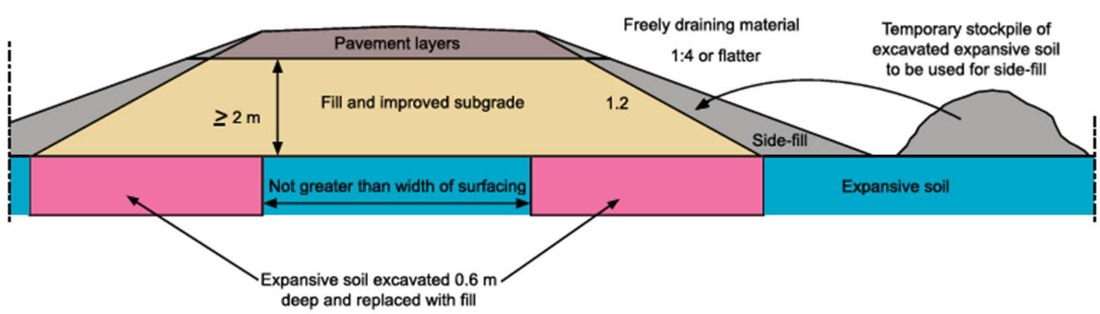

Figure D-7: Construction on expansive soils (embankment height > 2 m) [11]

The other countermeasures mentioned above, including stabilisation, surcharging and use of waterproofing membranes would normally be ruled out on cost grounds for LVRs.

D4. Collapsible soils

Collapsible soils exhibit a weakly cemented soil fabric which, under certain circumstances, may be induced to rapid settlement. A characteristic of these soils is that they are all unsaturated, and generally have a low dry density and a low clay content. At the in situ moisture content they can withstand relatively large imposed stresses, well in excess of the overburden pressure, with little or no settlement. However, without any change in the applied stress, but an increase in moisture content, additional settlement will occur as shown in Figure D-8 and Figure D-9. The rate of settlement will depend on the permeability of soil.

Countermeasures for dealing with collapsible soils

The countermeasures include:

- excavation of material to the specified depth below ground level; break down collapsible structure; re-place in the excavation; and re-compact with conventional rollers in lifts typically not exceeding 250 mm;

- ripping of the road bed, inundation with water and compaction with heavy vibrating rollers; and
- use of high-energy impact compactors from the surface of the subgrade, with or without the use of water.

The risk of collapse occurring on LVRs, particularly in arid or semi-arid areas, is small. Thus, other than in exceptional circumstances, the above measures are unlikely to be economically justified for application to LVRs.

Figure D-8: Collapse settlement in excess of 150 mm following impact compaction [11]

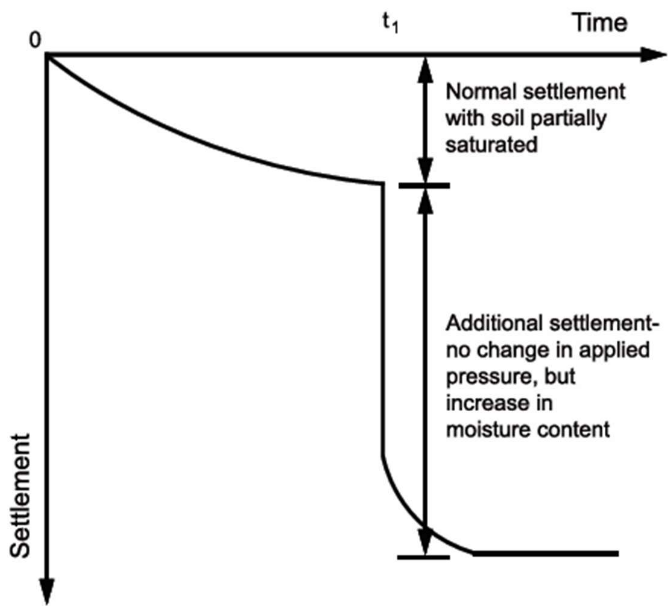

Figure D-9: Manner of additional settlement due to collapse of soil fabric [11]

D5. Dispersive/erodible soils

Although dispersive and erodible soils (see Figure D-10) are similar in their field appearance (highly eroded, gullied and channelled exposures), they differ significantly in the mechanisms of their actions and are differentiated as follows:

- Dispersive soils are those soils that, when placed in water, have repulsive forces between the clay particles that exceed the attractive forces. This results in the colloidal fraction going into suspension and in still water staying in suspension. In moving water, the dispersed particles are carried away.

