Vanuatu Rural Roads Design Guide

Incorporating Climate Resilient Design

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Public Works Department

Preamble

The purpose of this Guide is to develop and promote appropriate methods of road engineering that gives the best possible access to rural communities at minimal cost.

This Guide has been prepared for use across PWD for the rural road network in Vanuatu.

The Public Works Department Standard Technical Specification for Road and Bridge Works and Standard Drawings are complementary documents addressing how the work shall be undertaken. They have been prepared as separate documents.

This Guide does not include urban roads.

The Austroads Road Design Series is the basis for this Vanuatu Rural Roads Design Guide.

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PART A - Design Guide for Geometry, Pavement and Drainage

1 Introduction

Currently in Vanuatu, there is no classification and design standards for roads.

The Ministry of Infrastructure and Public Utilities (MIPU) / Public Works Department (PWD) have never adopted official geometric design standards and technical specifications for road works. Rather, road design has been undertaken on a case-by-case basis, often design-by-eye and dictated by provincial engineer / consultant / donor driven projects.

Surveys reveal that road widths are inconsistent. In some cases, some roads are very wide without a requirement, whilst others in comparison are narrow without requirement. In this case restricted access can affect the safety of users including pedestrians. A lack of guideline is leading to inefficient spending through overdesign or under design, ultimately resulting in road development that does not match the needs of its users.

There are 2,241 kilometres of public roads in Vanuatu with 83% (1,861 km) over 8 islands. Most of the public roads network already exists and there is a low justification for new roads. Nevertheless, all roads need to be maintained and many of them need to be upgraded from a basic track to a standard that is compatible with the actual need. In addition, there is also need to address ways to make road infrastructure more climate resilient and this design guide is a significant step forward to addressing these issues in future road design and maintenance.

With the adoption of the Public Roads Act, there is a need for MIPU / PWD design standards and technical specifications for roads to be developed and implemented. They should be based on Vanuatu's environment and experiences, forming a pragmatic point of view recognising the particular conditions of the Vanuatu context, in particular:

- Access needs for communities.
- Low traffic volumes and light traffic type (70-80% of vehicles constituting 4WD pick-up trucks and max of 5% of heavy vehicles).
- Environmental factors (rainfall, topography, cyclone and other extreme weather events).
- Limited budgetary resources for road works.
- Lack of uniformity in the network due to lack of standards and guidance.

It is essential to develop and promote appropriate methods of road engineering that give the best possible access to communities at minimum cost.

2 Austroads Standard Guides

In 2009, Austroads launched a comprehensive set of technical guides covering 10 subjects relating to road construction and management:

- Asset Management
- Bridge Management
- Pavement Technology
- Project Delivery
- Project Evaluation
- Road Design
- Road Safety
- Road Transport Planning

- Traffic Management
- Road Tunnel

It is a very detailed and comprehensive set of documents containing 96 individual parts and sub-parts, which may not all be relevant to conditions and context in Vanuatu.

The vast majority of the roads in Vanuatu fall into Rural Class 5 roads of Austroads classification and as such are defined as *“Those roads, which provide almost exclusively for one activity or function which, cannot be assigned Classes 1 to 4”.* In addition, Australian Road Research Board (ARRB) edited in 2009 a Manual for Unsealed Roads - Guidelines to Good Practices, which also gives a full range of relevant information. However, the range of roads considered in this Guide is often on flat and open terrain with an important percentage of heavy traffic (similar to Central Australia).

Consequently, considering the Austroads Guides series allow enough flexibility to accommodate the local context, it was decided to retrieve from Austroads and ARRB the most relevant guidelines and insert it in an adapted brief “Design Guide” that would best suit Vanuatu’s environment.

> From AUSTROADS GUIDE TO ROAD DESIGN, Part 1, section 2.1
>
> *"Although local conditions and circumstances may sometimes require unique or innovative approaches to design, the bulk of works can be well accommodated by the approach outlined in the Guide to Road Design. However, it is recognised that member organisations may develop and publish supplementary guidelines and manuals to cover specific design situations. "*
>
> From AUSTROADS GUIDE TO ROAD DESIGN, Part 3, section 2.2.2
>
> *"Most road authorities in Australia [sic] have developed a functional hierarchy for their road networks. This hierarchy enables each authority to systematically plan and develop their network to meet the needs for local access, cross town/city travel, intrastate and interstate travel."*

It is suggested that the Austroads Standard Guides be adopted by PWD as Reference Guides for any particular design or particular case, excluding the day-to-day standard design. A Design Guide for low-volume rural roads in Vanuatu is herein proposed.

3 Methodology

3.1 Road Network Description

According to the 2014 road inventory, there are a total of 2,241 kilometres of public roads in Vanuatu distributed across 24 islands. From this, 50% of the road network is found on 3 islands (Santo, Efate and Malekula) and 83% on 8 islands. The distribution is shown on Table 1 and Figure 1 below.

Province	Island	Length (km)
Sanma	Santo	520
Shefa	Efate	337
Malampa	Malekula	267
Penama	Pentecost	199
Penama	Ambae	182
Tafea	Tanna	177
Sanma	Malo	94
Malampa	Ambrym	84
Shefa	Epi	71
Penama	Maewo	46
Sanma	Aore	43
Shefa	Tongoa	37
Tafea	Erromango	31
Malampa	Paama	23
Torba	Vanua Lava	23
Shefa	Nguna	22
Shefa	Emae	20
Torba	Moto Lava	14
Torba	Gaua	13
Sanma	Tutuba	12
Tafea	Aniwa	12
Shefa	Emao	9
Shefa	Tongaoriki	5
Shefa	Pele	4
	Total	**2,241**

Figure 1 Road distribution

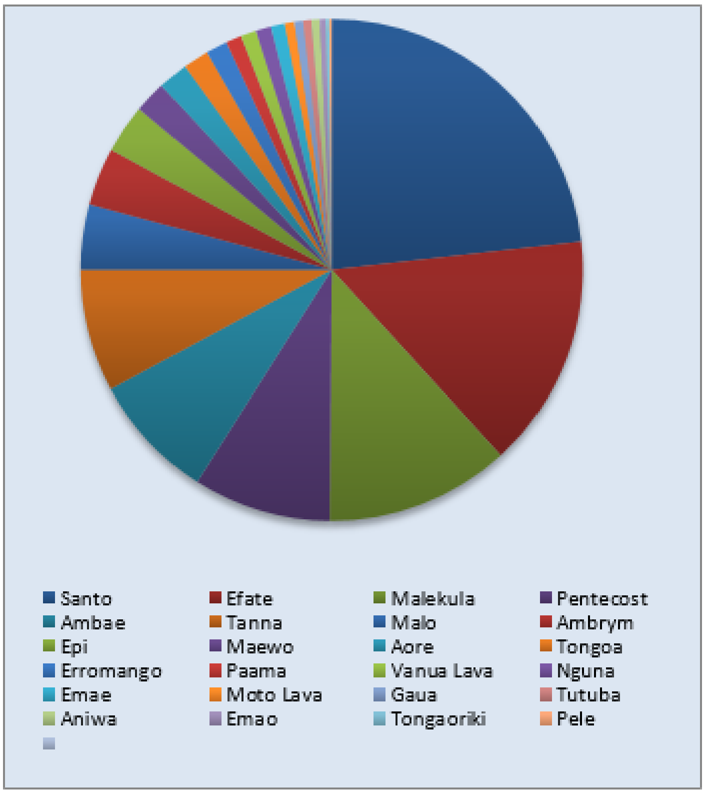


Table 1 Road distribution (length of kilometres)

3.2 Approach to Design Standards

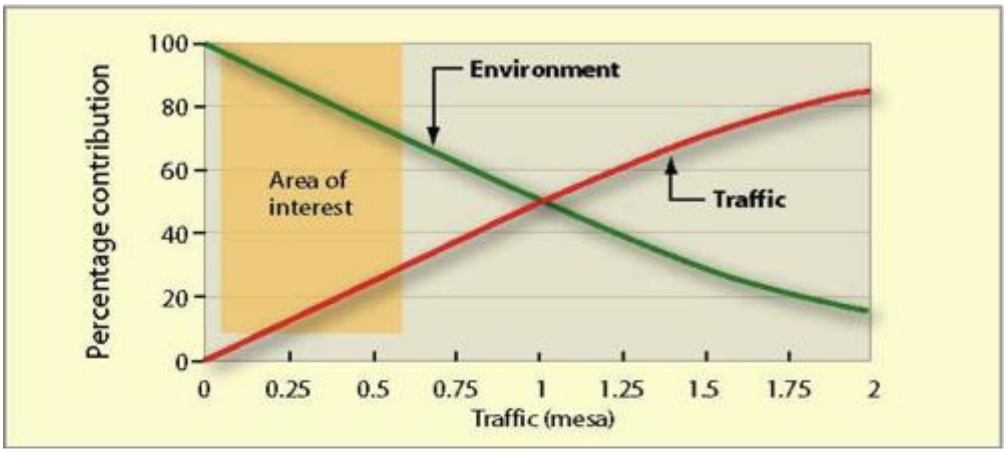
Unpaved gravel and earth roads constitute around 95 per cent of the designated road network in Vanuatu, whilst earth roads and tracks dominate the undesignated network. Only about 10% of the road network is sealed, and these roads are located on Efate and Santo only. Therefore, unsealed roads are the primary road network on all other islands. They play a vital social and economic role in the development of rural areas where the majority of the population live.

The traditional approach of road design generally considers traffic parameters (volume and type) to address security and sustainability aspects. However, for low-volume roads such as those in Vanuatu, innovative solutions need to challenge the conventional assumptions regarding road design criteria. The concept of an appropriate, or locally environmentally optimised design approach provides a way forward. Low volume road standards and designs need to support the function that the road is providing as well as recognising the important influences of the deterioration mechanisms. The approach needs also to consider the availability of funds, the local technical capacity and the social impacts.

Recent research around the world has questioned many of the accepted assumptions about the planning, design, construction and maintenance of low-volume roads. This research has quite clearly shown:

- The importance of adopting a more holistic, sustainable approach to the provision of low-volume roads
- The need to revise conventional approaches to planning, economic appraisal and the environment
- The shortcomings of conventional specifications and, to some extent, of test methods, in assessing the adequacy of local materials for use in low-volume roads
- The advantages of adopting more appropriate geometric and pavement design standards
- The economic success of innovative construction methods
- The importance of paying greater attention to the environmental aspects of road provision

Austroads and ARRB base their assumption on the fact that traffic is the major factor contributing to the deterioration of the road. However, for low volume roads, as in Vanuatu, where climate conditions can be severe, the environment will be the major contributor. According to the last traffic count (November 2013), the busiest road would have less than 0.1 Mesa[1]. This is shown in Figure 2. below.



Ref. World Bank

Figure 2 Relative effect on traffic and environment on road deterioration

Controllable factors include engineering design, selection of materials, construction quality and control, standard and timeliness of maintenance intervention to name a few. Uncontrollable factors include climate, ground shape (terrain), geological and geomorphological conditions, surface and sub-surface hydrology. Thus there are many very influential factors that the engineer cannot control and hence understanding risk and reliability is a key aspect of design to cater for this uncertainty.

[1] Millions of Equivalent Standard Axles

Main Climate Resilience Considerations

Low volume roads are more affected by rainfall (erosion, landslide, overflows, etc.) than by traffic. In the future, climate-related deterioration factors are likely to be amplified by the effects of climate change. Engineers should consider the following points in order to design climate resilient roads and mitigate negative effects of climate change:

- Sea level rise. This is currently measured to be 6 mm per year throughout Vanuatu and this will probably continue at, or around, this rate in the future.
- Time horizon. Due to the permanent nature of coastal infrastructure such as walls or jetties, a life cycle of 50 years should be considered. For coastal roads a life cycle of at least 20 years should be considered.
- Storm surges. Storm surges cause overtopping of coastal roads. Wave heights are driven by wind speed and "fetch" so are hard to predict but any locations currently experiencing flooding during storms will experience more severe events in the future.
- Rainfall will become more intense, of shorter duration, but may happen more often.
- Temperatures will increase. Longer periods of drought can be expected. Anticipate less water availability. Also a 1^{o}C rise in temperature may cause a 10% increase in precipitation.

The Public Works Department is responsible for significant lengths of low volume roads and on this basis, the establishment of the following is recommended:

- A Road Classification System for Vanuatu to ensure consistency in the management (design, maintenance, etc.) of the road network across the range of roads on all islands.
- Design Guide together with Standard Drawings and Standard Technical Specification.
- Procedures to monitor the performance of road conditions for the various road types and appropriate intervention levels to set priorities for scheduling road maintenance works.
- Periodic training for local contractors and inspectors in order to allow the implementation of all the above.

The key principles for the classification and design approach proposed are summarised in Table 2.

	Based On	To Achieve	Design parameter
Accessibility	Road function, climate	The right management of accessibility and mobility to communities and users	River crossing, all design aspect (for year-round roadway access)
Security	Traffic of vehicles and pedestrians, slope, climate	Safety for all user (geometry)	Geometry, pavement, drainage design
Sustainability	Traffic of vehicle, slope, climate	Resilient when flood or other environment event, better value for money and	Geometry, Pavement design, drainage

Table 2 Design approach

This Guide proposes:

- A Road Classification System;
- Guidelines for appropriate Design Standards for each road class;
  - Geometric Design
  - Pavement Design
  - Drainage Design

4 Proposed Road Classification System

4.1 Road Function

With the recently adopted Road Act, the public road network has been divided into 3 functional classes. The road function classification does not consider traffic volume, but only the function as the accessibility and the connectivity. Classifications are as follows:

- Arterial roads (71 % of the public road network)
- Feeder roads (20 % of the public road network)
- Urban roads (9 % of the public road network)

Arterial and Feeder roads are found in rural areas on all islands. Urban roads are found only in Port Vila and Luganville. This Guide will address only the Arterial and Feeder rural roads.

As arterial roads are the major link (and often the only one) to critical economic and social infrastructure (e.g. hospitals, airport, etc.), it is appropriate that they provide a high degree of accessibility and connectivity all year round. Therefore, the function of the road will determine the level of access expected for each type of road and therefore, to adapt the appropriate design component to suit this requirement.

In addition to the functional classification included in the Road Act, a supplementary classification has been established in order to address particular environmental characteristics, which might need to be considered for design purposes.

4.2 Traffic Class

An understanding of traffic volume is essential to establish the appropriate pavement design and the geometry. It also helps to better plan the level of maintenance on the pavement (pot holes, reshaping, etc).

In November 2013, a traffic count was conducted on the main roads on 4 islands with results shown in Figure 3:

- Malekula (8 roads, 4 days)
- Pentecost (1 road, 1 day)
- Ambae (5 roads, 2 days)
- Tanna (6 roads, 3 days)

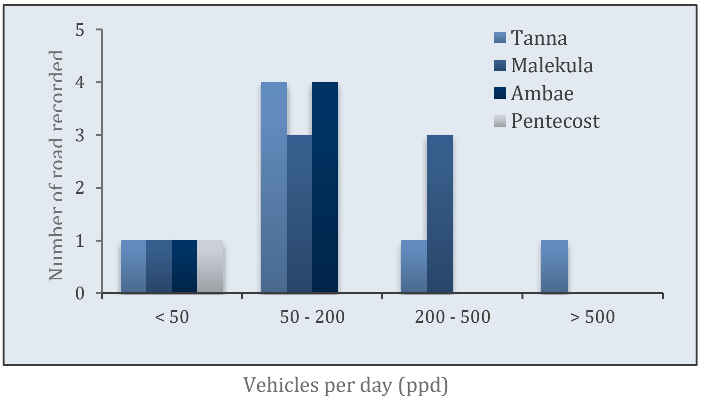


Figure 3 Traffic distribution

The findings were as follows:

- The maximum daily traffic recorded on average for one road section was 681 vehicles per day (vpd) on Lakatoro to Aoup Junction, in Malekula.
- Four sections had between 200 and 500 vpd (2 on Malekula and 1 in Tanna).
- Eleven had between 50 and 200 vpd (3 in Tanna, 4 in Malekula and 4 in Ambae)
- Four had less than 50 vpd (1 on each of the 4 islands)

Therefore, in order to address the technical and security aspects of the road design (geometry, pavement), 5 traffic classes along with the number of lanes required are designated for rural roads in Vanuatu, shown in Table 3:

Traffic Class	TRAFFIC Vehicles per day (vpd)	Number of Lanes
T1	> 500	2
T2	200 – 500	2
T3	50 – 200	1
T4	< 50	1
T5	< 20	1

Table 3 Traffic classes

These classes will guide the design specifications in terms of safety and sustainability. For example, a one lane road would not be suitable if the traffic is more than 500 vpd. A summary of the traffic counts performed on 4 islands is included in Appendix A.

4.3 Pedestrian Users

In addition to traffic counts, the numbers of pedestrians were also recorded. On almost half of the roads surveyed, the number of pedestrians was higher than the number of vehicles. This highlights the need to consider pedestrian requirements and road safety design for non-motorised users. An increase in the shoulder width of the road addresses this situation in most instances. This is shown in Figure 4 below:

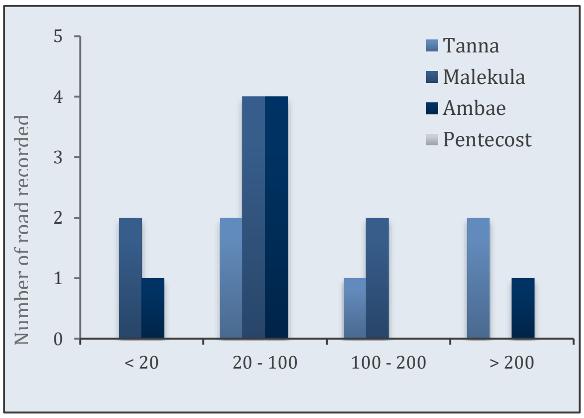


Photo Tanna - Children walking to school

Pedestrian per day (ppd)

Figure 4 Number of roads per pedestrian class

4.4 Terrain and Slopes

The major effect on steep slopes is erosion, particularly due to heavy rain. Average annual rainfall in Vanuatu is around 2,500 mm per year, with peaks of up to 4,000 mm per year. Deterioration of slopes will affect safety when slippery and/or cause the occurrence of deep erosion channels. This may lower or stop access through a given section.

A simple classification of 'flat', 'rolling', and "hilly and steep" terrain descriptions has been adopted as a basis for specifying appropriate geometric standards. The definition of each can be described in general terms as follows in Table 4:

Terrain	Class	Description	Gradient	
Steep	S4	Roads in rugged with substantial restrictions to both horizontal and vertical alignments	> 1:7	> 15%
Hilly	S3	Roads can have substantial cuts and fills	1:10 to 1:7	10-15%
Rolling	S2	Roads can have substantial cuts and fills	1:20 to 1:10	5-10%
Flat	S1	Roads generally follow the ground contours	Up to 1:10	< 5%

Table 4 Terrain / slope class

5 Guidelines to Geometric Design Standards

5.1 Design Considerations

The geometric design standards for roads are generally governed by the function of the road (level of access), traffic volumes and vehicle type (width and safety factors), non-motorised users (safety), terrain (safety and sustainability), social environmental (communities, farm) and physical environmental (rainfall, climate) issues as well as cost considerations. Ideally a compatible cross section, horizontal and vertical alignment is required which will provide users with an adequate quality of service in terms of ride comfort, and convenience, resulting in a safe facility.

The geometric design of low volume roads presents unique challenges, which require the application of common road engineering practices to a lower cost facility that serves only a small number of vehicles, with many pedestrians, often in sensitive environmental conditions and with constrained budgets. The design must provide a road, which can cater for vehicles, recognise the safety of all road users, and be accomplished at minimal cost. This requires a unique and flexible approach, without overlooking the principles of roadway engineering.

Photo Tanna

The quality of service is a qualitative term based on the concept of providing varying levels of convenience, comfort and safety to a driver. Convenience can be associated with the travel time taken for a journey, (i.e. travel speed). Comfort can be associated with ride quality (i.e. road profile), and safety related to the consistency of road standards (i.e. no surprises). Considering the traffic is low and the islands are small (normally less than 80 kilometres in overall length), comfort riding and travel speed are not the priorities. Priorities are focussed on accessibility, safety and sustainability.

Roads in Vanuatu should be ideally designed to withstand heavy storm events to extend maximum levels of access to as many people as possible within the current resource allocations. The principle of life cycle costing should be incorporated when designing major road rehabilitation projects, especially those for Arterial roads. Positioning roads in vulnerable areas should be avoided and, if not possible, expected negative effects mitigated using appropriate engineering methods.