- Erodible soils are those soils in which the cohesion (or surface shear strength when wet) is insufficient to resist the tractive forces of rain or runoff water flowing over them. Such soils tend to lose material as a result of flowing water over the material exceeding the cohesive forces holding the material together.

Figure D-10 Example of severe erosion in erodible/dispersive soils [11]

It is not normally important, or even easily possible, to quantify the actual potential loss of dispersive/erodible material as the process is time-related and given enough time, all of the colloidal material could theoretically be dispersed and removed, leading to eventual loss of material on a large scale. However, it is important to identify the presence of dispersive/erodible soils so that necessary precautions can be taken if they affect the constructed pavement.

Countermeasures for dealing with erodible and dispersive soils

Methods for dealing with dispersive soils include (Paige-Green, 2008):

- Avoid the use of such soils in fills and remove and replace it in the subgrade;
- Manage water flows and drainage in the area;
- Treat the soil with lime or gypsum to allow the calcium ions to replace the exchangeable sodium cations; and
- Compact the soil at 2 to 3% above optimum moisture content to as high a density as possible (Elges, 1985).

Methods for dealing with erodible soils include (Paige-Green, 2008):

- Ensure that the drainage in the area is well controlled;
- Cover the soils with non-erodible materials and vegetation; and
- Once erosion has occurred, back-fill the channels and gullies with less erodible material and redirect the water flows.

D6. Micaceous soils

Micaceous soils contain large quantities of mica (muscovite) and occur in such materials as weathered granite, gneiss, mica schist and phylite materials. These soils often cause problems with compaction because of the "spring action" of the muscovite materials which may prevent achievement of the intended density or, even if it is achieved initially, can cause rutting in the compacted layer at a later stage.

Countermeasures for dealing with micaceous soils

Methods for dealing with micaceous soils include:

- removing the micaceous soil layer to below the material depth in the subgrade; and
- stabilising the micaceous soil with lime or cement.

For LVRs, the loss of shape associated with micaceous generally must be accepted, unless the overlying pavement warrants the expense of the countermeasures indicated above.

D7. Use of geosynthetics in subgrade strengthening

The primary uses of a geosynthetics in a pavement system are to serve as a construction aid over soft subgrades, improve or extend the estimated service life of the pavement, and reduce the thickness of the structural cross section for a given design period. These objectives are achieved through four functions (separation, reinforcement, filtration (drainage), and containment) as shown in Figure D-11.

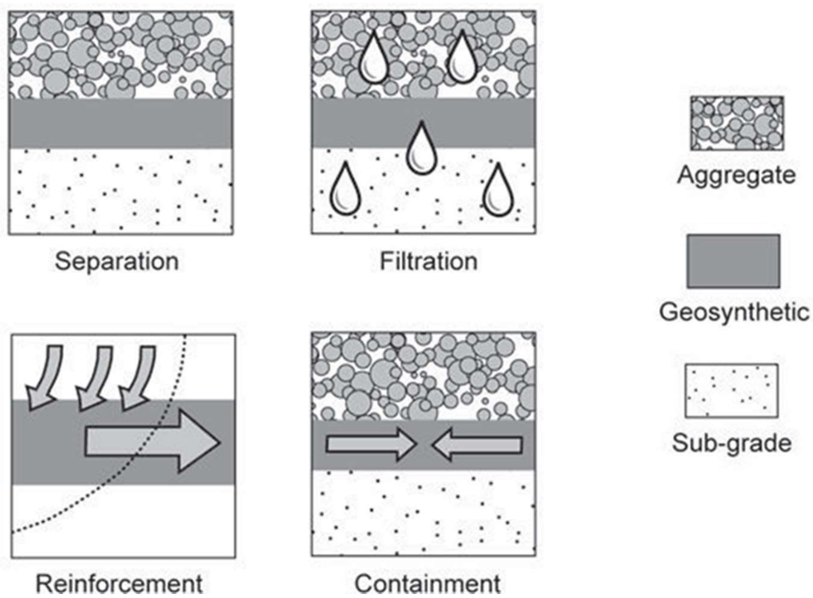

Figure D-11 Main functions of geosynthetics in pavement systems [11]