Identifying vulnerable areas

To identify vulnerable areas one should check if roads are in areas of:

- Close proximity to the shoreline where erosion is self-evident.
- Close proximity to the shoreline where overtopping by storm waves is known to occur.
- Flat areas prone to flooding which take a long time to dry out.
- Steep gradient > 10%.
- Road below steep slopes prone to landslides.
- Roads crossing watercourses.

Reference is made to the vulnerability maps produced under the Climate Resilient Road Standard (CRRS) project.

Design standards proposed for road works make use of existing modalities from countries with similar environmental, geological and topographical conditions as is found in Vanuatu. In addition, it is necessary to use local materials for pavement, in particular coronous and volcanic scoria (base / wearing course) as well as aggregates in masonry / concrete works.

To ensure that expectations are met, quality control procedures need to be specified and enforced during project preparation and construction.

Guidelines relating to the geometric design standards for each road class are given in Part D. The standards are based on the roadway engineering principles with applied judgement to reach practical and reasonable standards relating to a range of low volume roads. However, for the lowest design class of road, it is considered inappropriate to design on the basis of geometric standards, and the sole criterion should be the achievement of an appropriate level of access. Design in these situations should be based on the limiting values of radii, width and gradient for the passage of a suitable design vehicle.

This is a starting point for further discussion towards Vanuatu design standards and technical specifications. The notes below outline the main geometric design considerations used in arriving at the various values given in Appendix A.

5.2 Design Speed

The design speed considered has a major impact on the capital and maintenance cost of a road. The design speed, together with other considerations will determine geometric features, including sight distance, horizontal and vertical alignments, width of lanes and shoulders, etc.

The design speed considered is based on several overseas studies relating to low volume roads as well as traffic volume and practical local experiences.

The design speed proposed varies with the topography, (the main factor) adjacent land use, function of the road and type. Ideally, every effort should be made to use as high a design speed as practicable to attain the desired degree of safety, comfort and convenience while under the constraints of economics, environmental and aesthetics requirements. However, for rural roads in Vanuatu, the objective was to set an appropriate speed, which may be below the geometric design speed capability of the road, for environmental reasons, amenity of site users and safety. In such cases appropriate signs or road humps could be necessary to control speed to the desired level.

Certain features, such as curves radius, super-elevation, and sight distances are directly related to the design speed adopted. The design speed is adopted for design purposes as shown in Table 5 below.

Terrain	S4	S3	S2	S1
Rolling	40 km/h	30 km/h	20 km/h	10 km/h
Flat	60 km/h	50 km/h	40 km/h	30 km/h

Table 5 Design speed

Lower design speeds are appropriate for hilly and steep terrain because of horizontal and vertical constraints. Higher design speeds are appropriate in flat terrain where horizontal and vertical geometry requirements may be attained without an appreciable increase in construction costs.

Ideally the design speed should be continuous throughout the length of the route. If this cannot be maintained because of physical or economic reasons, consideration should be given to actions that will alert a driver to a change in travel speeds, possibly with the use of transition zones and/or appropriate warning signs.

5.3 Terrain Considerations

Due to economic constraints, it has been considered that in most cases where the road already exists, current slopes should remain. However, in the case of a new road or whenever it is possible to rectify the slope, it is highly recommended that the slope be kept at the following maximum slope:

- 12% for a maximum distance of 600 m
- 15% for a maximum distance of 200 m and
- 18% for a maximum segment of 50 m

This would reduce the devastating effect of rainfall and increase the level of service and standard of operation.

Considering the heavy level of rainfall all over Vanuatu, hilly and steep roadways sections are much more susceptible to erosion and very deep ravelling and this is observed on many roads. Therefore, terrain and slopes are also used to recommend segments, which can be sealed with concrete slabs, tracks, grouted stone or other approved sealant options.

Steep grades on unsealed roads, where the longitudinal gradient is steeper than the crossfall, are prone to severe erosion in the wheel paths, particularly when these coincide with the centre of the road. Considerable attention must be paid to maintaining adequate crossfall in these situations, as this will minimise the erosion. If severe damage persists, consideration should be given to paving the gradient either by surface dressing or with a concrete pavement.

5.4 Cross Section Elements

The main elements of a Road cross section, for both a sealed and unsealed road, are shown in Figure 5.

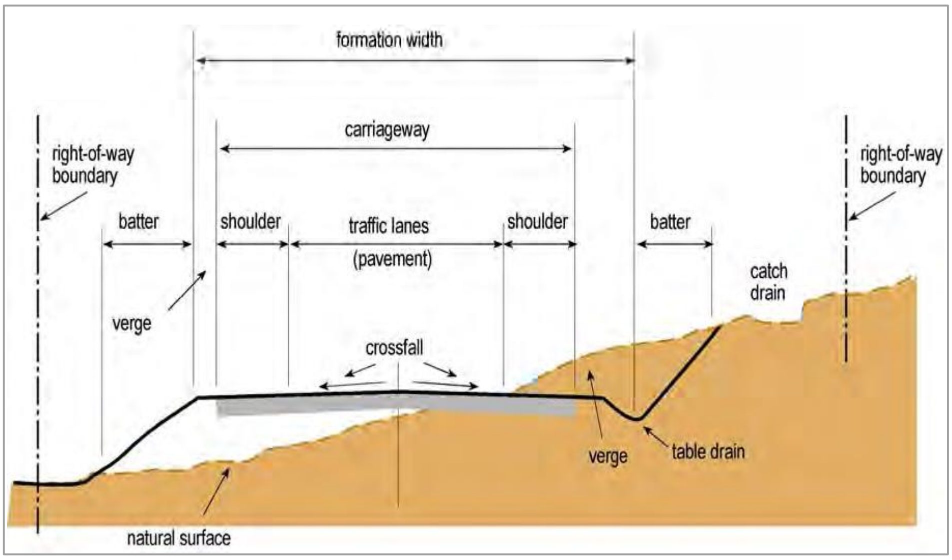


Figure 5 Road cross section elements (Source Austroads 1989)

For most access roads with low volumes of traffic (<200 Average Daily Traffic (ADT)) single lane operation is often adequate as there will only be a low probability of vehicles meeting. In such circumstances passing manoeuvres can be undertaken at reduced speeds using passing places or the road shoulder, or higher traffic levels a wider cross section should be adopted to allow 2 lanes.

Cross sections widths should be kept as low as possible within the terrain with the dimensions chosen to ensure that the material cut from the side drains and back slope is sufficient to construct a low embankment and fill the side slopes, and to minimise haulage.

5.4.1 Width

Carriageway widths, which include traffic lanes and shoulders, are based on the functions of road, traffic volume, traffic mix, design speed and surface type. The standard width selected does not provide for emergency and leisure stops because the frequency of traffic conflicts on low volume roads associated with stopped vehicles does not justify an additional width for sheltering. Locations where there is such a requirement will need to be considered on a case-by-case basis.

For roads carrying truck traffic over 20% of ADT, the overall roadway width could be increased by 0.5 m to allow for the safe passage of opposing vehicles. However, according to the traffic count performed in 2013, a maximum of 5% of trucks was recorded on only 2 segments out of 20 segments surveyed.

Due to economic considerations, if very low traffic volumes are recorded (T3, T4 or T5), 1-lane two-way road is proposed with a roadway width of 3 or 2.5 metres. This limits the road to a 1-lane facility with a passing bay that may be necessary for opposing vehicles to pass. Passing bays should desirably be inter-visible and a maximum distance between passing bays should be in the order of 300 metres and locations for these should be selected when natural terrain suit.

In the case of a sealed single lane, two-way road it is desirable that the road shoulders are constructed from material suitable for carrying vehicles both in dry and wet weather and be large enough to allow passage of two vehicles. A traffic lane width of less than 3.5 metres can results in excessive shoulder wear. A carriageway width greater than 4.5 metres but less than 6.0 m may lead to vehicles trying to pass with each remaining on the lane sealed. A width of 3.5 metres ensures that one or both vehicles must have the outer wheels on the shoulder when passing.

For unsealed roads the traffic lanes and shoulders are all considered as part of the travelled way or carriageway as there is no distinction to the driver. Carriageway widths should be selected for either a double or a single lane operation as in between widths will result in the 'three wheel' effect causing extra wear on the road crown.

Traffic lane and shoulder width for unsealed (including concrete or bituminous sealing of steep longitudinal sections) and sealed rural roads are designated as follows in Table 6.

	UNSEALED (including concrete or bituminous sealing of steep longitudinal sections)				
Traffic Class	**T1**	**T2**	**T3**	**T4**	**T5**
Average Daily Traffic (ADT)	> 500	200 - 500	50 - 200	< 50	< 20
Number of lane	2	2	1	1	1
Min. traffic lane width (m)	2.5 m	2.0 m	3 m	3 m	2.5 m
Min shoulders width (m)[1]	0.5 m	0.5 m	0.5 m	0 m Passing Bays[2]	0 m Passing Bays[2]
Min carriageway width (lanes + shoulders)	**6 m**	**5 m**	**4 m**	**3 m**	**2.5 m**
Operating speed (km/h) (Flat - Rolling terrain)	> 50	35 - 50	20 - 35	0 - 20	0 - 20
Road Function **(Arterial, A; Feeder, F)**	**A**	**A**	**A**	**A or F**	**A or F**

	SEALED				
Traffic Class	**T1**	**T2**	**T3**	**T4**	**T5**
Average Daily Traffic (ADT)	> 500	200 - 500	50 - 200	< 50	< 20
Number of lane	2	2	1	1	1
Min. traffic lane width (m)	3 m	2.5 m	3 m	3.5 m	3 m
Min shoulders width (m)	1 m	1 m	0.5 m	0.5 m	0 m Passing Bays[2]
Min carriageway width (lanes + shoulders)	**8 m**	**7 m**	**4 m**	**4.5 m**	**3 m**
Operating speed (km/h) (Flat - Rolling terrain)	> 60	> 60	40 - 50	20 - 40	0 - 20
Road Function **(Arterial, A; Feeder, F)**	**A**	**A**	**A**	**A or F**	**A or F**

[1] Increase shoulder width of 0.5 m if there are more than 100 pedestrians per day (on arterial roads), especially if it is in the vicinity (500-1,000 m) of a school, hospital, town, church, airport, etc.

[2] If natural gravel is suitable and passing lane (3 m wide) is provided min every 300m or when condition facilitate, shoulder may not be necessary.

Table 6 Traffic land and shoulder width

5.4.2 Crossfall

Sufficient crossfall should be provided to allow the easy run-off of water from the surface and to prevent potholes developing. If too great a crossfall is applied, the surface material will be prone to scouring and erosion.

It is recommended for ease of construction and maintenance operations, shoulders should have the same surface crossfall as the traffic lanes for unsealed roads so that they may be constructed and maintained to the same crossfall.

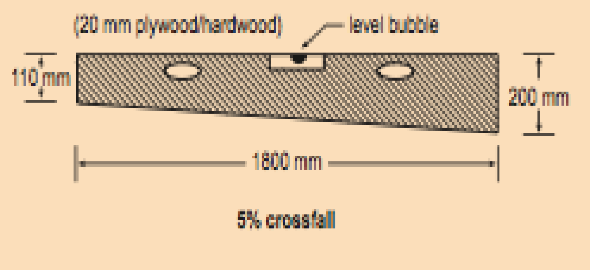
Unfortunately, it is common to find that most unsealed roads are not provided or maintained with the desired crossfalls and shaped to a crown. While flat crossfalls may be desirable for the travelling public, it is most undesirable for road maintenance purposes because it will not permit the shedding of surface water off the road, which will lead to the rapid development of potholes and deterioration of the pavement. Steep grades on unsealed roads, where the longitudinal gradient is steeper than the crossfall, are prone to severe erosion in the wheel paths, particularly when these coincide in the centre of the road. Considerable attention must be paid to maintaining adequate crossfall in these situations as this will minimise the erosion.

Crossfall measurements can be expressed in various forms:

- By ratio such as 10:1 (10 horizontal H and 1 vertical V distance m/m).
- By percentage such as 10% (vertical divided by horizontal distance and multiplied by 100%).
- By degrees.

Crossfalls in the field can be measured in various ways. Some graders have levelling devices that provide the crossfall of the road. Care should be taken that the rear wheels on which the level is based on the actual roadway being measured and the tyres are all correctly inflated. A better method is to use a 'smart level', which provides a digital readout, in either percentage values or degrees of the actual crossfall of the road being measured. An alternative is to use a camber-board which is cut to the required crossfall and has a spirit level on top to show when the desired crossfall is achieved. Checks should be made at regular intervals along the road and if the camber is too steep or too flat, then the road must be graded again.

See below in Figure 7.



Use of a specially made up camber board for a given crossfall.

Figure 6 Camber board

The crossfall which should be used is dependent on the local conditions and material properties. Crossfalls in the range of 4–6% have been used with success. In practice it is recommended that the road crossfall be initially constructed at 6% as it will not be long before it flattens to around 4%. In terms of fall from the crown to the edge of the roadway the values for different crossfalls and road widths are given in Table 7 below.

Crossfall	Total Road width			
	4 m	5 m	6 m	8 m
4%	80 mm	100 mm	120 mm	160 mm
5%	100 mm	120 mm	150 mm	200 mm
6%	120 mm	150 mm	180 mm	240 mm

Table 7 Fall from the crown

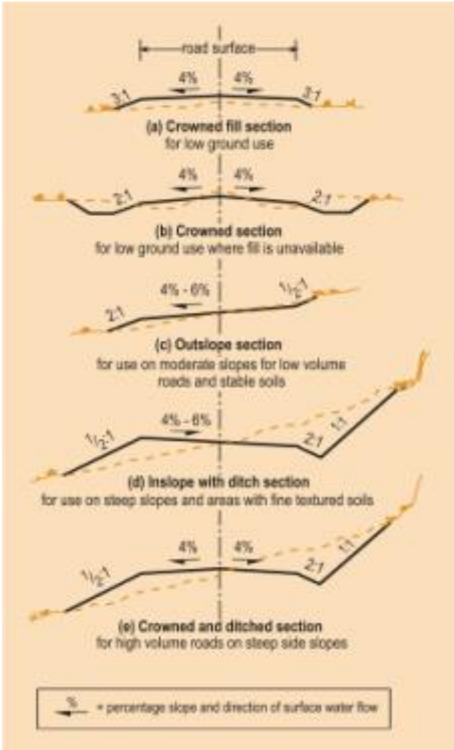


Figure 7 Alternative road shapes and crossfalls

Camber from 6% to 8% could be specified when drainage is or is suspected to be an issue. This will encourage water to be shed quickly from the running surface and will reduce the rate at which ruts form and areas of ponding water.

It is very important to ensure correct camber on steep alignments. 'Flat' cambers are frequently the cause of the longitudinal gullying commonly found on such alignments. Lack of adequate crossfall is suggested (Ferry 1986) as the most common defect of unsealed roads as this does not provide adequate drainage of the road surface.

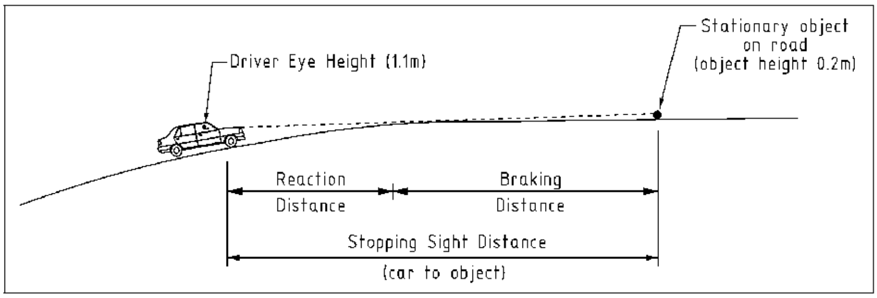
Two-way crossfalls should meet with a crown. This will help to prevent the development of potholes in the road centre. For single-lane carriageways, it may be best to have a single crossfall for ease of grading during regular maintenance.

Five road cross-sections typically used in road construction are shown in Figure 8 above. The choice of which cross-section should be used depends on drainage needed, soil stability, slope and the expected traffic volume on the road.

5.5 Sight Distance Requirements

A principle aim in road design is to ensure that a driver is able to see any possible hazards on the road in sufficient time to avoid an accident. To help calculate this requirement the term stopping sight distance has been used.

Details on the basis of the sight calculations are given in Austroads (1989) and Giummarra (2000). The values provided in the Table in Appendix B are based on two of the main safety requirements. The designer should also take into account other possible requirements relating to passing, and lateral sight distances particularly at tight horizontal curves.



Source: Based on Austroads (2003).

Figure 9 Car stopping sight distance

Definitions used are as follow:

- Minimum stopping sight distance (SSD) – This is the distance required for a vehicle to stop in time to avoid hitting a fixed object on the road. This is applicable for two-lane and one-lane two-way roads. Shown in Figure 9 above.
- Intermediate sight distance (ISD) – This is applicable for one-lane two-way roads where enough sight distance is required for two vehicles approaching each other to stop before colliding. It is taken as twice the stopping sight distance required for a vehicle approaching a fixed object. The values given in Appendix B are based on selected friction values appropriate for sealed and unsealed roads.

Sight stopping distance is mainly based on Design Speed and slightly on the slope, which will act on the level on deceleration. The following table, Table 8 outlines recommended stopping sight distances for flat terrain.

Metric				
Design speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Stopping sight distance	
			Calculated (m)	Design (m)
20	13.9	4.6	18.5	20
30	20.9	10.3	31.2	35
40	27.8	18.4	46.2	50
50	34.8	28.7	63.5	65
60	41.7	41.3	83.0	85
70	48.7	56.2	104.9	105
80	55.6	73.4	129.0	130
90	62.6	92.9	155.5	160
100	69.5	114.7	184.2	185
110	76.5	138.8	215.3	220
120	83.4	165.2	248.6	250
130	90.4	193.8	284.2	285

Note: Break prediction distance on a time of 2.5 s, deceleration rate of 3.4 m/s2 used to determine calculation sight distance.

Table 8 Stopping sight distance

These stopping sight distances are provided as a guide to address design on sharp curves, steep hill top, etc. in cases where there is a safety issue for a given road segment.

5.6 Vertical Curves

Crest and sag vertical curves for low volume roads should be based on the minimum stopping sight distance. The calculations are based on a driver height of 1.15 m and a fixed object height of 0.2 m. This is considered to provide an appropriate basis for low volume roads where there may be an absence of continuous maintenance and a likelihood of a vehicle having to stop for a fixed object such as logs, washouts etc. The values in Appendix B allow for vertical curves on two-lane two-way roads based on providing minimum stopping sight distance.

On single-lane, two-way roads the values for stopping sight distance do not provide an adequate level of safety for the situation of two approaching vehicles travelling in the same lane. In this situation the stopping sight distance is required with a sight line from driver eye height to eye height. For such cases the ‘K’ values need to be doubled. Where this increased stopping sight distance is not available or is uneconomical to provide, an alternative is to widen the road (by about 3 m) to form a two-way road over the length of the vertical curve to allow oncoming vehicles greater manoeuvring space to take evasive action.

For sag curves, on low volume roads, the design value proposed is based on comfort control criterion. See Figure 10 below.

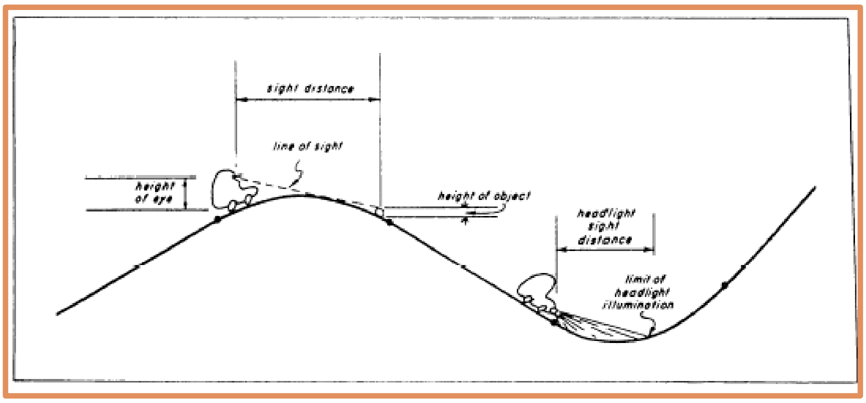


Figure 8 Crest and sag vertical curve

It is recommended to refer to the Austroads (2009) - Guide to Road Design Part 3 – Geometric Design, for further details if there is any localised issue potentially or effectively unsecured along the road alignment as the:

- Vertical curve overlaps one or both ends of the horizontal curve,
- Insufficient separation between the curves,
- Dissimilar length horizontal and vertical geometric elements,
- Long flat grades,
- Roller coaster grading or
- Any other issues affecting the safety.

Photo Tanna

6 Guideline to Pavement Design

6.1 Pavement Requirements

Unsealed road pavements are often constructed in development stages as they move from unformed to formed, and formed to gravelled pavements.

A formed and gravelled road pavement generally consists of distinct layers as shown in Figure 11 below. The preferred pavement make-up, (left hand diagram) consists of a base and a wearing course. In some cases where pavement thickness required is greater than 150 mm a sub-base may be used.

The common pavement type found consists of just a base course or a wearing course, which also serves as a base course (right hand diagram). In this case the base course must also perform the function of a wearing course. This is not the best option as the base course will need to have a higher plasticity index (PI) to bind the pavement material to withstand the abrasive action of vehicles. However, in Vanuatu, like in many other countries, it is common to have only one pavement material that acts as both a base course and wearing course.

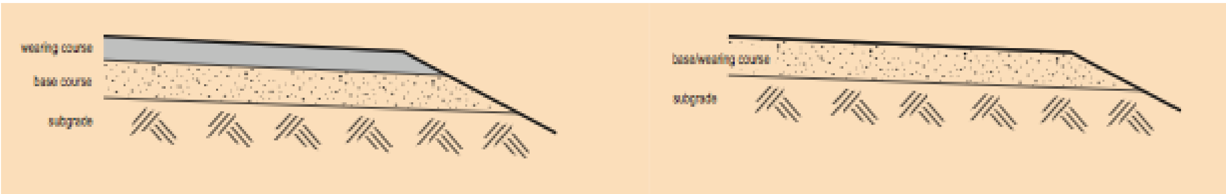


Figure 9 Pavement layer options

The "best practice" requirement for the different preferred layers are described below.

Sub-grade – consists of in situ soil or rock, previously placed landfill or spoil or other existing natural local material over which a road is to be placed.

The support provided by the subgrade is the most important factor in determining pavement design thickness. The subgrade support is dependent upon soil type, material density and moisture content both during construction and seasonal changes whilst in service.

Subgrade strength is commonly defined in terms of the California Bearing Ratio (CBR), which essentially represents the ratio, expressed as a percentage, of the penetration resistance of a soil to the penetration resistance of a standard crushed rock.

Sub-base – is the lower layer within the base course of a road. It usually consists of compacted granular material. Marginal materials and coarse rocks are the general components of this layer. Apart from providing structural strength, by distributing heavy wheel loads over a larger area, they also serve other purposes such as preventing intrusion of the subgrade soil into the base course and providing a working platform for construction traffic on the base course.

Base course – is the layer of crushed aggregate placed directly onto the subgrade or sub-base if used. Usually better quality aggregates are used with the required grading and moisture content. The base course provides the main source of the pavement strength. Material specifications for the base course are generally more stringent than for sub-base material.

Wearing course – is the uppermost layer of the pavement that comes into direct contact with vehicle tyres. An unsealed road surface should generally be constructed with fine gravel with closely controlled grading and plasticity to help bind the material together to avoid ravelling under load and to minimise dust emissions. The primary purpose is to provide a more tightly bound surface to reduce aggregate loss. This in turn provides a smooth running surface to minimise tyre wear, and high surface friction for vehicle braking and accelerations. It can also be referred to as a surface course as its purpose is to gradually wear away under traffic whilst protecting the base course from ravelling.

6.2 Pavement Development

As the surface of an unsealed pavement is maintained by routine grading and periodic reshaping and re-gravelling, the consequences of loss in shape are of less concern than a similar deformation of a sealed pavement. Because of these circumstances, staged development of unsealed pavements is widely practised.

Consequently, the first consideration in the design of an unsealed pavement is the determination of the stage to which it is to be constructed, e.g. cleared and made trafficable, formed, formed with minimum paving, partially paved, or fully paved. This decision depends on the following factors:

- Soil type
- Type and volume of traffic
- Climatic conditions
- Drainage
- Social and economic benefits derived from the improvement
- Cost
- Availability of material
- Future maintenance cost

Photo Pentecost

6.3 Design Stages

6.3.1 Unformed Roads

This is the first stage in the construction of a road where the road alignment is cleared and the surface made trafficable. The permanent alignment is cleared of all vegetation and topsoil with the running surface consisting only of in situ materials. This stage of construction will sustain only very light traffic. Usually, minimum drainage is provided. Building at this stage enables subsequent improvements to be made on the final road alignment. Cleared vegetation and topsoil should be stockpiled separately for later use.

6.3.2 Formed Roads

At this stage, the earthworks are constructed on the permanent alignment. Further drainage is provided.

Fair to good soils (e.g. sand-clay or sand-silt-clay) are likely to sustain higher volumes of traffic for the same maintenance cost as poor soils (e.g. clays or silts). For example, 80 vpd on fair to good soils may be equivalent to 20 vpd on poor soils.

Good drainage of the road surface, i.e. by having adequate crossfall, a hard surface and table drains, will enhance the performance of these roads. At the most, 50 mm of gravel is needed only on sections of poor soil.

6.3.3 Formed and paved (gravel) roads

An earth road may warrant paving (or sheeting) when maintenance costs increase to unacceptable levels, where existing soils are weak or when economic or social benefits are evident. Average traffic for gravel roads usually varies between 20 and 200 vpd. It would require a consequent drainage system.

6.3.4 Pavement Design

Tanna

The design of an unsealed road pavement requires the determination of the granular base thickness, which depends on the strength/CBR (California Bearing Ratio) of the underlying soil (generally measured when the soil is wet) and the number of heavy vehicle axle passes converted to the number of equivalent standard axles (ESA) within the design life.

Often granular pavement thickness is not designed and normally a minimal thickness of granular material is used. This thickness is based on experience and ranges from 100 to 300 mm in depth. This is because unsealed roads are more forgiving than sealed roads in that if significant rutting occurs on a sealed road, the seal has also to be replaced and becomes a more costly operation. While this may be common practice, it is more cost-effective to provide the required thickness initially, rather than having to undertake additional maintenance, or providing a greater pavement thickness than is needed.

In theory the pavement structure of a sealed or unsealed road is the same, as both are required to support the same traffic load over a given subgrade. A spray seal adds no strength to a pavement but provides greater abrasive resistance to traffic wheels and reduces penetration of moisture into the pavement compared to a gravel-wearing course. In practice, however, the material specifications for unsealed roads are typically of a lower standard than for a sealed road due to limited funding available and the extensive coverage in the road network.

Pavement design needs only to be undertaken for formed, gravel roads or particular road segments to establish the thickness of gravel that should provide for the design life. The other road types, unformed and formed roads, have usually no granular materials added.

Australian Pavement Research Group Report No. 21 (APRG 1998) provides pavement thickness design curves for constructing both sealed and unsealed rural roads of low structural integrity with granular materials. The empirical design chart is shown in Figure 12 and is based on a probability level of 80% (i.e. 20% risk of rehabilitation of the pavement being required before the end of the design life).

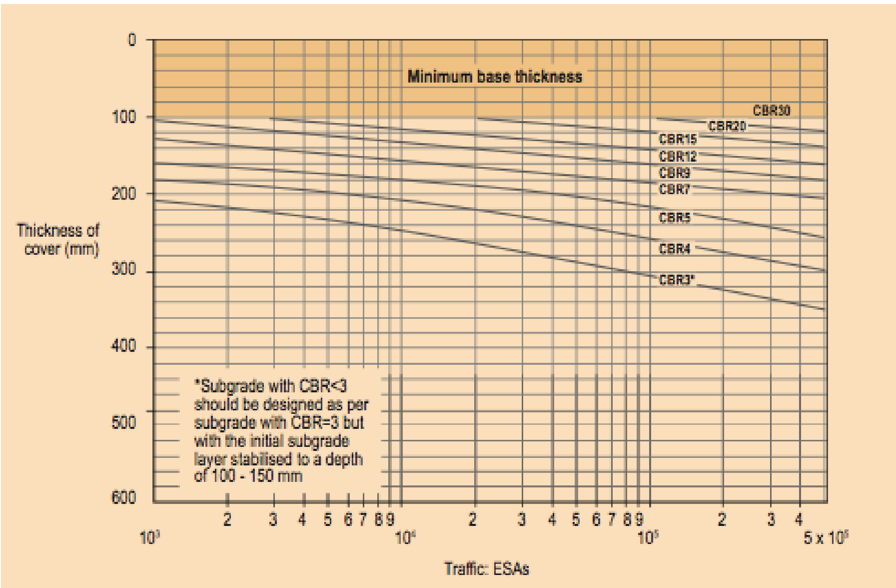


Figure 10 Design chart for granular pavements (80% confident) Source: APRG (1998)

Unsealed roads can be periodically reshaped, and re-gravelled. The 80% probability curves will provide a reasonable estimate of the full thickness of pavement for unsealed roads, taking into account traffic - equivalent standard axles, (ESA), subgrade soil strength (CBR) and moisture conditions. If a wearing course is applied, it should not be included as part of the structural thickness as it will wear away over time.

Specifically the curves apply to the design of flexible pavements if the design traffic is in the range 10^3 to 5×10^5 ESA. This accords reasonably well for sealed roads and their use is recommended for the pavement thickness design for most of the unsealed roads in Vanuatu.

The relevant pavement design procedures include:

1. Subgrade evaluation − determining the design CBR for the subgrade at equilibrium moisture content.
2. Design traffic estimation − determining the design traffic value, i.e. the number of equivalent standard 80 kN axles (ESA).
3. Thickness design − using the design traffic ESA and the design CBR value, determining the pavement thickness from the thickness design curves.

The top layer of the pavement should desirably consist of a wearing course material. The minimum depth of wearing course should be taken into consideration as well as the likely loss of material during the period of the re-gravelling cycle. This is usually in the order of 10 to 45 mm/ year / 100vpd for the first phase of the deterioration cycle lasting possibly two or three years.

6.3.5 Environment Factors

Roads that are subject to low traffic volumes have relatively more pavement distress attributable to the environmental effects than is the case for higher volume situations.

This leads to a requirement for a greater pavement thickness than the traffic volume alone would indicate. The main environmental factors affecting pavement performance are moisture and temperature.

Moisture environment

The moisture regime associated with a pavement has a major influence on its performance. The stiffness, strength and susceptibility to permanent deformation of unbound materials and subgrades are heavily dependent on the moisture content of the materials.

Factors influencing the moisture regime within a pavement include:

- Rainfall and evaporation pattern.
- Permeability of the wearing surface and adjacent areas.
- Surfaces and drains.
- Effectiveness and proximity of drainage (table drains, culverts).
- Depth to the water table.
- Roadside vegetation, in particular overhanging trees.
- Shading pavement.
- Movement of ground water.
- Relative permeability of the subgrade and pavement layers.
- Local geology – specifically the presence of open jointed or fractured rock materials that frequently have permeable layers that may allow in high seepage flow.
- Pavement construction type (boxed or full width).
- Topography.

Most pavements contain measures to control the ingress of water into the pavement structure. The provision of a high crossfall (4–6%), a wearing surface that is tightly bound, table drains, cross drains and, if necessary, sub-surface drainage (or moisture barriers) will help to reduce the influence of water on pavement performance. These effects may be more significant adjacent to the edge of the pavement, the critical area of the pavement in respect of moisture effects.

Temperature environment

The temperature environment and wind effects can have a major influence on pavement performance. At high temperatures the pavement surface can become dry and dusty and may crack. At low temperatures, usually associated with periods of precipitation, moisture can remain within the pavement layers and subgrade for considerable amounts of time, potentially softening the materials and weakening the structure.

6.3.6 Subgrade Evaluation

Subgrade support is in many respects beyond the control of either the designer or constructor, and is therefore the primary factor influencing the pavement thickness design. The designer should assign a CBR value to the subgrade. This is evaluated by field and/or laboratory testing and/or experience.

The purpose of subgrade evaluation is to estimate the support provided to the pavement during its lifetime. The support will be dependent upon the material type, its moisture content and degree of compaction. Although the material at the top of the subgrade may be uniform along the project, the moisture variations that will occur in this material, both along the road (due to topography, drainage, underlying soil profile etc.) and cyclically with time (annual wetting and drying cycles), should be considered in assessing the support provided. For pavement design procedures presented in this Guide, the subgrade strength is characterised by its design CBR.

The strength / CBR of the subgrade soil is affected by water. In pavement design, three different subgrade CBRs can be defined by moisture content:

- At equilibrium moisture content (EMC) which is described as the moisture content at any point in a soil after moisture movements and changes have stabilised in a constructed pavement.
- At in situ moisture content which is dependent on the time of the year the CBR is measured. This may be wetter than EMC if the road and drainage ditches are not yet constructed.
- At a four day soaked moisture content as commonly used in Australia and New Zealand for sealed pavements.

Photos Malekula

Subgrade evaluation is an important component of pavement design. It can be undertaken using either presumptive CBR values, based on overall experience or by field-testing.

The subgrade should have a CBR of more than 8%. In most part of the Islands, the subgrade will have a much higher bearing capacity than that. However, soft material containing a high proportion of clay and/or organics can be lower. If the pavement designer is uncertain about subgrade capability, it is strongly recommended to undertake a subgrade evaluation. The Dynamic Cone Penetrometer (DCP) is very easy and fast to use. The correlation is shown in Figure 13 below.

Suggested spacing of test sites should vary from a minimum of 20 metres for spot improvement to a minimum of 300 metres for longer rural projects. However, not less than three sites should be tested in any one project so as to enable confirmation of the CBR value. Where there is generally some variation along a project, at least three test sites should be selected in each subgrade, topography and drainage combination. It is recommended that the project be subdivided into sections, in areas deemed to be homogeneous. A design subgrade CBR should then be determined for each section taking the 10th percentile low value of all estimated equilibrium CBRs.

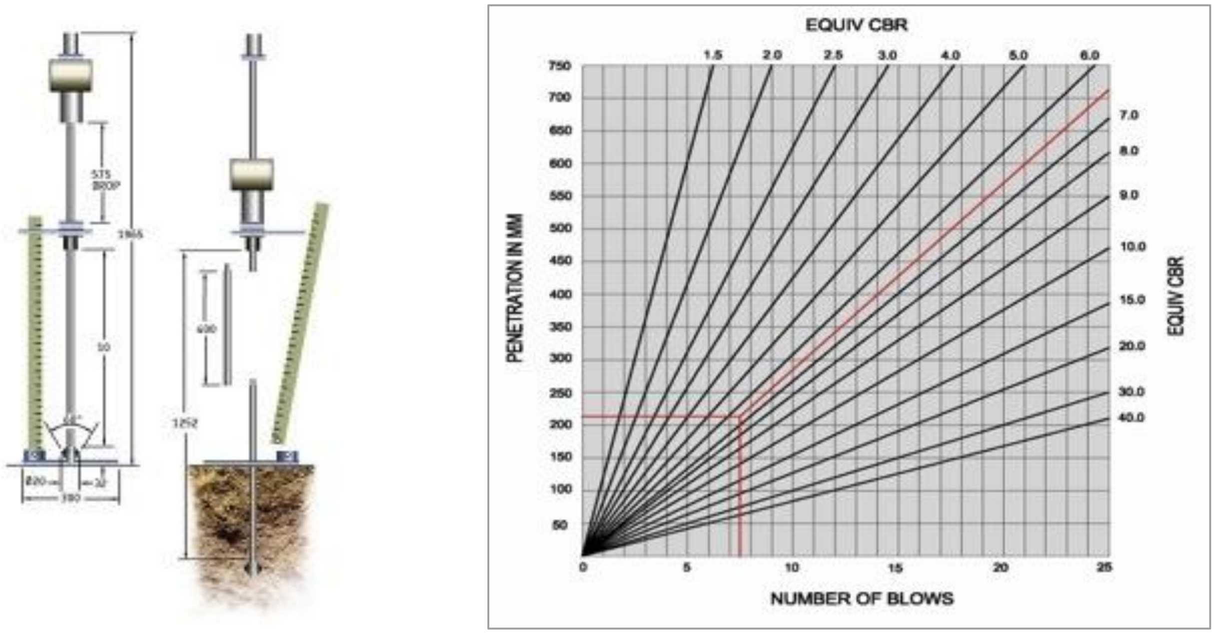


Figure 11 Correlation between DCP penetration and CBR

If results are marginal, subgrade may be sampled to verify various characteristics such as laboratory CBR testing (unsoaked or four day soaked), natural moisture content, particle size distribution and Atterberg Limits.

In addition, visual appearance, the feel of the material in the palm of the hand and local knowledge provide valuable additional information when assessing materials.

The soil composition (gravel, sand, silt, and clay) and the degree of moisture present can give a quick and simple indication of the soil strength. Dry materials will generally have a higher strength than wet. Coarser-grained and well-graded mixtures will generally be stronger than fine-grained or uniform sands or clays. In a dry environment clays can be very strong but will rapidly lose strength when wetted. A small amount of moisture in a sandy material will actually improve cohesive strength. Where available field data is insufficient to indicate a CBR value, typical presumptive CBR values can be used as given in Table 9 below.

Description of subgrade		Typical CBR values (%)	
Material	USC* classification	Well drained	Poorly drained
Highly plastic clay	CH	5	2–3
Silt	ML	4	2
Silty clay	CL	5–6	3–4
Sandy clay	SC	5–6	3–4
Sand	SW, SP	10–15	5–10

* USC – Unified Soil Classification system.
Source: Austroads (2004 b).

Table 9 Typical presumptive design CBR values

6.3.7 Design Traffic Estimation

Light vehicles such as cars contribute very little to structural deterioration and only commercial or heavy vehicles are considered in pavement design. A commercial vehicle (CV) is defined as one with more than two axles or dual rear tyres. For the traditional pavement design approach, traffic volumes in terms of the number of heavy vehicles and vehicle type, are needed to convert to the number of ESAs to estimate pavement thickness. As there is little (5%) or no heavy traffic in Vanuatu on most roads, the maximum number of ESAs should be below 10^5 ESA, and average around 10^3 ESA. For some particular stretches of roads they may be subject to more heavy traffic locally, for example near a port or a quarry. In these instances, these particular stretches should be addressed separately.

6.3.8 Pavement Thickness

Knowing the number of ESAs (derived from ADT and %HV and number of lanes) and the CBR of the subgrade, the chart in Figure 14 recommends the design thickness.

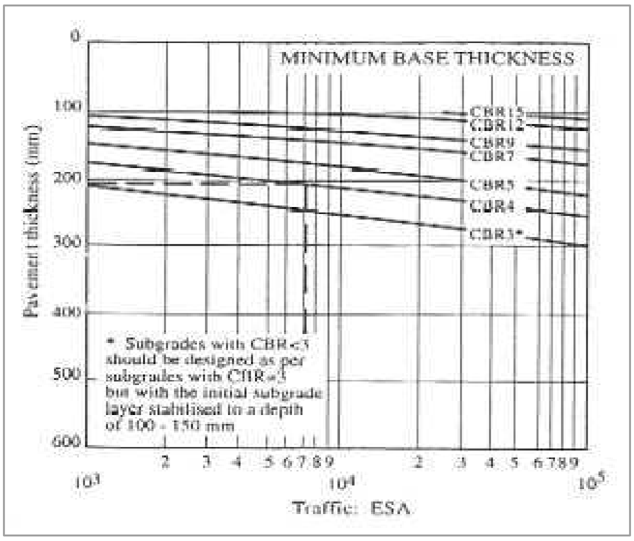


Figure 12 ARRB Gravel Thickness Design Chart

Pavement thickness in Vanuatu based on traffic volume should have a thickness of 100 mm to 300 mm, with 100 mm being the minimum. Most pavement thickness in Vanuatu is specified at 150 mm. If the subgrade CBR (when wet) is higher than 5 %, this thickness should be suitable for most traffic purposes. Even 100 mm should be fine if the subgrade CBR is higher than 15%. However, if the subgrade is weaker than 5%, thickness should be increased. It is therefore important to be able to evaluate the real subgrade CBR when weakness is suspected. Some examples are illustrated in Table 10 below.

ADT[1]	% HV[2]	Lanes	ESAs	CBR values			
				3	5	9	15
50	1	1	4×10^2	100	100	100	100
150	2	2	1×10^3	210	160	100	100
250	3	2	3×10^3	220	165	100	100
250	10	2	9×10^3	245	180	130	100
400	4	2	6×10^3	240	155	110	100
600	5	2	1×10^4	250	180	130	100
800	20	2	6×10^4	290	210	150	115

[1] Average Daily Traffic [2] Percentage Heavy Vehicles

Table 10 Estimated pavement thickness required (mm)

6.4 Selection of Pavement Material

Materials for unsealed road pavements are usually selected on the basis of availability, material properties, cost, environmental factors or social issues. Often the selection decision is a compromise between achieving the desirable properties and available funds.