Geotextile and geogrid materials are the most commonly used geosynthetics in pavement design. This is especially true when only the pavement itself is considered without fills and cut slopes, abutments, or drainage facilities. Stabilization using these materials is achieved through a combination of separation, filtration, and reinforcement. The separation function of a geotextile prevents the subgrade and the sub-base from intermixing (see Figure D-18), which might occur during construction and later in-service due to pumping of the subgrade by traffic loads. The filtration function is required because soils requiring stabilization are usually wet. By acting as a filter, the geotextile retains the subgrade without clogging, while allowing water from the subgrade to pass up into the sub-base, permitting the pore pressure to dissipate, and promoting strength gain due to consolidation.

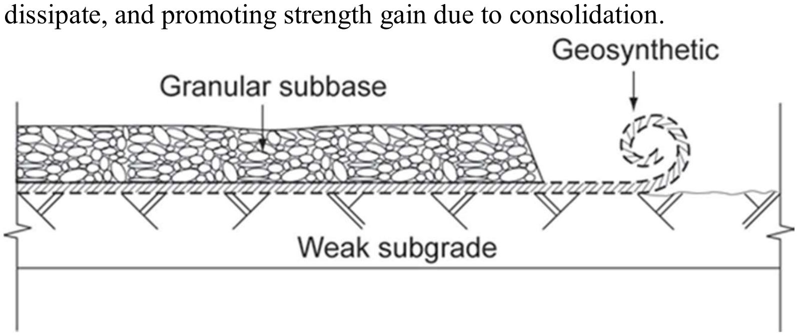

Figure D-12 Use of geosynthetic to separate a sub-base from the subgrade [11]

Geosynthetics also provide some level of reinforcement by laterally restraining the base or sub-base and improving the bearing capacity, thus decreasing shear stresses on the subgrade. Soft subgrade soils provide very little lateral restraint (containment). Hence, when the granular material moves laterally, ruts develop on the surface and also in the subgrade. A geogrid with good interlocking capabilities or a geotextile with high frictional capacities can provide tensile resistance to such lateral aggregate movement. Geosynthetics also increase the system bearing capacity by forcing the potential bearing surface under the wheel load to develop along alternate, longer mobilization paths and, thus, higher shear strength surfaces.

Geotextiles serve best as separators, filters and, in the case of non-woven geotextiles, drainage layers, while geogrids are better at reinforcing. Geogrids, as with geotextiles, prevent the sub-base from penetrating the subgrade. When geogrids are used, either the sub-base must be designed as a separator or a geotextile must be used in conjunction with the geogrid, either separately or as a geo-composite material.

ANNEX-E: ASSESSMENT OF SUBGRADE STRENGTH

E1. Subgrade testing

The subgrade can be characterised on the basis of a centre-line material testing survey. This can be done using the methods provided in Table E-1.

Table E-1: Methods of subgrade testing

Subgrade Testing				
Method	**Cost**	**Time**	**Representation**	**Laboratory testing**
CBR	Relatively expensive	Time consuming	Small sample of overall materials	Sampling of materials required. Transport of samples from site to laboratory needed. Testing of materials necessary.
DCP	Relatively inexpensive	Rapid testing possible	Good representation of materials at regular intervals	Test performed in situ, no sampling or transport of materials required.

The subgrade is classified using the standard soaked CBR test to provide a strength index. It is not expected that the subgrades will become soaked in service except in exceptional circumstances and so the design catalogues show different thickness designs based on climate and drainage conditions for the same indexed subgrade class. A standard soaked CBR test is also used to evaluate the strength of the imported pavement materials.

Subgrades are classified on the basis of the laboratory soaked CBR tests on samples compacted to 97% of MDD. Samples are soaked for four days or until zero swell is recorded. On this basis, the soaked CBR is used to assign a design subgrade class.

The use of the Dynamic Cone Penetrometer allows the in situ subgrade strength to be determined at many points along the road and thereby provides an important set of subgrade strength data for a statistically reliable design to be produced. Allowance has to be made for the likely long-term subgrade strength under the completed road. The DCP Structure Number 450 (DSN450) is the total number of blows required for the DCP to penetrate to 450 mm and provides a broad measure of overall strength of the pavement, somewhat analogous to the AASHTO Structural Number. The DSN800 is typically used on high volume roads (this is the number of blows required for the DCP to penetrate to 800 mm), but the DSN450 is more relevant to LVRs where pavement structures are not required to be as deep as for high volume roads.