Environmental factors may eliminate some sources of new materials due to inappropriate location (erodible beach) or the difficulty and delays in obtaining approvals from the environmental agency. Social issues may result in refusal from landowners or communities to access borrow pits.

6.4.1 Base / Wearing course material

The wearing course material should be durable and of consistent quality to ensure it wears away evenly. The desirable characteristics of the wearing course of an unsealed road are:

- Resistance to ravelling and scouring.
- Wet and dry stability.
- Low permeability.
- Cohesive properties.
- Load spreading ability.
- Skid resistance.
- Smooth riding characteristics.

For ease of construction and maintenance, a surface material should also be easy to grade and compact. The material properties having the greatest influence on these characteristics are the particle size distribution and the chemical/physical properties of the fine particles in terms of plasticity. Particle size distribution and its effects may conveniently be described in terms of standard particle size classifications (e.g. gravel, sand, silt and clay) or, alternatively, the fraction passing various sieve sizes. Visual evaluation in the field, using standard classifications, and/or laboratory tests, can be employed to assess a material's potential.

Gravels and sands that are low in fines will be porous, lack stability when dry and will unravel under traffic. However, fines in the form of a sand–clay may be incorporated into these materials to give added stability.

Corrugations in Ambae

Gravel loss in Tanna

The least desirable materials are those with silty fines, lacking gravel-sized particles, i.e. silts and silty-sands. These materials are likely to be porous and unstable and will unravel under traffic. They also tend to generate considerable dust.

Predominantly clay soils can provide a good dry-weather surface but will be slippery and/or will rut when wet. Sand–clay or sand–silt–clay mixtures can provide a satisfactory surface course for low traffic volume roads.

Either the Plasticity Index (PI) or the Linear Shrinkage (LS) can be used to evaluate whether the clay content of a material is appropriate. The PI or LS should desirably fall within minimum and maximum values, depending on climatic conditions, grading of the material and traffic conditions.

Particle strength and susceptibility to weathering will affect the ultimate grading and plasticity of paving material. In general, it can be said that the easier a rock is to rip, the more it is likely to break down in construction and service. A material, which breaks down readily or has a history of weathering, should be thoroughly evaluated before use. It may be useful to expose the material to the elements over a short section of roadway for a while to test its suitability.

The specifications proposed, have been developed to comply with the requirements of “ideal” wearing course materials, which also perform as a base course. On this basis the following should be considered in the context of Vanuatu. The specifications should:

- Be kept as simple as possible, with as few requirements or different test methods as possible.
- Give limits as wide as possible and not restricted to a narrow range of significant properties (e.g. a tight grading envelope), but comprehensive enough to accept suitable materials and reject unsuitable materials.
- Require properties that require inexpensive, quick, simple tests, which are repeatable and reproducible and need minimal sophisticated equipment and a relatively low level of operator training.
- Be practical to implement and apply to the total area for which they are intended.
- Adequately define important properties (indirectly if necessary) such as cohesion and strength and eliminate obvious problems such as oversize material.
- Be in terms of existing test methods or combinations of results from existing methods, although scope exists for the development of simple new methods.
- Be based on performance related studies.
- Be rigidly adhered to. The user should appreciate the consequences of use of non-complying materials e.g. increased construction, maintenance and road user costs, increased dust and poor safety standards.

The choice of the gravel surfacing material is most often a compromise between a material, which possesses sufficiently high plasticity to prevent gravel loss in the dry season, and sufficiently low plasticity to prevent serious rutting and deformation in the wet season. Choice of materials will also depend, when possible, on haul distances, as this will greatly affect construction costs and rate of progress.

Malekula

Tanna

Material specifications proposed are provided below in Table 11:

Sieve (mm)	Envelope (% passing)	Note on grading specification
53	100	This envelope is assuming that some of the largest particle (37.5-53mm) will break down during compaction. It is also assuming that the spread-water-compact operation is performed adequately. Some quarries may also have harder particles, which wouldn't break down. This could make the wearing surface to become fairly rough after a few months of heavy traffic and rain. In that case, it is advised to revise the grading specifications in order to reduce (or eliminate) the coarser content (37.5-53mm), at least for the wearing course. A smaller nominal size would ease spreading and compaction and a smoother ride.
37.5	90-100	
19	70-100	
2.36	35-65	
0.425	15-50	
0.075	10-30	

Table 11 Specification for grading

Considering the variation in the characteristics of the coronous and scoria between quarries and even within the same borrow pit, it is suggested to perform regularly a visual assessments of the fine content of the material during the extraction process and to sample the quarry to build the knowledge of the material. It is also important to sample different zones within the borrow pit.

Other characteristics that can be relevant to verify are PI, LS and CBR. Therefore, the specifications would ideally be those listed in Table 12.

Characteristics	Specification	
Grading Coefficient	16 – 34	(% passing 26.5 mm - % passing 2 mm) x % passing 4.75 mm / 100
Grading Modulus	1.5 – 2.5	(200 – (% passing 2 mm + % passing 0.425 mm + % passing 0.075 mm)) / 100
Fine to sand ratio	0.25 – 0.24	% passing 0.075 mm / % passing 2.36 mm
Plasticity Index (PI)	Max 15	If CBR in unknown or < 8 %
Plasticity product	300 - 400	PI x % passing 0.425 mm
Shrinkage Product (Sp)	100 - 365[1]	LS x % passing 0.425 mm
Soaked CBR	Min 30%	

[1] 240 Preferable

Table 12 Indicative specification for other properties

The limits stated for the characteristics in Table 12 come from experience in other countries and documented studies. These may or may not be suitable for Vanuatu. In order to develop specific requirements for local material, a better knowledge of the material properties are needed. The actual information required for this is almost non–existent and sometimes irrelevant. Therefore, sampling and testing must be done on the local material.

When properties of the local material are better known, revision of the above limits will be required.

7 Guidelines on Drainage Design

7.1 Overview

Drainage is probably the most dominant factor affecting the performance of a rural road. When such roads fail it is often because of inadequacies in drainage resulting in the ingress of water into the road structure, causing structural damage and needing costly repairs.

One of the most important aspects of the design of a road is the provision made for protecting the road from surface water or ground water intrusion. If water is allowed to enter the structure of the road, the pavement will be weakened and it will be much more susceptible to damage by traffic. Water can enter the road as a result of rain penetrating the surface or as a result of the infiltration of ground water. The road surface must be constructed with a camber so that it sheds rainwater quickly and the formation of the road must be raised above the level of the local water table to prevent it being soaked by ground water.

Drainage is one of the most important and critical factors in the ability of an unsealed road to withstand traffic loads. Its main components are illustrated in Figure 15

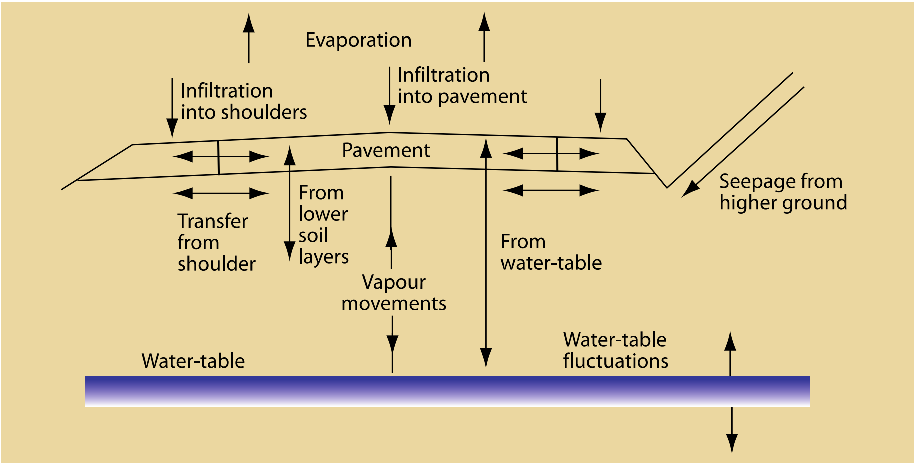


Figure 13 Moisture movements in pavements and subgrades (NAASRA, 1987)

Water can also have a harmful effect on shoulders, slopes, ditches and other features. High water velocities can cause erosion which, when severe, can lead to the road being cut. Alternatively, low velocities in drainage facilities can lead to silt being deposited which, in turn, can lead to a blockage. Blockages often result in further erosion. In addition, surface water can form a road safety hazard for vehicles.

A good road drainage system, which is properly maintained, is vital to the successful operation of a road. It has four main functions:

- To convey rainwater away from the surface of the carriageway to outfalls (streams and turn- outs).
- To control the level of the water table in the subgrade beneath the carriageway.
- To intercept surface water flowing towards the road.
- To convey water across the line of the road in a controlled fashion.

Side drains perform the first three functions and the fourth by culverts, drifts and bridges.

Common drainage problems include:

- Blocking of drains by debris and/or vegetation.
- Silting: the deposition of silt in the bottom of drains and culverts, often reducing the gradient.

- Erosion of the bottom of side drains in erodible soils or on steep gradients, particularly where insufficient turnouts/off-shoot/mitre drains result in large flows in drains.
- Erosion at culvert outfalls, resulting from high discharge velocities.
- Erosion of shoulders and side slopes.

Even if the drainage system of a new road has been carefully designed, it is likely that for several years after construction it will be necessary to observe its performance closely and to make additions and amendments to it. It is important to consider design as this forms part of the maintenance requirements.

Both in the design and maintenance of drainage, it is important to interfere as little as possible with the natural flow of water. Culverts on natural watercourses should follow the existing alignment as closely as practicable and re-alignment resulting in sharp changes in direction should be avoided. The surface flows in drains and culverts should also be kept to a minimum by the use of frequent turnouts where side drains cannot be discharged to existing watercourses. In side-long ground, where discharge from the side drain on the high side passes to the low side, it is best to use frequent small culverts rather than occasional large ones. But in this choice, maintenance needs to be addressed. In such cases, the spacing will be governed by the maximum flow acceptable in the side drains and the capacity of the culverts will not usually be a constraint as the minimum requirements for access for maintenance (often taken as 600mm diameter for a pipe drain or 600mm x 600mm for a box drain) will ensure adequate capacity.

7.2 Internal and External Aspects of Drainage

Many rural roads have been constructed with inadequate engineering and drainage design. Even with properly engineered roads, on-site inspection is necessary to correct any unforeseen conditions during construction.

Two inter-related aspects of drainage require careful consideration during construction, namely:

- Internal drainage of the pavement that seeks to avoid the entrapment of water by allowing it to permeate through and drain out of the pavement structure.
- External drainage which seeks to divert water away from, and prevent its ingress into, the pavement structure through measures such as the construction of sealed shoulders, side drains, etc.

Figure 14 Pavement and shoulder breaking up on Efate and Ambae roads

Internal drainage involves measures to minimise moisture contents in the embankment and pavement layers and importantly to prevent unwanted movement of water within the structure. Internal drainage is vital for the satisfactory performance of earthworks and pavement layers made of natural soils and gravel, especially those that utilise fine grained materials.

External drainage involves methods of crossing of watercourses, measures to divert water away from the road and prevention of damage caused by erosion as seen in Figure 16 above. In the construction of rural roads there is often wide scope for the use of various measures to improve external drainage, such as low-level structures, drifts etc. where 100% pass ability to traffic throughout the year may not be required.

7.3 Permeability of Pavement Layers

Wherever possible, each layer in pavement and earthworks should be more permeable than the overlying layer in order to prevent any water entering the structure from being trapped. It is often not possible to meet this requirement consistently and the provision of **crossfall** in all earthworks and layer works for water to escape from the pavement structure can alleviate the problem.

Under severe conditions, especially where there is risk of water seeping into the pavement structure, consideration should be given to installing subsurface drainage systems or, better still, to **increase the height** of the road in such areas.

7.4 Seepage and Subsurface Drains

Inadequate surface and subsurface drainage are typical deficiencies associated with cut-and-fill pavement sections. Figure 17 shows typical problems resulting from inadequate drainage.

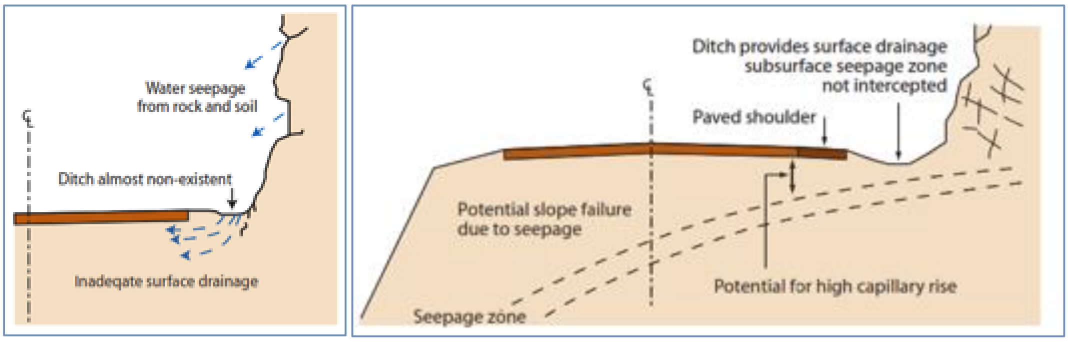


Figure 15 Typical problems resulting from inadequate drainage

Subsurface drainage may be constructed using pipe or rubble drains set into the subgrade or by using a subbase layer of material with free draining properties such as a coarse gravel or sand.

Subsurface drains can be made of geotextiles wrapped around aggregate, with or without pipes installed, but various specialised systems are also marketed. Such drains have commonly been made out of aggregate surrounded by filter sand instead of geotextiles, depending on the grading of the in-situ soils.

These drains are expensive and may not be justified for low-volume unsealed roads, except for localised areas where no other way of preventing ingress of water into the pavement is possible. As subsurface drainage systems usually incur relatively high installation costs and there is the risk of blocking of buried systems, alternative options are preferred.

7.5 External Drainage

It is not possible to provide a detailed description of all the various measures that make up a good drainage system. Conditions on site will vary tremendously in respect of in-situ soils, topography, vegetation, climate, human settlement patterns, environmental concerns, etc. Knowledge about local conditions are critical for successful installation of mitre drains, catch-water drains, side drains, berms, channels, cut-off drains and crossings along roads which are essential components of an effective drainage system.

7.6 Surface Drainage

The need for subsurface drainage can be reduced by use of adequate surface drainage, which prevents water penetrating into the pavement and subgrade.

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

7.7 Crossfall and Shoulders

It is very important to provide adequate crossfall to allow surface water to run off the pavement on unsealed roads.

However, in areas of negligible slope, which are prone to flooding, a raised formation may act as a dam for floodwaters and this should be avoided. In such cases the alignment should be chosen to be along the higher elevated sections of the ground surface. If the ground level is such that the road formation will act as a dam, then the road should be designed so that the surface of the road is level with the natural surface level. This means that the road will not be passable when wet. The decision as to when to re-open the road, after flooding, will depend on the likely initial deformation and other damage caused by traffic on the wet road.

Low formation roads, which closely follow the natural surface level (about 300 mm above), have many benefits and risks. The benefits are less earthworks and costs with the risks associated with a higher water table and increased moisture in the pavement.

Construction of shoulders needs to be undertaken carefully if typical drainage problems are to be avoided. Preferably, the granular base should extend to the embankment slope with sufficient height above the ditch to prevent water intrusion.

Shoulder materials should be selected which have a permeability similar to that of the base course, so that water does not get trapped within the pavement. However, the material properties for unsealed shoulders may well be different from those required for the base for reasons of durability. Unsealed shoulders are similar to a gravel wearing course and require material with some plasticity, which is a property that might be considered less desirable for road base material.

A common problem is water infiltration into the base and subbase, which occurs for a number of reasons as illustrated in Figure 18 below. The figures show effects with a sealed surface but similar problems can arise with an unsealed but well compacted wearing course:

- Rutting adjacent to the sealed surface.
- Build-up of deposits of grass and debris.
- Poor joint between base and shoulder (more common when a paved shoulder has been added after initial construction).

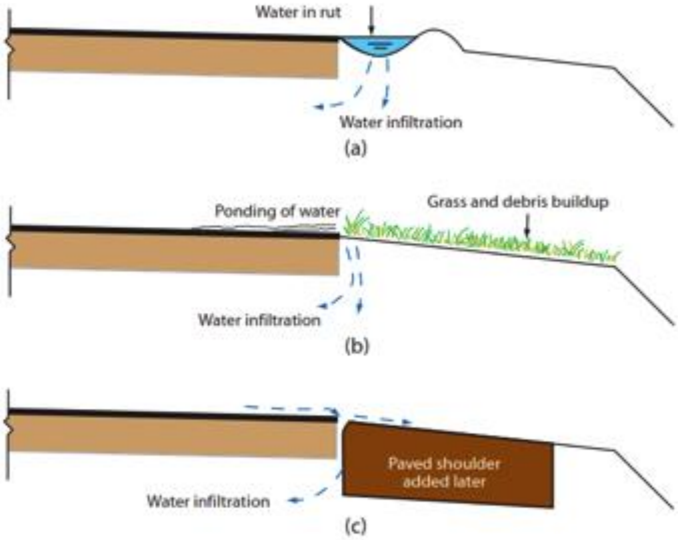
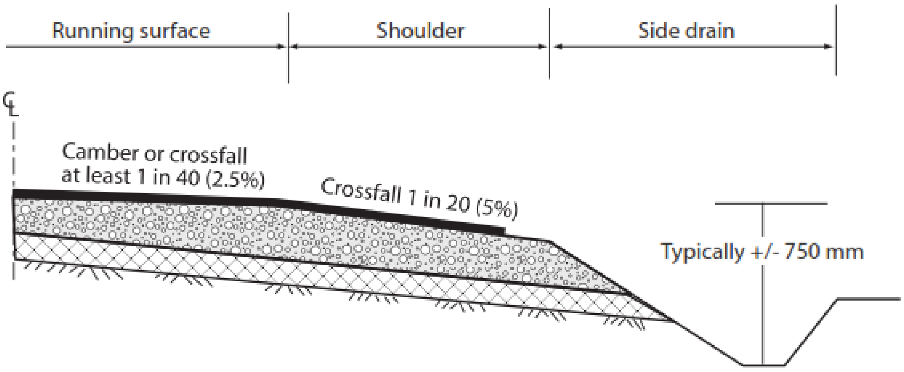


Figure 16 Drainage deficiencies in pavement shoulder construction

Ideally, as illustrated in the figure below in Figure 19, the base and subbase layers should be extended outwards to form the shoulders, which should preferably be sealed if the road is sealed.



Crossfall >= 2.5% if sealed

= 4 – 6% if unsealed

Figure 17 Ideal shoulder construction / drainage arrangements

7.8 Crown Height

Crown height is the vertical distance from the bottom of the side drain to the finished road level at the centre line and needs to be sufficiently great to allow proper internal drainage of the pavement layers. It maintains the height of the pavement above the adjacent water level in the drains.

Economical ways to achieve sufficient crown height include the use of material from the side drains and road reserve to lift the height of the road. Maintaining sufficient crown height through cuttings is of particular importance, owing to the unfavourable drainage conditions in such areas.

However, this may result in a considerable increase in the quantity of earthworks. Alternatives, such as subsurface filter drains, should be considered as a last resort because of cost and maintenance implications. The traffic safety aspects of large crown heights should be taken into account by moving the side drain further away from the shoulder break point.

In areas where in situ soils are considered to be self-draining, such as in sandy areas, priority should be given to providing good side support within a low embankment profile and shallow side slopes (typically 1:6 or 1:8) rather than a large crown height and relatively steep side slopes.

Minimum crown height 750mm recommended

Figure 18 Minimum crown height

Such deficiencies can affect the pavement by erosion, decreasing soil support or initiating creep or failure of the downhill fill or slope.

7.9 Road Elevation

In order to minimise subsurface drainage, elevation of the road on to an embankment should be considered whenever high water tables are encountered. Table drains should be constructed to be 600 mm below the bottom of the wearing surface.

7.10 Table Drains

Table drains, otherwise known as drainage ditches or side drains, run parallel to the road and are used to drain water from the road surface and adjoining slopes. These drains are usually placed in cut sections and at grade sections, but can be used along the toe of a fill section if required to collect water to discharge to a suitable location. Table drains can have flat bottoms and may be lined or unlined. For low-volume unsealed roads, most table drains are unlined, unless there is a potential scouring problem.

In cuttings, table drains on one side of a road may be eliminated by either in-sloping or out-sloping the road formation as shown in Figure 21 and Figure 22 respectively.

7.10.1 In-sloping

In-sloping can be used:

- To keep water away from unstable fill slopes.
- With or without a table drain or ditch (subject to grade).
- For short sections of roads.
- Cross drains can be installed as required to avoid build-up of fast running water in table drains.

It is important to ensure at curves that the cross fall conforms to superelevation requirements.

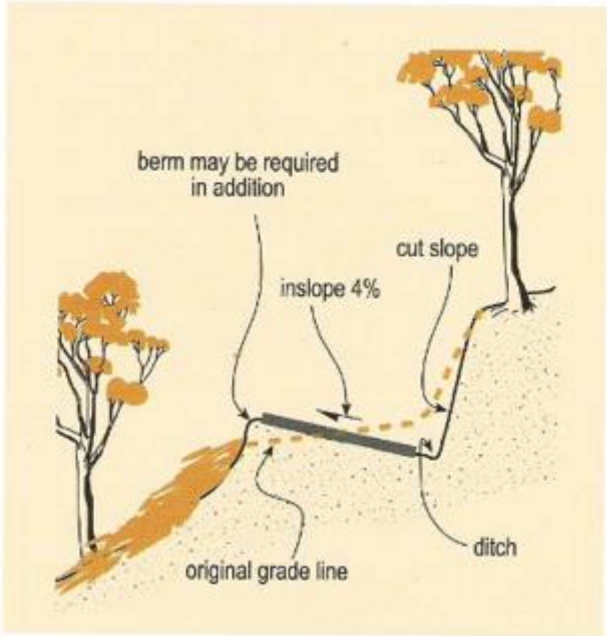


Figure 19 In-sloping

7.10.2 Out-sloping

Out-sloping:

- provides a means of dispersing water in a low energy flow from the road surface,
- is appropriate where fill slopes are stable,
- is good for contour roads having gentle gradients,

It is important to ensure at curves that the crossfall conforms to safety requirements.

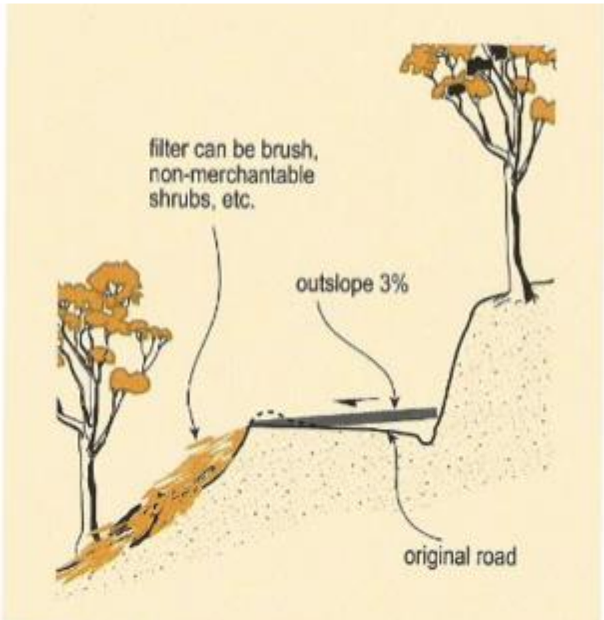


Figure 20 Out-sloping

It is preferable to transfer high water flows in the table drain to discharge to the lower side of the road more frequently by the use of cross drains (or culverts) rather than to carry excess water which can cause additional scouring and possible overflow onto the pavement. Lining table drains with materials to minimise erosion should be avoided as this is where most of the fines will be deposited which will need to be collected during routine maintenance operations.

7.10.3 V-shaped and Trapezoidal Drains

V-shaped drains as shown in Figure 23 will be sufficient for normal rainfall. For prolonged heavy rainfall larger volume side drains are usually trapezoidal in shape and have a lower flow velocity. Trapezoidal or wide V shaped drains are better as they provide a greater flow capacity, reduce the flow velocity and thereby minimise scour. They should be vegetated with grass where possible and maintained by mowing.

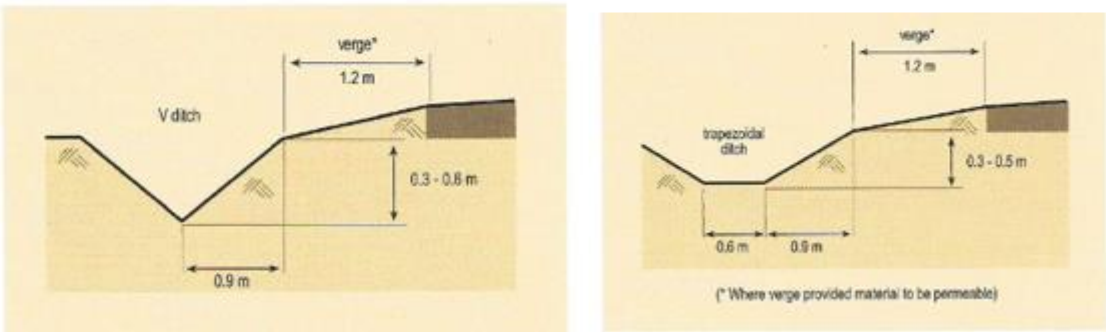


Figure 21 V-shaped and trapezoidal drains

In flat areas, consideration should be given to the problems of longitudinal flows between widely spaced culverts. The geometry of the drains should be compatible with the maintenance techniques to be used. It is important that, at any time, the lowest point in the pavement is well above the free water level in the table drains (aim for a distance of> 0.5 m).

To provide reasonable safety for vehicles that run off the road, the inverts of the ditch should be preferably rounded and it is recommended that the side slopes should not be steeper than 1:1.5.

Use of swales that have a wide base and gently sloping sides are preferable for safety reasons providing the extra width required is not excessive.

The longitudinal slope of the drain should be sufficient to avoid silting, but below the value at which scouring and erosion can occur. To avoid silting, a minimum longitudinal slope is recommended of 0.5% (1:200) for an unlined ditch, and 0.33% (1:300) for a ditch lined with concrete or equivalent. Also recommended is a maximum slope of 5% (1:20) for an unlined ditch. It is important to emphasize that drains should normally not be lined on an unsealed road section, as it makes it difficult to effectively maintain the section using the motor grader without damaging the drains.

Provisions to prevent erosion are recommended for ditches which will carry a fast flow and which due to topography cannot be restricted to less than 5% longitudinal slope. Check walls and drop walls can be used at intervals on steep slopes, as can stepping the ditches down. However, attention must then be paid to localised erosion damage (e.g. at the steps). Grassing of the drain may also be used to reduce erosion and catch silt. However, during maintenance operations there is a risk that the grass cover may be removed as table drains are cleaned out and re-established.

7.11 Cut-off (or Mitre) Drains

Cut-off (or mitre) drains, taking water away from the table drains into the surrounding area, should be constructed as often as the terrain will permit water to flow into a natural drainage course.

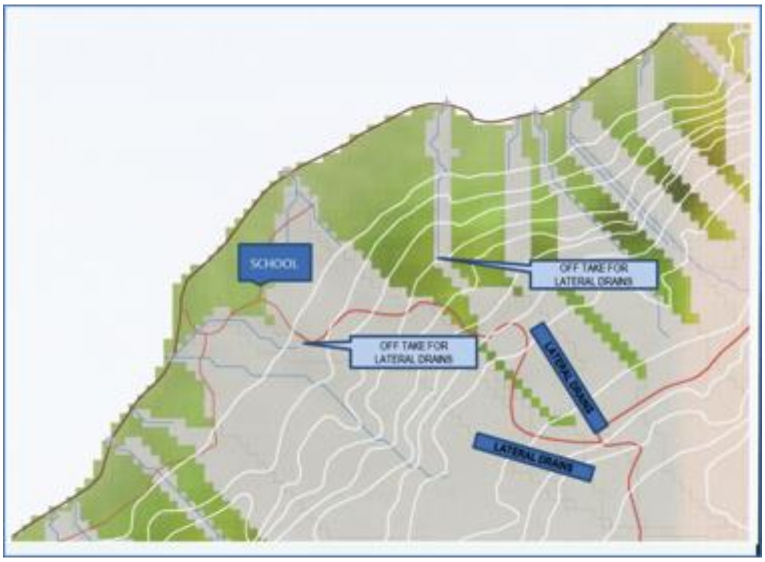


Figure 22 Lateral drains

The principle is to place the cut-off drains at intervals that avoid ponding, adjacent to the road but not too far apart to allow build-up of high concentrations and flow velocities, which lead to scouring. Frequent cut-off drains will minimise the amount of water flowing in a table drain, reduce the potential for scouring, erosion and the need for cross drains, and minimise the concentration of water discharge into the surrounding land.

Where cut-off drains are constructed it is essential that the water from the drain to be dispersed as far as practical to minimise erosion downstream. In some cases it may be necessary to provide obstructions downstream of the discharge point by the use of a dense cover of filtering ground vegetation. This may consist of windrow trees, logs (100 mm diameter), rocks or brush laid across the slope.

In locations with restricted road reserve widths, it will generally be necessary to negotiate with downstream property owners for access to construct and maintain side drains as well as give consideration to the legal point of discharge.

7.12 Cross Drains

The spacing of cross drain culverts to transfer water from the high side of the table drain to the low side is a function of the slope of the table drain, the soil erodibility and quantity of water flow.

As a general rule, water should be dispersed from the table drain as frequently as possible either in cut-off drains or across the road.

Figure 25 below, provides a design layout of a cross drain such as to ensure self-drainage with a slope across the road.

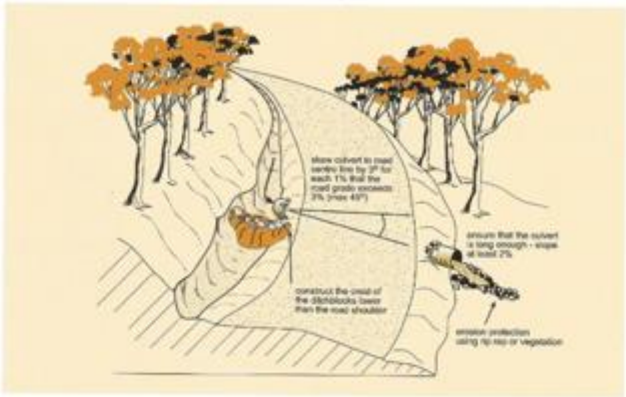


Figure 23 Cross drain layout

As a rule of thumb, the spacing of cross drains used to reduce erosion along table drains is: Spacing of cross drains (m) = 300 / % grade of longitudinal drain

This must be checked based on local knowledge. Alternatively, Table 13 gives various spacing criteria for rural roads.

Road grade	Soil erodibility class		
	Low to moderate – high (m)	High (m)	Very high (m)
1–5 %	150	120	70
6–10 %	120	90	40
11–15%	95	70	30
16–20%	50	35	30

Table 13 Spacing of cross drains

The minimum diameter of culvert pipes should be 600 mm to minimise frequent blockage. The optimum size will depend on local knowledge of climate and catchment conditions. It is preferable to go for a larger size where possible.

Aim to achieve a grade of pipe that will promote scouring velocities to maintain self-cleaning. Provision of a silt trap on the inlet side is desirable to minimise potential silting in a pipe. In some cases a small diameter pipe may be used (375 mm) due to costs. Culvert pipes should be flanged nestable pipes or alternative materials of sufficient strength with the required soil cover to handle the estimated traffic loads.

When a road is overtopped with water, an inspection for scour around the head wall will be required. When grading a road ensure that the culvert ends/headwalls are not buried and lost.

Bar screens should be fitted on the upstream side of cross drains to catch debris. These will require regular cleaning.

7.13 Catch Drains/Banks

Catch drains/banks are used to drain water flowing towards the road from the higher surrounding area. These drains are often used at the top of deep cuts. If these drains are not used, then severe erosion can occur at cut batters leading to batter instability, higher maintenance cost and table drains becoming blocked. Where it is not possible to provide a catch drain/bank then special provisions have to made to stabilise the cut batter slope (i.e. use of revetment or retaining walls).

The same care should be taken, as for other surface drain types, to prevent erosion and scour. Typical shapes and dimensions of catch drains are similar to those used for table drains. They should be as near as possible to the top of a cutting and channelled into culverts or natural watercourses wherever possible.

If the material surface is prone to scour and it is undesirable to cut the natural surface, catch drains can be formed by creating levees or catch banks. Catch drains at the top of slopes are frequently located beyond the reach of equipment for maintenance, and consideration should be given to gaining access for maintenance.

The longitudinal slope of the catch drain should be greater than 1 % to prevent pooling of water above catch batters and the potential of creating landslips. To prevent scouring, the slope should be less than 5%, depending on the likelihood of the soil to erode.

Vegetating the drain is an environmentally sound way to minimise erosion, even on difficult soils. Covering the surface of the drain with hessian or plant slashings, and applying grass seed can carry this out.

7.14 Culverts

Culverts can be pipe culverts or box culverts. Culverts are constructed on roads using a variety of methods and materials. Pipe culverts include corrugated plastic pipes, steel pipes or arches, pre-cast or fresh concrete pipes, boxes, arches or half arches.

Box culverts can be precast or cast in situ, and road crossings can be reinforced concrete slabs resting on a box culvert.

Pipe culverts must be designed so as to accommodate traffic loads and the depth of superimposed fill. There are also minimum cover requirements for pipes and box culverts.

Culverts should be provided with sufficient cover to protect them from traffic loads in accordance with manufacturer's guidelines e. g. minimum 600 mm for reinforced concrete pipe.

7.14.1 Location

Wherever possible, culverts should be located in the original streambed with the invert following the grade of the natural channel. Streambed realignment may be undertaken in exceptional cases.

Figure 24 Box culvert from concrete and pipe culvert from corrugated metal sheeting on Malakula

7.15 Grade

The ideal grade line for a culvert is one that produces neither silting, excessive velocities or scour. Normally, the grade of the culvert should coincide with the stream bed, however, in some circumstances it may be desirable to deviate from it to be in the range of 1-3%. Examples are:

- Where sediment is expected to occur, the culvert invert may be set several millimetres higher than the stream bed, but at the same slope.
- Where headroom is limited, setting the culvert below the stream bed grade is likely to result in sediment and reduced waterway area. This should be avoided either by using a low, wide culvert such as a box culvert or pipe arch, or by raising the road grade.
- In steeply sloping areas, as on hillsides, it is not always necessary to place the culvert on the same steep grade. The culvert can be put on a 'critical' slope and then a spillway provided at the outlet to prevent scouring. This keeps the culvert shorter and under shallow cover.
- At times a shorter length of culvert can be used and/or a better foundation obtained by shifting the culvert to one side of the natural channel. When this is done, care should be taken to construct the inlet and outlet channels to provide for a smooth flow of the water, particularly on the downstream side so as to minimise or prevent erosion.
- Any new watercourse crossings designated to be of significant environmental value should be designed and maintained to minimise disturbance to the passage of fish and other aquatic fauna.
- Energy dissipaters, such as large rocks, to provide sufficient protection against bed scour or erosion, should protect culvert outlets on watercourses.

7.15.1 Foundations

Ideally, culverts should be located on sound foundations such as rock. Soft, saturated and expansive clayey soils may cause settlements or seasonal movements of the culvert. Removal of poor soils or stabilisation of the foundation should be considered.

7.15.2 Siltation in Culverts

To minimise silting problems in culverts:

- the level of the invert of a culvert at its outlet should be a minimum of 75 mm below that at the inlet,
- pipes of less than 450 mm diameter and box culverts of less than 300 mm high should be avoided,
- the use of galvanised steel pipes should be avoided where water is acidic.

7.15.3 Inlets

Culvert inlets should be eased to a smooth entry without abrupt changes in direction or drops that can cause turbulence. Where these are unavoidable they should be adequately protected by concrete, gabion mattresses or rip rap. Geotextile material should be placed under gabions or riprap and a cut-off wall to prevent undermining.

To avoid silting, culvert inverts should be placed at a grade of not less than 1.25 % for pipes, and 0.5 % for box culverts. Invert gradients should be increased by 1 % in the case of culverts provided with drop inlets.

7.15.4 Outlets

The invert level at the outlet of a culvert should coincide with ground level. Where culverts are unavoidably constructed on a steep slope, the energy generated must be dissipated to avoid serious erosion at the discharge end of the culvert. A stilling box and widening at the outlet are effective methods of reducing the velocity of the water.

7.15.5 Energy Dissipation

Rock dissipaters or gabions can be used in channels as shown in Figure 27. These also assist natural channel restoration by trapping silt and preventing it from reaching downstream waterways. Other means to trap sediment can consist of logs, rocks, straw bales etc. These can also be used in places where high flows of water are expected on high erodible soils or other sensitive areas.

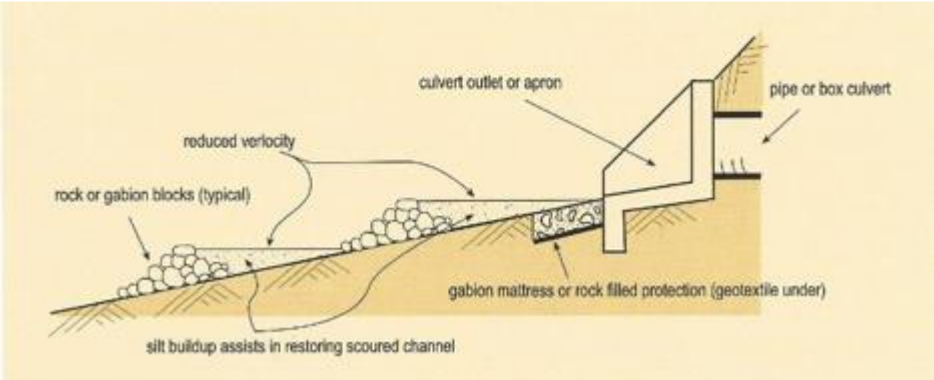


Figure 25 Culvert outlet and energy dissipation

For Culvert outlets, extension of the protection or energy dissipaters to prevent downstream scour should be considered.

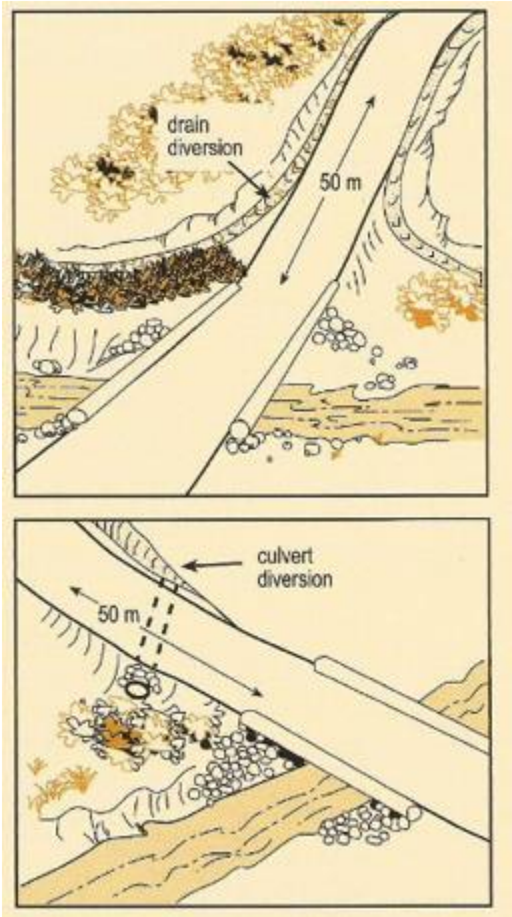


Figure 26 Avoiding discharge to streams

7.15.6 Avoiding Discharge to Streams

During the last 50 m before a road crosses a significant watercourse the roadside drainage should be diverted into the surrounding vegetation or sediment traps and not allowed to continue to the stream unchecked (see Figure 28). Where necessary, a culvert should be installed to pass drainage from the topside of the road to the lower side and then diverted into the surrounding vegetation. This is to ensure that sediment carried by the water is not discharged directly into a watercourse to the detriment of aquatic life.

7.15.7 Allowing Water Flow over Road

As most culverts provided on unsealed roads are not designed to take the higher storm flows, consideration should be given as to the various ways the higher discharge should be accommodated so as to minimise future road repairs and restoration work.

For larger catchments, a floodway with scour protection can be used to supplement a culvert designed to take low flows only. For smaller catchments, a 'drop-section' may be used, i.e. a section of the grade line of the road is lowered close to the natural surface to allow part or all of the discharge to pass over the road with the minimum of obstruction and without the need for any substantial scour protection.