Since the subgrade strength is likely to vary along the project road, it is necessary to perform DCP testing at an appropriate interval such that the variability can be assessed. This will also improve the reliability of the design as the variability in the subgrade is better understood.

It is recommended that at least two DCP tests to 800 mm depth should be carried out per kilometre of road, alternating between the outer wheel tracks in each direction for an existing road and alternating with 2m offsets to the left and right of the centre-line for a new road after removing the upper soil layer containing humus, vegetable matter or any other undesirable materials. If the subgrade conditions appear to be highly variable, the frequency of testing should be increased, even up to one test per 250 m if necessary. There should be at least 8 results for each uniform section for statistical validity, which may require more frequent DCP tests for shorter uniform sections.

Various correlation between the DCP and the CBR value have been determined, including the following, both of which apply to 60° cones:

$\text{Log CBR} = 2.48 - 1.057 \text{ Log DN}$ (Overseas Road Note 8, TRL, 1990)

Conversion from DN to CBR needs to be approached with caution and with knowledge of the type of in situ materials at the DCP test locations. The DCP penetration rate is influenced by:

- Grading. Fine grained materials generally have consistent penetration rates, but coarse materials and materials containing larger stones can have erratic penetration rates which over-estimates actual bearing capacity.
- In situ moisture conditions. Certain material types such as calcretes and other pedogenic materials can exhibit very low penetration rates when dry, but may become very soft when saturated.
- Plasticity and clayiness. High plasticity may increase suction and friction along the shaft of the DCP thereby slowing penetration rates and overestimating actual bearing capacity, particularly deeper into the pavement or subgrade.

E2. Delineation of subgrade uniform sections

The CBR test results and DSN450 can be used to delineate the road into smaller uniform sections by using the cumulative sum (CuSum) method. The following formula is used to calculate the CuSum:

$$\text{CuSum} = W\sum_{i=1}^{i=n} x_i - \bar{x}$$

Where
xi is the current value;
x̄ is the mean value; and
n is the total number of readings in the data set.

Table E-2: Example of Cumulative Sum calculation [11]

Location	(xi) DN450	xi- x̄	CuSum*
1	31	17,5	17,5
2	31	17,5	35
3	25	11,5	46,5
4	26	12,5	59
5	11	-2,5	56,5
6	14	0,5	57
7	13	-0,5	56,5
8	9	-4,5	52
9	10	-3,5	48,5
10	13	-0,5	48
11	5	-8,5	39,5
12	3	-10,5	29
13	4	-9,5	19,5
14	5	-8,5	11
15	6	-7,5	3,5
16	11	-2,5	1
17	15	1,5	2,5
18	13	-0,5	2
19	14	0,5	2,5
20	11	-2,5	0
Mean (x̄)	13.5		

Table E-2 provides an example of a CuSum calculation. Figure E-1 provides a graphical representation of the CuSum calculations and also provides the basis of identifying uniform sections along the road. Significant changes to the gradient of the CuSum line indicates that the underlying properties are also changing. This suggests that a new uniform section can be introduced. The actual DCP readings also assist in determining boundaries between uniform sections. It must be kept in mind that the length of the uniform sections must be practical for analysis and construction purposes. The delineation of uniform sections is not an exact science and it is common for practitioners to differ somewhat in their interpretation of the same data set.