For unsealed roads, because of lower traffic volumes, and where the costs of delays are usually lower than on sealed roads, a lower rainfall intensity is adopted based on lower storm frequencies (e.g. l, 2 or 5 years). Consequently, in the design of culverts for unsealed roads, it is acceptable that water be allowed from time to time to pass over the road or be temporarily ponded upstream, when the discharge from the catchment is of greater magnitude than the discharge of the culvert. In so doing, care must be exercised to minimise possible damage to the road embankment and it is strongly recommended that inspections be conducted after such events to assess the extent of damage and works required to restore the road.

7.15.8 Calculating Size of Culvert

The size of a culvert (*waterway area*) to be provided under a road is mainly a function of the catchment size, the rainfall intensity and the nature of the vegetative cover of the area. The estimation of storm discharge for the detailed design of a drainage structure should make use of the Rational Method (see Section 8.22).

Inadequate culvert capacity can result in severe damage and expensive remedial works. At all natural watercourses an appropriate culvert or water crossing must be provided to take the estimated design flow. The detailed calculation of the flow and waterway area required is given in Section 8.16.8/9. A simplified method of calculating the size of a culvert required is to use Talbot's Formula method below.

7.15.9 Simple Culvert Sizing Method

Although the accepted method of estimating peak discharge and designing culverts should be used whenever time permits, there may be occasions when such a degree of accuracy is unwarranted. In these situations, the Talbot's Formula method could be used (Australian Army 1985).

Talbot's Formula method provides a convenient way of determining the cross-sectional area of waterways required for small catchment areas. Talbot's Formula should be used with caution in tropical areas where seasonal rainfall is extreme.

Talbot's Formula is an empirical relationship between the area of waterway required, the catchment area, and the run-off coefficient relating to the type of country being drained. The results of the formula have been plotted in Figure 29.

This relationship was derived for a catchment area having an anticipated rainfall intensity of 100 mm in 1 hour. For areas having a different rainfall, the result should be divided by 100 and multiplied by the anticipated rainfall. Where accurate prediction of the maximum rainfall intensity in 1 hour is not known, then any of the following will give acceptable values:

- If the daily rainfall is known, assume 40% could fall in any 1 hour period.
- If the average annual rainfall is known use:
  - 8% of the value for areas having less than 2,500 mm of rain per year
  - 4% of the value for areas having greater than 2,500mm of rain per year.

Selection of an appropriate value of C (the catchment coefficient) is critical to the accuracy of this method. Figure 30 should be used to set an appropriate value.

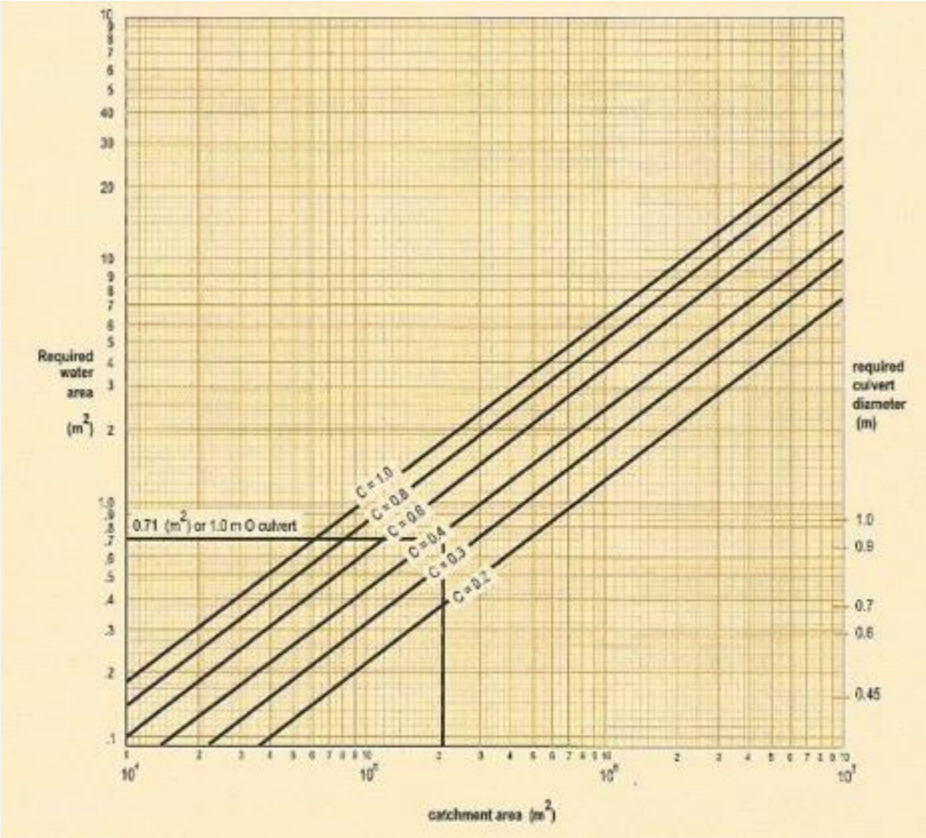


Figure 27 Talbot's formula

Above figure shows required waterway area using Talbot’s Formula based on rainfall of 100 mm in one hour.

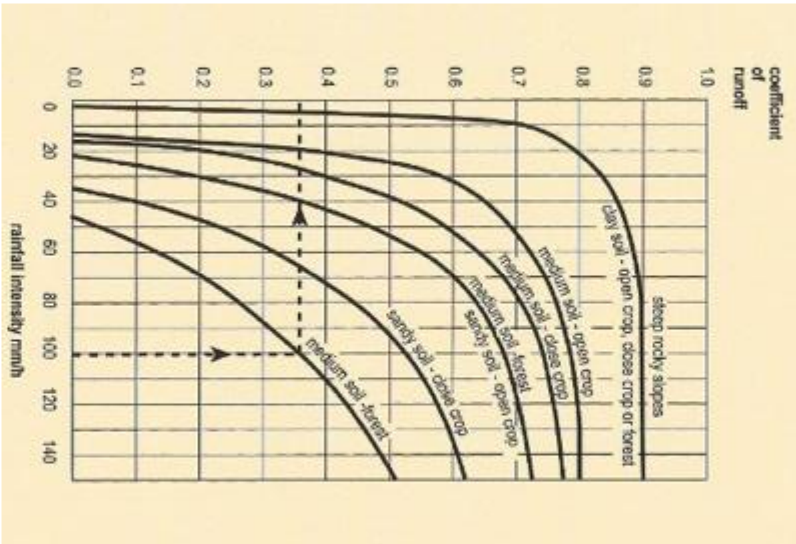


Figure 28 Run-off co-efficient for rural catchments

<u>Example</u>

The following are two examples of the use of Talbot's Formula:

1. Select a suitable culvert size for a catchment area measured at 210,000 m^2. The rainfall is 100 mm in 1 hour and the catchment area is predominantly medium soil in a forest area.

By referring to Figure 30 for a rainfall intensity of 100 mm the run-off coefficient is estimated at 0.36.

For a catchment area of 2.1×10^5 m^2 and referring to Figure 29 the area of waterway is estimated at 0.7 m^2. This is close to a pipe with a **diameter** of 1 m.

2. What area of waterway is required for the same catchment area if the anticipated rainfall is 160mm/h?

$$\text{Area of waterway required} = 0.7 \times \frac{160}{100} = 1.12 \text{ m}^2$$

7.16 Use of Labour-Based Methods

Labour-based methods are very well suited for the construction of drainage structures, excavation of drainage channels, construction of soil berms, stone pitching, scour protection, etc. Pre-cast concrete culverts are not well suited for rural roads if the weight of each element is too great for manual handling.

Figure 29 Stone masonry works

7.17 Maintenance

The importance of maintenance cannot be overemphasized. Inadequate maintenance, or total absence of maintenance, will lead to blockages, particularly of small diameter pipes. This will lead to structural failure of the drainage system and eventually the road.

Figure 30 Cross drainage poorly maintained (Tanna roads)

If necessary drainage systems should be adopted which do not rely on regular maintenance, such as proving crossing drifts at grade and allowing stream water to flow over them.

7.18 Bridges and Stream Crossings

Bridges and other forms of stream crossings are key elements in any road network and represent a major investment. Because of the cost and importance of road structures, main water crossings require careful selection of site, structure type and design. Design of large bridges is a specialist subject and is not included in this Guide.

Figure 31 Wooden bridge and concrete bridge, Malekula

7.18.1 Site Selection

Careful site selection provides the greatest potential for cost savings. Poor site selection can result in longer, wider or higher structures than are really needed or may result in costly foundations. Poor site location can cause operational difficulties, unsafe alignments and shorten structural life.

Determining the optimum stream crossing site requires balancing many variables, involving road design, structure type and bridge design.

An ideal stream crossing has some or all of the following characteristics:

- A road would cross the stream in an area with well-defined banks. The stream is generally narrower at these locations and the stable banks indicate a stable stream flow.
- The road would cross the stream away from curves in the stream. These areas are often unstable because the stream tends to move to the outside of a curve. Also a stream usually is wider in a curve.
- A road would cross the stream in an area with uniform stream gradient. An increasing gradient increases erosion and scour potential. A decreasing gradient can cause stream bed loading and debris deposition.
- It would cross the stream at a location where the channel has relatively non-erodible streambed materials. Non-erodible streambed materials reduce scour potential.
- The road should cross at right angles to the stream to reduce the span length of the bridge pipe or other structure used.
- The road should cross the stream at the minimum elevation necessary to pass the design flood flow. Raising the elevation of the bridge increases the abutment costs and in some cases lengthens the bridge.

Obviously ideal crossing locations are seldom found and balancing all of the above variables is a complex process. Solving the problem in the most cost-effective way requires working closely with road and bridge design engineers.

7.18.2 Selection of Structure Type

After site selection the next greatest cost savings potential occurs in structure type selection. There are a number of possible structures for different stream sizes. It is taken that fish passage is required at nominated stream crossings. Further details on the requirements of fish passage can be obtained from the Department of Environment.

7.18.3 Small Stream Crossings (<6m)

For a small stream crossing, culverts with about 0.5 – 1m of streambed material over the invert are possible alternatives to bridges.

7.18.4 Medium Stream Crossings (6-15m)

For larger sizes, with spans up to 15 m, the culvert requires special site considerations including adequate depth of embankment to allow space for the structure plus 1.5 m of fill over the pipe. Culverts can be constructed faster than most bridges and often at substantially less cost. Culverts can become blocked by debris particularly after a storm and require regular maintenance.

For bridges across medium stream crossings, concrete precast or prestressed multi-beam sections can provide an economical alternative to conventional treated timber or cast in-situ concrete superstructures.

Most bridges on low volume roads are of simple configuration, based on standard drawings, which are made to order for precast work. The precast bridge can be constructed much faster than the cast in-place type and erection can proceed during all weather.

7.18.5 Large Stream Crossings (>15m)

For bridge lengths of 25 m or under, consider using single spans. They present the minimum obstruction to the waterway and may also be the most economical. For longer structures over flood plains, consider using span lengths of 15-30 m, as they often will be more economical than shorter spans depending on bridge height and type of intermediate piers.

The relationships between the type of material, the span length of the superstructure and the cost must be considered. Simple timber bridges are the most economical for spans up to 10 m for heavy vehicles. Simple span reinforced concrete superstructures are feasible for spans up to 30 m. Spans can be as long as 45 m if prestressed girders are used.

7.18.6 Low-water Crossings

Low-water crossing structures are generally designed to allow flooding during periods of high annual run-off. However, the design flow is something that should be evaluated in the design process.

The standard of the road, its importance and use, the magnitude of the stream flow and its variability, the topographical characteristics of the crossing site are all factors that should be considered in determining the design flow of the low-water crossing structure.

A low-water crossing can substantially reduce costs. Typical design standards that can be adopted for low-cost crossings are as low as a one in two year flood with greater floods overtopping a low bridge structure.

Low-water crossings involve compromises and trade-offs between providing access and often conflicting objectives to:

- provide for traffic safety,
- permit water, sediment and debris passage on flooded plains,
- limit construction and maintenance costs.

Designing a crossing aims to optimise these objectives. Road access needs and water crossing characteristics largely control whether a structure, if designed for overtopping, will be appropriate. Selecting the best structure for a low-water crossing depends on a number of factors listed in Table 14 below.

Considerations	Most desirable	Least desirable
Access priority	Low	High
Alternative route available	Available (within a 2 hour trip)	Not available (or > 2 hour trip)
Traffic speed	Low	High
Average daily traffic	Low (< 100 vpd)	High (> 200 vpd)
Flow variability	High	Low
High flow duration	Short (< 24 hours)	Long (3 days)
High flow frequency	Seldom (rare closure < 10 times per year)	Often (frequent closure > 10 times per year)
Debris loading	High	Low
Channel entrenchment	Shallow	Deep

Table 14 Low-water crossing selection factors

7.18.7 Safety in Low-water Crossings

A low-water crossing is a possible alternative for any size of stream. Low-water crossings come in two basic forms, as illustrated in Figure 33.

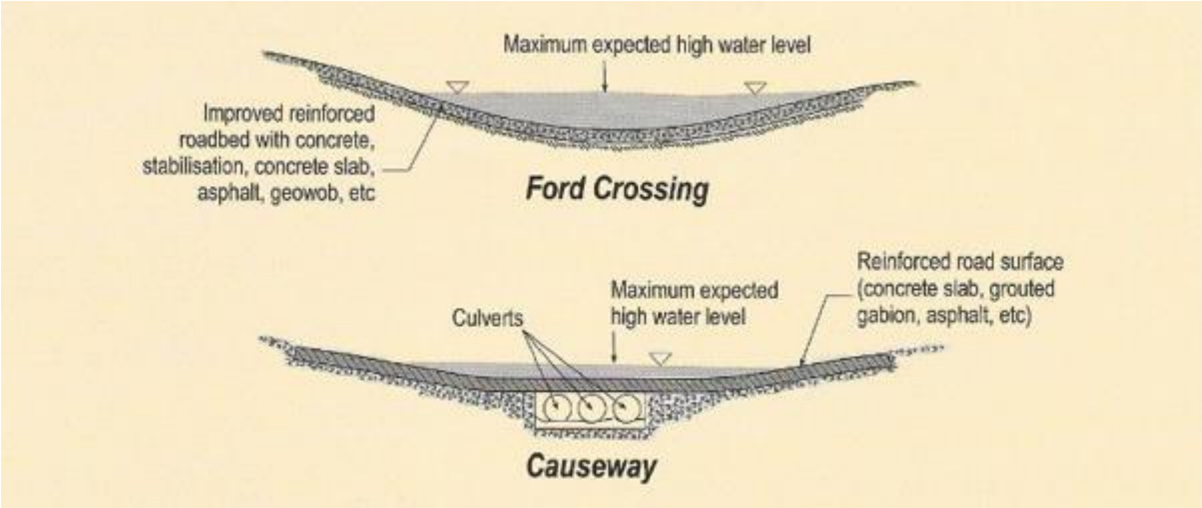


Figure 32 Types of Low Water Crossings

Low-water crossings can have substantial limitations and are most suited for roads with low traffic volumes. Safety is of primary concern and it is reported that 10 deaths per year occur in Vanuatu when people attempt to cross flooded crossings by foot. Drivers may underestimate how fast small streams can rise during a flood. Even 300 mm of water can float a car or truck causing it to lose control and 600mm can cause it to overturn (Figure 34).

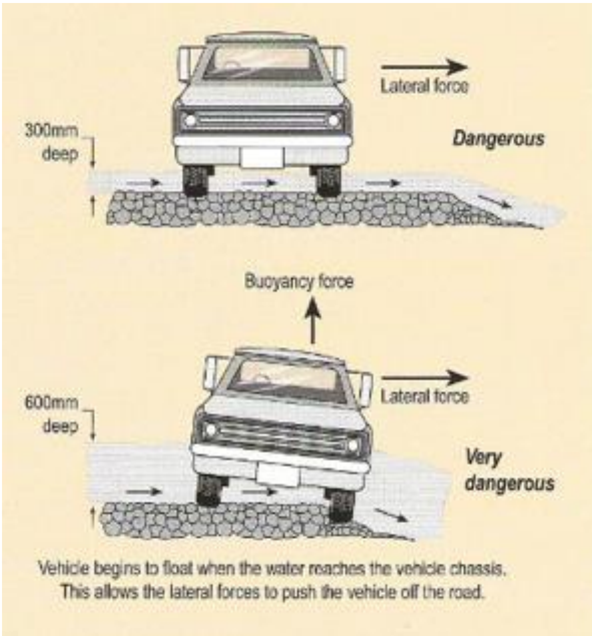


Figure 33 Effects of water flow on crossing vehicles

7.18.8 Floodways

The road crosses the stream at the location where the stream banks are low and the road grade follows the cross-section of the stream. It is often used when the stream flows infrequently and traffic disruption is minimal during the year.

In order to minimise bank erosion, floodways should be designed to cause minimal interference to the natural stream flow. This is best achieved by siting them at right angles to the direction of water flow and level to the existing stream bottom for buried floodways. This is the case for wide riverbeds or creeks, which are normally dry, but at times carry considerable volumes of water.

If they are elevated, floodways will create a weir effect and the downstream velocity of flow may increase to a level that will cause erosion of the stream bottom. Construction of a causeway at grade generally consists of excavating any soft material until firm material is reached and replacing the excavated material with sound granular material to provide a sound trafficable surface.

7.18.9 Gabions

Gabions can be used to provide a strong road base across a streambed. It is desirable to strengthen the road surface against scour using either a sealed surface or concrete base or providing a cement stabilised pavement.

Figure 34 Gabions used in water crossings (Malakula)

7.18.10 Causeways

These are a form of floodway except that the roadway is elevated above the stream bed. They have a more substantial road bed constructed and a number of culverts provided for the passage of low water flows. The frequency of flooding and disruption to traffic is less than a floodway.

Causeways are sections of roadway designed to be temporarily overtopped by water flow. They are used when it is more economical and practical to ford an intermittent flowing creek or river than to use major culverts or bridging, and when interruptions to traffic for short periods are not of great importance. Various types are illustrated below.

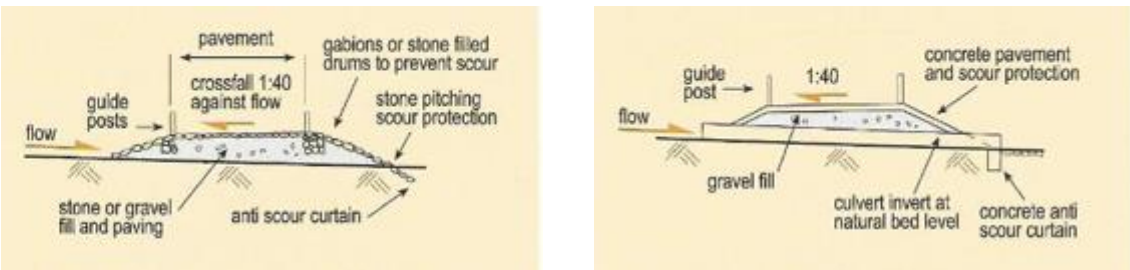


Figure 35 Causeways

When it is necessary to elevate a causeway in order to minimise the time it will be covered by water during flooding, it must be designed as a series of culverts using hydrological design procedures to calculate flows and culvert sizes. The ends of the structure must be well anchored into the banks and obstruction to flow should be kept to a minimum by using gentle batter slopes on the up and downstream faces.

The best material for elevated floodway construction is concrete. Well-graded riprap, dumped on the roadsides of a causeway, is superior to a mass of uniformly large stone, since the latter has large voids through which the filter material can be drawn by the action of water.

7.18.11 Drifts

In Vanuatu, a low-level structure designed to accept overtopping without damage is ideally suited for rural roads in locations where full all-weather pass ability is not necessary and delays are acceptable to the community.

Various alternative names are sometimes used to describe these structures. Drifts are designed to provide a firm driving surface in the riverbed, where traffic can pass when water levels are moderate. Road safety must be considered and guideposts should be provided.

It is essential to erect guideposts and flood gauges so that the edges of the causeway are defined and water depth can be determined.

Figure 36 Low Level Crossing with flow and drift guideposts

Vented drifts, sometimes named fords, causeways or Irish bridges (larger structures are called low level bridges), allow water to pass through openings, but can withstand overtopping without damage.

Vented drifts fall into two categories—low vent-area ratio (VAR) and high VAR—each of which affects stream channels differently (Figure 38). Vented drift with culverts that are small relative to the bank full channel area have a low VAR. A vent opening that approximates or exceeds the size of the bank full channel has a high VAR.