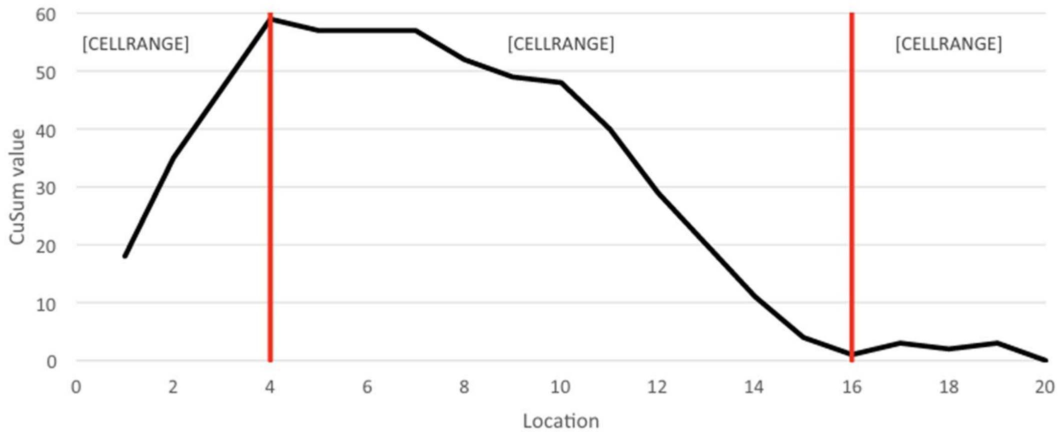

Figure E-1: Example of a cumulative sum plot [11]

E3. Determining the subgrade design CBR or DSN450 value

The CBR and DSN450 results obtained from the subgrade soils testing and DCP testing are used to determine which subgrade class should be specified for design purposes in accordance with Table E-3. In some cases, a variation in results may make selection unclear. In such cases it is recommended that:

- firstly, the testing process is checked to ensure uniformity (to minimise inherent variation arising from, for example, inconsistent drying out of specimens); and
- secondly, more tests are performed to build up a more reliable basis for selection.

Table E-3: Design CBR/DN values related to Traffic Load Classification

Traffic Load Class	Design Reliability	Percentile
TLC 1.0	90%	10th percentile
TLC 0.3	85%	15th percentile
TLC 0.01	70%	30th percentile

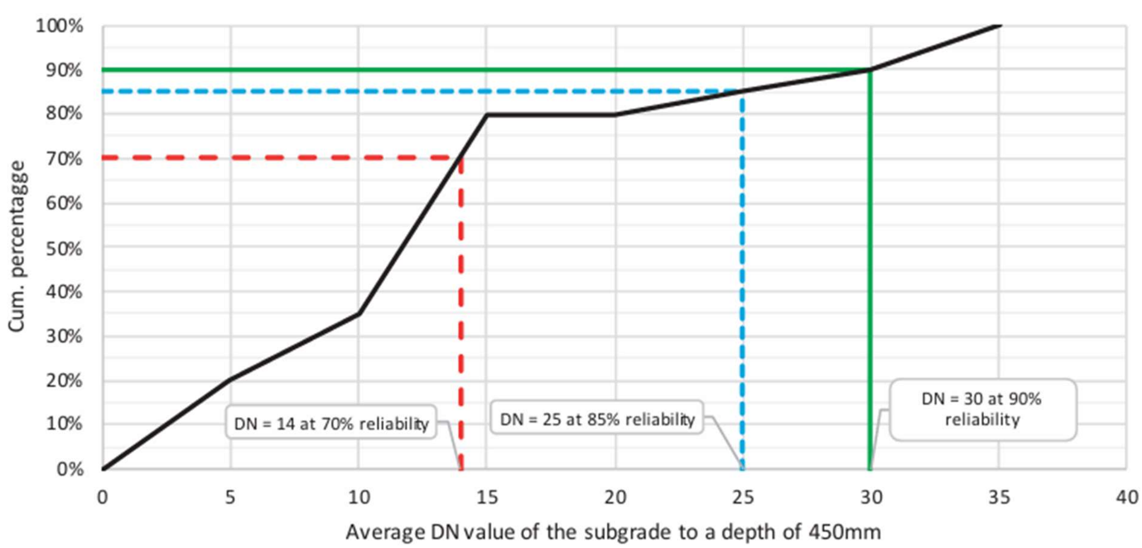

Figure E-2: Example of a cumulative distribution plot [11]

Plotting these results as a cumulative distribution curve (S-curve), in which the y-axis is the percentage of samples less than a given CBR/DN value (x-axis), provides a method of determining a design CBR/DN value (Figure E-2). The percentiles to be used for determining the design subgrade CBR/DN value depend on the Traffic Load Class and are indicated in Table E-3. For a design Traffic Load Class of TLC 0.3, the design CBR value should be the 15th percentile (i.e. the value exceeded by 85% of the CBR measurements) or if the DN value is used, the 85% percentile value (i.e. the value exceeded by 15% of the DN measurements). The cumulative distribution of the full data set of DN values as per the example presented in Table E-2 are shown in Figure E-2, but the same principles can be applied to determine the percentile value for each individual uniform section.