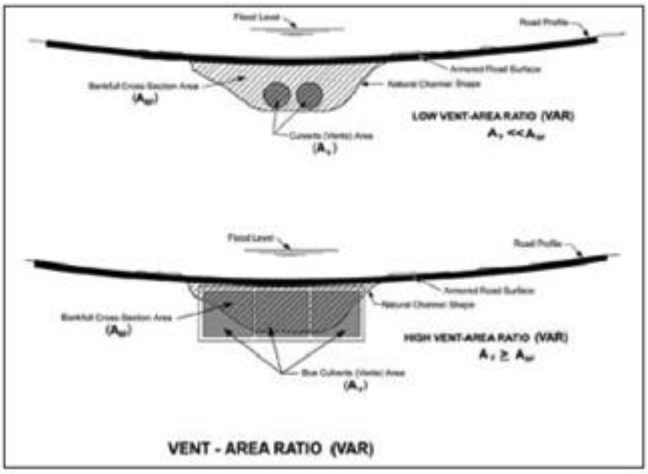


Figure 37 VAR definition sketch

In very stable streams, low-VAR drifts may not have severe detrimental effects on channel stability. It is common, however, to see at least a fair amount of channel instability associated with these structures. When flow begins to exceed the vents' capacity, low-VAR drifts begin to function like low dams. They backwater flow upstream of the structure, and where the stream is carrying a substantial bed sediment load, deposition reduces channel capacity and elevates the streambed. This frequently leads to bank erosion and channel widening. In channels that are already laterally unstable, low-VAR structures exacerbate the tendency for bank erosion and channel shift

Openings in vented drifts should, like culverts, be made large enough, preferably not less than 600mm diameter, although 900mm is preferable, so that cleaning during maintenance is made easier and the risk of blockage is minimised.

7.19 Erosion

7.19.1 Introduction

Any disruption to the natural flow of water carries a risk of erosion that may lead to environmental degradation, silting, damage to roads, damage to buildings and services, destruction of farming land and loss of fertile soil.

Thus, there is a responsibility to ensure that the construction of the drainage system for a road receives the same attention to good practice. Indeed, avoidance of erosion can be more critical in the case of rural roads because of the greater challenges faced in maintaining the drainage system in remote areas where these roads are often located.

7.19.2 Scour Checks

There are many examples in the region of inexpensive and effective methods that are used to protect drainage channels and side drains by the use of scour checks that are easily constructed by labour-based methods. The scour checks can be made of wooden sticks, rocks, concrete or other materials depending on the most economical source of materials. The frequency of scour checks needs to be properly adjusted according to slope gradient in order to prevent erosion between the checks causing damage to the system. The following can be used as a guide:

Gradient of the ditch	Scour check spacing (m)
4% or less	(not required)
5%	20 m
8%	10 m
10%	5 m

Scour checks can also be placed across pavements to prevent loose materials being carried away (see Figure 39 and 40).

Figure 38 Horizontal scour checks

Figure 39 Cross road scour checks

7.19.3 Slope Protection

If required, placing of topsoil and planting of vegetation on the slopes of embankments should take place in order to minimise erosion before indigenous vegetation can establish roots. Where grass or other vegetation is planted for protection of slopes, advice should be obtained from local residents and/or farmers.

Figure 40 Need for protection of slopes against erosion

7.19.4 Erosion of Culverts

Short culverts requiring high headwalls and wingwalls are prone to erosion around both inlets and outlets, especially along the wingwalls. Constructing culverts that are sufficiently long to reach the toe of the embankment will minimise necessary protection measures, future maintenance and the risk of damage to the embankment around the openings. It is necessary to carefully assess the additional cost of lengthening culverts against these benefits, especially in the case of rural roads that are often located in remote areas where regular maintenance is a challenge.

7.19.5 Coastal Roads

Roads in close proximity to the sea are generally associated with increased risk of degradation induced by adverse weather events, such as wave overtopping and erosion. During the design phase, special attention must be paid to identify and mitigate these potential hazards. General guidance on this process is provided below and within flowchart (see Figure 46).

Identification:

a) Danger of wave overtopping

- Road located within 50 m of coastline - slightly vulnerable.
- Road within 20 m of coastline - moderately vulnerable.
- Road within 10 m of coastline - highly vulnerable.

b) Danger of erosion: visual evidence of beach retreat / sea advance

- Loss of trees.
- Tree stumps in sea.
- Interview local residents. Ask about situation 10, 20 years ago.

Figure 41 Evidence of coastal erosion

Although coastal erosion is not necessarily attributable to climate change it makes coastlines more vulnerable to sea level rise and wave overtopping.

Figure 42 Wave run up and over topping

Mitigation:

- Realign inshore. Do not make minor re-alignments, for example 10 m. Make major move, 100 - 200m inland.
- Raise road height above level of inundation by at least 0.5 m.
- If road raised on embankment, incorporate pipe culverts for cross drainage to allow water drainage back to sea.

- Provide Beach protection. Place boulders, wire mesh gabions, or textile mesh gabions to form seawall on beach side of road. Provide concrete vertical seawall if funds allow.
- Select alignment to exploit natural protection such as mangroves.
- Check local residents are not removing mangroves for other purposes.
- Determine Highest Astronomical Tide (HAT) from hydrographic charts, tide tables for nearest port or highest high tide recorded.
- Check for tide gauge on wharf.
- For projections 50 years into future; assume SLR = 0.5m.
- Set freeboard (height above sea level) at 0.5 m.
- Take HAT + SLR + 0.5 as height of upper surface of platform.

Figure 43 Wharf with low free board at high tide

Figure 44 Tide gauge

Designing Climate Resilient Roads

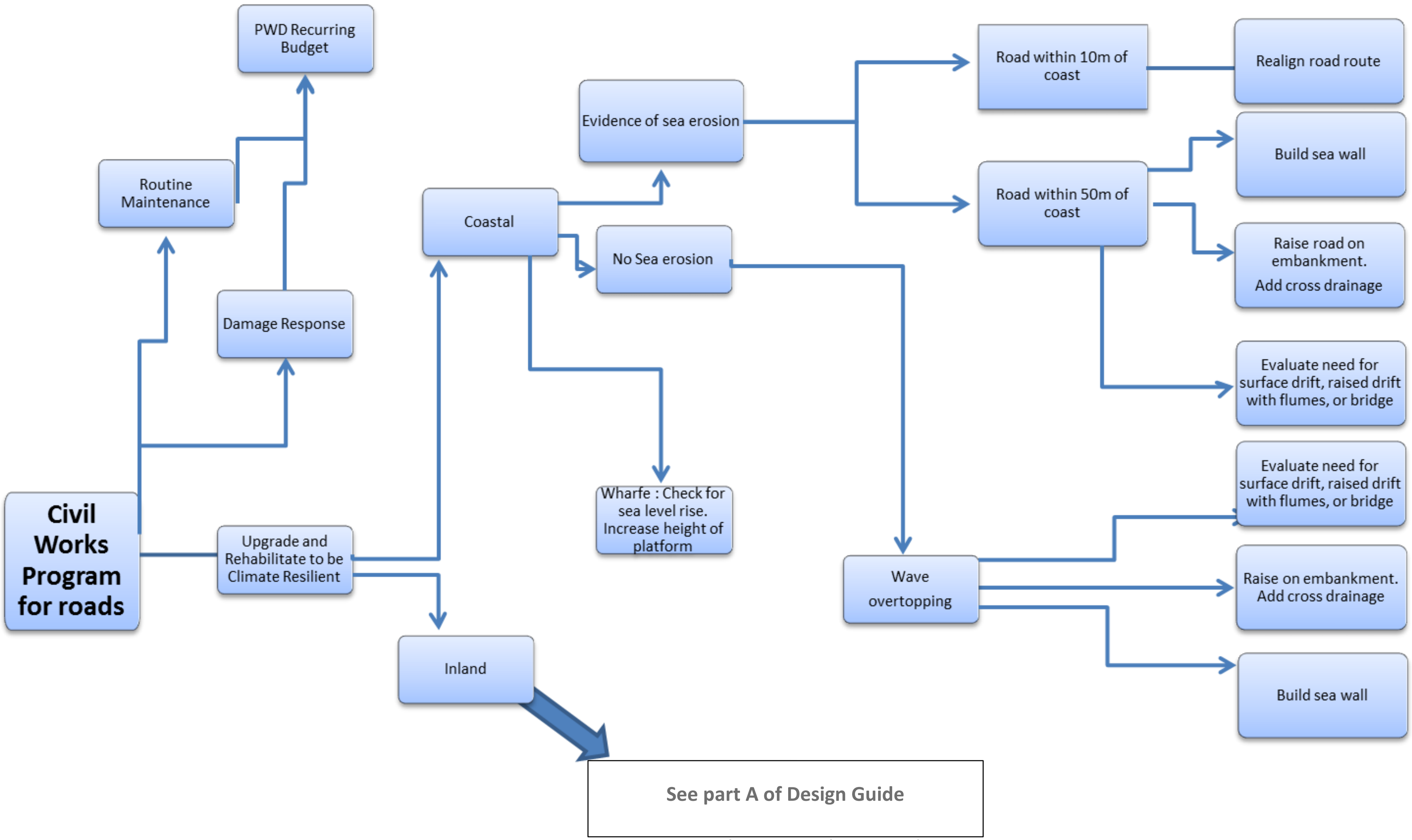


Figure 45 Designing climate resilient roads

7.20 Hydrology

The drainage methods used for unsealed roads are the same as those used for sealed roads. The capacity of drainage structures should ideally be calculated on the basis of local experience gathered over a long period of time and should be updated to cater for any recent changes in rainfall pattern and climate. However, such information is often not readily available, prompting a need to develop standards for drainage design and calculations. In all cases it is advisable to combine calculations with observations on site, in addition to information from reliable local sources. It is desirable to increase the size of drainage structures to a minimum of a 600 mm opening so that they can be easily maintained although a 900 mm opening is preferable.

7.20.1 Return Period

The return period for a given flow of water is related to the estimated statistical risk of overtopping of drainage structures. It is part of the hydraulic calculations required for each type of structure for each project on the basis of policy and anticipated consequences to the road or the public. The return period is therefore a critical parameter in the design of rural roads because it controls the level of risk in relation to cost of construction and the type of structure that is appropriate.

As a broad guide, the following return periods can be considered for rural roads:

Structure	Minimum ARI	Desired ARI
Major Bridges	50 years	100 years
Lesser Bridges	10 years	50 years
Culverts: 5 - 10 years	5 years	10 years
Low Level Drifts	2 years.	5 years.
Flumed Drifts	5 years	10 years
Lateral Drainage	5 years	10 years
Cut off Drains	2 years.	5 years.
Cross Drainage	2 years.	20 years.

Table 15 Return periods for structures

7.21 Hydraulic Calculations by the Rational Method

The 'rational method' is a standard approach to estimating floods for drainage of small catchments.

The basic formula is: $Q = 0.278\ C\ I\ A$

Where Q is peak flow rate in m^3/sec

C = runoff coefficient

I = rainfall intensity in mm/hr

A = Area in km^2

0.278 = Conversion factor for flow in m^3/s, rainfall in mm/hours and area in km^2.

To use the method, one must first derive basic data on the drainage area (or catchment).

- Catchment area (A in km^2),
- distance from the further point to the outlet (L in km),
- "Fall" between the highest point and the outlet (H in metres).

Calculate the slope (S in m/km) which is given as the fall, H, divided by distance, L.

The duration of the critical storm is then calculated by the Bransby Williams formula:

Duration = L / ($A^{0.1}$ x $S^{0.2}$) where duration is in hours.

If the duration is given in minutes the formula is Duration = 58.5 x L / ($A^{0.1}$ x $S^{0.2}$)

Given the duration, the intensity can be calculated from the IDF curve.

The final element to be estimated is the runoff coefficient, C. The runoff coefficient can be calculated by the method of partial runoff coefficients. [2]

The four elements are:

- 0.30: Hilly with average slopes of 10 % to 30 %,
- 0.20: Negligible surface depression. Drainage paths with steep banks and small storage capacity. No ponds or marshes.
- 0.10: Normal , deep loam
- 0.05: Good to excellent; about 50 % of area in good grassland; woodland or equivalent cover

The methodology is applicable in small rural catchments.

7.22 Summary of Key Points

- Appropriate drainage design is one of the most important factors that enable a road to withstand traffic loads and minimise maintenance.
- Balance design standards with the purpose of the road and maintenance levels in mind.
- Consider the economics of the design standards in relation to road classification, volume and type of traffic.
- Keep in mind the variable characteristics of unsealed road surfaces and be on the generous side of design standards where possible.
- Crossfall will be determined by the ability of the pavement to drain water and the materials used in the pavement.
- Crossfalls should generally not be less than 4% and preferably as high as 6%.
- Drainage channels, drains/ ditches and inverts should be rounded to provide reasonable safety for vehicles which may accidentally leave the road.

1. "California Department of Transportation, Highway Design Manual, 1995, pp. 810-816". And other older references.

8 Technical Summaries

A. Traffic Count – October 2013

B. Standard Proposed for Road Design

1. Geometry
2. Pavement
3. Drainage and Structures Design

8.1 Technical Summary A – Traffic Count – October 2013

SUMMARY OF TRAFFIC COUNT

TANNA

Type	Date	Road	Lenakel/ VTSSP1 End	Lenakel/Nose Blong Pig	Whitegrass/T anna Lodge	Imanaka/ Lowiaaru jnt	NoseBlong pig /Lowiaru jct	Lowiaru jct/Imafin	TOTAL
Pedestrian	2013-10-11	Friday (pay week)	126	143	272	48	109	229	927
	2013-11-06	Wednesday (non pay week)	133	34	207	47	34	153	608
	2013-11-07	Thursday (non pay week)	25	264	132	38	146	477	1082
		Average	**95**	**147**	**204**	**44**	**96**	**286**	**872**
Motor Vehicle	2013-10-11	Friday (pay week)	183	122	598 / 4	140	41	51 / 1	1135
	2013-11-06	Wednesday (non pay week)	110	12	369	64 / 1	4	41	600
	2013-11-07	Thursday (non pay week)	68	71 / 2	162 / 3	74	37	68	480
		Average	**120**	**68**	**376**	**92**	**27**	**53**	**738**

Heavy vehicle (ponctual data): **Max 2%**
0 HV for 13 days reading point /16 days

More pedestrian than vehicle (average 1.2 x)
Highest average 1 pedestrian for 0.2 vehicle (5 x)
Lowest average 1 pedestrian for 2 vehicles

Traffic count in 2006
Max average: 550 (Tafea Cap Jct)

MALEKULA

Type	Date	Road	Litzlitz / Lakatoro	Aoup Jnt / PRV Jnt	Aoup Jnt / Kona Point	Norsup Loop at Airport	Lizlitz / Vao	PRV Jnt / Notre D Jnt	PRV Jnt / Norsup Loop	Lakatoro / Aoup	TOTAL
Pedestrian	2013-10-16	Wednesday (non pay week)	226	1	9	48	82	49	62	47	524
	2013-10-18	Friday (non pay week)	180	2	14	20	99	42	47	142	546
	2013-10-21	Monday (pay week)	137	7	25	11	106	55	78	185	419
	2013-10-23	Wednesday pay week)	184	5	9	11	108	108	101	194	720
		Average	**182**	**4**	**14**	**23**	**99**	**64**	**72**	**142**	**552**
Motor Vehicle	2013-10-16	Wednesday (non pay week)	647	690 / 6	73 / 4	326 / 4	32	189 / 4	140	630 / 14	2727
	2013-10-18	Friday (non pay week)	456 / 20	355	88	544	46	174	193	681	2578
	2013-10-21	Monday (pay week)	406 / 26	129	94	393	54	158	172	743 / 3	2149
	2013-10-23	Wednesday pay week)	444	123	66	344	59	153	216	672	1189
		Average	**488**	**324**	**80**	**402**	**48**	**169**	**180**	**681**	**2 161**

Heavy vehicle (ponctual data): **Max 5%**
0 HV for 24 days reading point /32 days

Less pedestrians than vehicle (average 4 x)
Highest average 1 pedestrian for 0.5 vehicle (2x)
Lowest average 1 pedestrian for 65 vehicles

Traffic count in 2006
Max average: 728 (Lakatoro Loopt)
48% increase

AMBAE

Type	Date	Road	Nahala / Lolopuepue	Lolowai / Saratamata	Saratamata / Novonda (Tankaru)	Longana airport / Novonda	Malangamara quarry	TOTAL
Pedestrian	2013-10-08	Wednesday (pay week)	103	344	49	100	13	609
	2013-10-11	Friday (pay week)	183	1078	60	193	24	1538
		Average	**143**	**711**	**55**	**147**	**19**	**1 074**
Motor Vehicle	2013-10-08	Wednesday (pay week)	51	163	117	92	24	447
	2013-10-11	Friday (pay week)	88	186	117	104	46	541
		Average	**70**	**175**	**117**	**98**	**35**	**494**

Heavy vehicle (ponctual data): **0%**

More pedestrian than vehicle (average 1.2 x)
Highest average 1 pedestrian for 0.2 vehicle (5x)
Lowest average 1 pedestrian for 2 vehicles

PENTECOST

Type	Date	Road	Waterfall
Pedestrian	2013-10-29		137
		Average	**137**
Motor Vehicle	2013-10-29		19
		Average	**19**

324	ADDT > 300
147	More pedestrian than cars
73 / 4	73 motor vehucle (all kinds) / number of 3 axial

Table 16 Summary of traffic count

8.2 Technical Summary B – Standard Proposed for ROAD DESIGN

8.2.1 Geometry

a) Cross section

	UNSEALED				
Road Function	**Arterial**				
				Feeder	
Traffic Class	**T1**	**T2**	**T3**	**T4**	**T5**
Average Daily Traffic (ADT)	> 500	200 - 500	50 - 200	< 50	< 20
Number of lane	2	2	1	1	1
Min. traffic lane width (m)	2.5 m	2.0 m	3 m	3 m	2.5 m
Min shoulders width (m) [1]	0.5 m	0.5 m	0.5 m	0 m Passing Bays[2]	0 m Passing Bays[2]
Min carriageway width (lanes + shoulders)	**6 m**	**5 m**	**4 m**	**3 m**	**2.5 m**
Operating speed (km/h) (Flat - Rolling terrain)	> 50	35 - 50	20 - 35	0 - 20	0 - 20
Desirable maximum grade [3]	12 %				

	SEALED				
Road Function	**Arterial**				
				Feeder	
Traffic Class	**T1**	**T2**	**T3**	**T4**	**T5**
Average Daily Traffic (ADT)	> 500	200 - 500	50 - 200	< 50	< 20
Number of lane	2	2	1	1	1
Min. traffic lane width (m)	3 m	2.5 m	3 m	3.5 m	3 m
Min shoulders width (m) [1]	1 m	1 m	0.5 m	0.5 m	0 m Passing Bays[2]
Min carriageway width (lanes + shoulders)	**8 m**	**7 m**	**4 m**	**4.5 m**	**3 m**
Operating speed (km/h) (Flat - Rolling terrain)	> 60	> 60	40 - 50	20 - 40	0 - 20
Desirable maximum grade [3]	12 %				

[1] Increase shoulder width of 0.5 m if there are more than 100 pedestrians per day (on arterial roads), especially if it is in the vicinity (500-1,000 m) of a school, hospital, town, church, airport, etc.

[2] If natural gravel is suitable and passing lane (3 m wide) is provided min every 300m or when condition facilitate, shoulder may not be necessary.

[3] It is suggested to keep the minimum following slope: 12% for a maximum segment distance of 600 m; 15% for a maximum segment distance of 200 m and 18% for a maximum segment distance of 50 m.

b) Camber (crossfall) after compaction

- Minimum 5% for coronous wearing course (could be increased to 8% when issues are found or expected like steep slopes).
- 3% (flat camber) for free draining cohesion less volcanic scoria.
- Minimum 3 % for bituminous / concrete surfaced roads.

c) Horizontal / Vertical Alignment (desirable)

	T1	T2	T3	T4 & T5
Minimum radius curve	100 m	60 m	60 m	10 m
Maximum superelevation	8 %			
Minimum stopping sight distance (m) for 2 lanes roads	85 (60 km/h)	65 m (50 km/h)	50 m (40 km/h)	35 (30 k1/h)
Minimum meeting sight distance (m) for 1 lane roads	Not applicable	130 (50 km/h)	100 (40 km/h)	70 (30 km/h)

NOTE: Need to be validated with every provincial Civil Engineer

8.2.2 Pavement

a) Unsealed / sealed	T1	T2	T3	T4 & T5
Total pavement thickness (mm)[1.]	250	200	150	100[2]

[1] If CBR ≤ 5%, improvement of subgrade needed.

[2] For Feeder roads, pavement material may not be provided if not necessary

b) Rigid pavement		T1	T2	T3	T4 & T5
Min. subbase for rigid pavement		150 mm			Not applicable
Mountainous	> 15 %				
Hilly	10 – 15 %				
Rolling	5 – 10 %			Not needed	
Flat	< 5 %				

Rigid pavement is to ensure accessibility and increase security. It is suggested on arterial roads only.

Strongly recommended to build rigid pavement. Width of 4 m (150 mm thick) (25 MPa reinforced concrete)

Tyre Paths/Tracks could be suitable in given case: 2 x 0.75 m with or without grouted stone

c) Material properties

Grading

Sieve	Envelope
53	100
37.5	90-100
19	70-100
2.36	35-65
0.425	15-50
0.075	10-30

Note on grading specification
This envelope is assuming that some of the largest particles (37.5-53mm) will break down during compaction. It is also assuming that the spread-water-compact operation is performed adequately. Some quarries may also have harder particles, which wouldn't break down. This could make the wearing surface to become fairly rough after few months of heavy traffic and rain. In that case, it is advised to revise the grading specifications in order to reduce (or eliminate) the coarser content (37.5-53mm), at least for the wearing course. A smaller nominal size would ease spreading and compaction and smoother ride.

Other characteristics that can be relevant to verify are PI, LS and CBR but not yet to become requirements.

Characteristics	Specification	
Grading Coefficient	16 – 34	(%passing 26.5 mm - %passing 2 mm) x %passing 4.75 mm / 100
Grading Modulus	1.5 – 2.5	(200 – (%passing 2 mm + %passing 0.425 mm + %passing 0.075 mm)) / 100
Fine to sand ratio	0.25 – 0.24	5 passing 0.075 mm / % passing 2.36 mm
Plasticity Index (PI)	Max 15	If CBR in unknown or < 8 %
Plasticity product	300 - 400	PI x % passing 0.425 mm
Shrinkage Product (Sp)	100 - 365[1]	LS x % passing 0.425 mm
Soaked CBR	Min 30%	

[1] 240 Preferable

8.2.3 Drainage and Structures Design

Design return period	
Peak discharge for Culverts	1:5 years
Peak discharge for Low Level Structure	1:2 years
Peak discharge for High Level Structure	1:50 years
Pipes and culverts	
Minimum gradient	2 %
Minimum diameter	750 mm
Minimum cover (reinforced concrete)	2/3 of pipe diameter
Minimum cover (galvanized iron ARMCO)	1/2 of pipe diameter
Maximum desirable velocities in un-lined channels	
No vegetation, sandy material	0.5 m/s
Bunch grasses, exposed soil	1.2 m/s
Well established grass	1.8 m/s
Beyond 1.8 m/s, line drains and/or scour checks are recommended.	
Table drains [1]	
Trapezoidal drains	1 x 0.5 bottom x 0.5 x 0.4 m deep
V-drains	1 x 1 x 0.4 m deep
Spacing of scour checks	
Gradient of side drain < 4 %	30 m (only if eroded)
4 – 6 %	20 m
6 – 10 %	10 m
> 10 %	5 m
Spacing of mitre drains and relief culverts	
Gradient of side drain < 1 %	50 m (avoid sedimentation)
1 - 4 %	200 m (avoid erosion)
5 – 6 %	160 m (avoid erosion)
7 – 8 %	120 m (avoid erosion)
9 – 10 %	80 m (avoid erosion)
> 10 %	40 m (avoid erosion)
Maximum slope proposed on embankments and channels	
Soil with stone pitching or large earth channel	1:1
Firm Clay, Coronous or small earth channel	1:1.5
Sandy or silty soil, scoria, grassed channel	1:3
Concrete drift	
Minimum thickness [2]	200 mm
Minimum width (when full width)	4 m

[1] A minimum crown height of 0.75 m above the invert level of the side drain is recommended.

[2] Considering the base is well compacted and built properly

PART B - Design Guide for Best Use of Local Materials

9 Purpose

Vanuatu is particularly unique as its archipelago is formed by 80 relatively small islands and therefore, not linked with a “main” road to each other. They are rather isolated from each other. This context makes the use of imported material and/or equipment very expensive.

Fortunately, there are satisfactory materials for construction purposes in abundance on most islands. Sometimes, the materials may not be “ideal” or “perfect” but it is affordable and acceptable for low volume roads.

Careful consideration of the properties of the local material can ensure that it is used appropriately. As most islands are relatively small, it could be very costly to have heavy equipment available and to keep them in a working state on each island. Therefore, compromise and adaptive actions are necessary.

Further actions are proposed to improve local materials. Those proposed actions are mainly based on the overall knowledge of the material type in general. As the knowledge of the specific properties of the local materials is known, the actions to improve the possibilities and requirements may be refined or revised.

Coronous is a good material for base and a wearing course as long as some care is taken in grading and compacting adequately. It can also be a good concrete aggregate but would require heavy processing (crushing, washing and sieving). Test results will be used to assess the potential of the material. Further, an economical study will be needed to evaluate the options and suitability for small-scale processing operations.

Scoria has a good bearing capacity but it is an “average” material for a pavement wearing course as it lacks plastic fines. However, it can be suitable as a base course if the road is sealed (bitumen, chip or concrete). It is hoped that stabilizing scoria with plastic fines to improve its stability, its compaction and its water resistance (less wear, less dust, less corrugate) will improve its use. The behaviour of scoria in concrete in unknown but if the gravel size has enough strength (which could be the case as VTSSP1 used on the Otta Seal trial), there is potential that the layer characteristics will be suitable.

There is little improvement to suggest this for the other local materials. Care would be needed with sand and coral/gravel from beach/stream for concrete to use the correct size in sieving and ensure salt is removed by washing when used in reinforced concrete. Together, they have the ability to make very good concrete.




Actions

Actions proposed to improve the local material or its performances in the roadworks are listed below:

1. Sieve gravel or coral (coarse aggregate) for concrete.
2. Sieve sand (fine aggregate) for concrete.
3. Wash sand and/or gravel/coral if appropriate to remove salt.
4. Take note of each mix proportion and behaviour (for further adjustment).
5. Remove manually or build/buy a screen to remove particles bigger than 50 mm (can be built with old steel bars).
6. Prevent segregation in the quarry by ensuring adequate stockpiling procedures.
7. Take regular samples and have them analysed by PWD laboratory.
8. Ensure proper operation in the field when using pavement materials: spread / shape / moisture / compaction.
9. Look for clayey deposit on Ambae, sample and perform tests (grade, LL, PL, IP, LS).
10. Develop an easy method to evaluate the water content in the field material.
11. Assist in developing a quarry management system (or borrow pit inventory) including all test results for each pit). Department of Geology & Mines are currently working to develop a GIS module on the matter.
12. Analyse test results for coronous material as pavement and revise recommendation.
13. Analyse test results for coronous material as concrete and revise recommendation.
14. Analyse test results for scoria material as pavement and revise recommendation.
15. Analyse test performed in clayed deposit from Ambae and perform trial in stabilising scoria with plastic fines. This was done as a research on 2 sections in Ethiopia and it showed a great improvement in the behaviour of the scoria.
16. Analyse test results for scoria material as concrete and give recommendation.
17. If scoria gravel gives good test results, perform trial mixes using scoria aggregates.
18. Analyse options to find the most cost-effective, realistic and applicable technique to process the material (coronous and/or scoria), which would be accepted by the local community.
19. Develop Test/Check forms to record quality activities, process and results (Quality control/Quality assurance).

10 Material Available in Vanuatu

10.1 Geography

Vanuatu is a mountainous archipelago consisting of 80 relatively small islands but having 2,528 km of coastline. They are geologically new islands of volcanic origin. 65 islands are inhabited and 14 have surface areas of more than 100 square kilometres. There is about 1,300 kilometres north to south distance between the outermost islands.

Most of the islands are steep, with unstable soil and little permanent fresh water. The highest of all the mountains is Mount Tabwemasana on Espiritu Santo at 1,877 metres. Its tropical climate is moderated by southeast trade winds. However, Vanuatu has a long rainy season, with significant rainfall almost every month. The wettest and hottest months are December through April, which also constitute the cyclone season. The driest months are June through November. Rainfall averages about 2,360 millimetres per year but can be as high as 4,000 millimetres in the northern islands. Its natural resources include hardwood forests, coconut, coffee, kava and fish. As of 2011, 2% of its land area is arable, 10% is devoted to crops.

Map of Vanuatu

Natural hazards include tropical cyclones from November to April and volcanic activity, which sometimes cause minor earthquakes. Earthquakes and associated tsunamis are also a hazard. The shoreline is mostly rocky with fringing reefs and no continental shelf, dropping rapidly into the ocean depths.

10.2 Geology

The archipelago is on the edge of the Pacific tectonic plate (Pacific Rim of Fire), which is being forced up and over the Indo-Australian Plate. This enormous and relentless pressure causes constant seismic activity in the form of earthquakes and volcanic eruptions, which produce a great deal of basalt.

Materials Commonly Used in Roadworks

Coronous

Coral beach

Scoria

Beach sand

Basalt cobble

Therefore, the substrata and most of the exposed bedrock on the islands are made of extrusive volcanic rocks as basaltic and andesite lava, breccia, basalt olivine basalt. Associated with volcanic activity, there is also a series of unconsolidated material as bomb, cobbles, tuff, scoria, pumice and sand. Sand along the coast can be of volcanogenic origin and transported from the interior by the main streams. With the sea surrounding the archipelago, corals have formed around most of the islands and as the sea bed is uplifting, some of these corals can now be found in various locations on most islands. They are sometimes categorised as Older Raised Limestone, Younger Raised Limestone and Recent Raised

Limestone by the Department of Geology and Mines. Basically, the older the deposit, the harder and more consolidated the particles will be. However, this material is commonly called "coronous" gravel. Corals are also found on the beach as coarse gravel size (100 mm) down to fine sand.

10.2.1 Coronous

Typically, the coral-derived material most widely available for use is termed coronous material; a land-based uplifted coral reef that may contain an abundance of plastic fines and that is usually easily excavated without the use of explosives. The wide occurrence of coronous in the Pacific region as well as the shortage of "traditional" road aggregates have promoted the study of the use of coral-derived aggregate as an alternative aggregate in pavement engineering works. Although coral-derived materials have been successfully used for pavement construction in the past, traditional engineering tests have generally indicated that it is a substandard product, and material from most pits does not pass typical "traditional" specification tests.

Coronous material

Coronous has been used in road construction for a long time. In the Second World War, airstrips used in the Pacific were made of coronous. It is widely used in Vanuatu. It is known to perform well under controlled conditions.

10.2.2 Scoria

Scoria is a highly vesicular, dark colour volcanic rock that may or may not contain crystals (phenocrysts). It is typically dark in colour (generally dark brown, black or purplish red), and basaltic or andesitic in composition. Scoria is relatively low in mass as a result of its numerous macroscopic ellipsoidal vesicles, but in contrast to pumice, all scoria has a specific gravity greater than 1, and sinks in water. The holes or vesicles form when gases that were dissolved in the magma come out as it erupts, creating bubbles in the molten rock, some of which are frozen in place as the rock cools and solidifies.

Scoria material

Scoria may form a part of a lava flow, typically near its surface, or as fragmental ejecta (lapilli, blocks and bombs), for instance in Strombolian eruptions that form steep-sided scoria cones. Most scoria is composed of glassy fragments, and may contain phenocrysts.

Scoria has several useful characteristics that influence how it is used. It is somewhat porous, has high surface area and strength for its weight, and often has striking colours. Scoria is often used in landscaping and drainage works. It is also commonly used in gas barbecue grills. Scoria can be used for high-temperature insulation. Scoria is used on oil well sites to limit mud issues with heavy truck traffic. It is also used as a traction aid on ice and snow covered roads.

The quarry of Puna Pau on Rapa Nui/Easter Island was the source of a red coloured scoria which the Rapanui people used to carve the pukao (or topknots) for their distinctive moai statues, and to carve some moai from.

Besides that, scoria can also be used as pavement material. It is known to be very sensitive to water erosion and traffic. It tends to be very dusty and corrugate.

10.2.3 Coral Gravel and Sand Beach / Stream

Coral is gravel size dead coral found on beaches. Gravel is loose gravel size rock normally polished by the action of water and normally found on beaches or streambeds. Sand is from terrigenous or coral origin. It is found mainly on beaches but can also be found on stream edges. They are all loose material, normally clean, often rounded and sometimes they may have a salt content.

All these materials have been used in concrete and masonry with great success.

10.2.4 Basalt Cobbles

Basalt gravel and cobbles are known to be found in Ambae. They are rounded or semi-rounded, hard fine-grained volcanic rock. They are found along streams.

Those materials have been used in concrete and masonry with great success. Cobble size can be successfully used for gabion (100-150mm), hand packed stone (150-200mm) and grouted stone (100-200mm).

mm	0.005	0.075	4.75	76.	300
CLAY	SILT	SAND	GRAVEL	COBBLE	BOULDER

Figure 47 Size definition used in engineering

11 The Importance of Using Local Material

11.1 Local Material

As Vanuatu is made of several relatively small islands, the source of the material is very limited. There are three possible sources of material in Vanuatu:

a. From a borrow pit (unconsolidated deposit) from the island where the work is to be undertaken.
b. From an imported processed material from another island or overseas.
c. From a quarry (hard rock to be blasted, crushed and sieved) which can be open on the island.

Importing materials or blasting the bedrock would result in an improvement in the quality of the material but the cost of the material from b and c above would easily be 4 to 20 times the cost of the material found loose on the island.

Many countries struggle with silty and clayed soils which are a disaster in road works. In Vanuatu, it is fortunate that on most islands, several deposits of loose gravel for pavement as well as sand and gravel for concrete can be found. This is the main material needed for road works.

As those materials are naturally occurring, it is normal that there is sometimes a fairly wide variation in the properties. Therefore, some precautions need to be done in the selection of the material and to make the most of it. In addition, gravel is not a renewable resource. It is wise not to waste it.

11.1.1 Gravel

Naturally occurring soils and gravels are an important source of material for use in the construction and maintenance of a Low-Volume Road (LVR). This is because these materials are relatively cheap to use by comparison with processed materials such as crushed rock. Moreover, in many countries such as in Vanuatu, they are often the only source of material readily available, at a low cost and within a reasonable haul distance of the road. Thus, because of the substantial influence that naturally occurring materials exert on the cost of a LVR, typically about 70 per cent, it is essential that the benefits of using them be fully exploited in road construction.

The term "natural gravel" refers to a gravelly material occurring in nature as such, (e.g. coronous or scoria) or which can be produced without crushing. Some processing, to remove or break down oversize may still be necessary. However, a distinction is made between these "natural" gravels, and material produced from crushed hard rock, and is referred to as "crushed stone".

Importing material on the island to use as wearing course would be nonsense considering the high cost as well as the availability of suitable local material.

Unfortunately, many of the naturally occurring road building materials in Vanuatu was disparagingly described as being "non-standard", "marginal", "low-cost", or even "sub-standard". This is because such materials are often unable to meet the required specifications, which are usually based on Australian, European or North American practice that does not always make provision for local conditions. There are many examples of naturally occurring materials, such as coronous, that have performed satisfactorily despite being "sub-standard" with respect to their grading, plasticity or strength. Where failures occurred, investigations often show that poor quality construction or drainage problems were more likely the cause, rather than the material itself.



Pentecost Malekula Ambae

The use of local materials requires not only a sound knowledge of their properties and behaviour but also of the traffic volume and loading, physical environment, and their interactions. In addition, it will require the use of appropriate pavement design methods and the application of appropriate design standards and materials specifications, coupled with construction quality that complies with the required standards and specifications.

Naturally occurring gravel is highly variable in size and properties. This requires the use of appropriate and flexible construction techniques and provision of adequate internal and external drainage. Standard methods for tests that, for the most part, have evolved as a result of experience of soils in temperate zones, do not always give a true assessment of the performance of locally available materials when used in road construction.

Conventional specifications apply to "ideal" materials and often preclude the use of many naturally occurring materials (coronous, etc.) despite their good performance in service.

Coronous and scoria are typical examples of natural gravels, which, although occurring throughout the Pacific, had generally been considered to be unsuitable for use in base courses. However, experience and full-scale trials have demonstrated that these materials (at least coronous) can be used successfully in the upper layers of pavements.

11.1.2 Other Material

Other material found on the islands and needed in road construction are:

- Beach Coral Gravel used as concrete aggregates.
- Sand deposit (beach and stream) used in concrete, mortar, bedding, etc.
- Basalt cobble used in gabions and grouted stone.

12 Material Requirements

The level of quality of a material is its ability to meet the particular requirements for a given usage. Considering the operations related to roadwork, the material requirements has been divided in 2 main categories,

- Pavement material, and
- Concrete and masonry

Apart from the quality and particular characteristics of the material, the following factors should always be considered when selecting any material.

Haul distance	Reserves must be within physically and economically feasible haulage distance.
Place ability	The material must be capable of being placed and compacted by the available plant.
Environmental impact	The material reserves must be capable of being won and hauled within any governing environmental impact regulations.

12.1 Requirements for Pavement Material

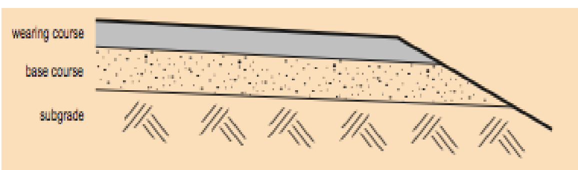
Pavement material traditionally include fill material, sub base, base, and wearing course.

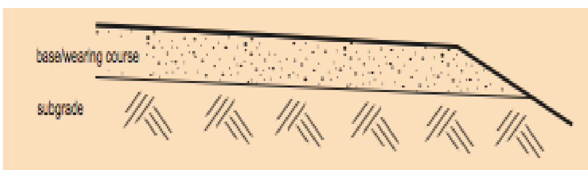
A wide range of natural materials including coronous, scoria, river gravels and other transported and residual gravels, or granular materials resulting from weathering of rocks can be used successfully in the road foundation as fill, sub base, base and/or wearing course.

Specific typical requirements considering low volume roads in tropical humid climate are described below for the most important usage, as a subbase/base and as a wearing course on unpaved roads.

As it is often the case in Vanuatu as well as in many other countries with low volume rural roads (New Zealand, Africa, etc.), the subgrade is covered with only one or two layers:

- A layer which act as sub-base, and a layer acting as base/wearing course, or
- A single layer acting as sub-base, base and wearing course.





Preferred layers Common layers

Figure 48 Pavement layer options

12.1.1 Material Requirement for Road Sub-base / Base

The basic role of the subbase is to give strength to the pavement. It is achieved in selecting the right material but also in ensuring that the drainage is efficient and that the water table is not near the ground surface. The important properties are described in the table below.

Properties	Depends on	Plays a role in	Target basic specifications
Particle size distribution	Mainly on the climate and the traffic	The compaction ability and therefore, the stability of the layer. Drainage.	The maximum size will generally be either 37.5 mm or 53 mm and the maximum fine content between 20 and 30%. A general requirement of five to ten per cent retained on successive sieves may be specified at higher traffic (>0.3 Mesa).
Strength	Traffic level and climate	Support of the pavement. Prevent deformation	Soaked CBR test is often used to specify the minimum strength of road base material.
Plasticity	Traffic level and climate	Stability of the layer.	Considering the low-volume (< 0.01 Mesa), the PI limit will depend on the stiffness of the subgrade. - If subgrade CBR is 5 to 8 : PI max 15 - If subgrade CBR in > 8 : PI max is 8xGM

Table 17 Important pavement materials properties

12.1.2 Material Requirements for Gravel Wearing Course

The role of the wearing course is to give a good and stable surface for the traffic. The wearing course material should be durable and of consistent quality to ensure it wears away evenly. The desirable characteristics of the wearing course of an unsealed road are:

- Resistance to ravelling and scouring
- Wet and dry stability
- Low permeability
- Cohesive properties
- Load spreading ability
- Skid resistance
- Smooth riding characteristics

For ease of construction and maintenance, a surface material should also be easy to grade and compact. The material properties having the greatest influence on these characteristics are the particle size distribution and the chemical / physical properties of the fine particles in terms of plasticity. Particle size distribution and its effects may conveniently be described in terms of standard particle size classifications (e.g. gravel, sand, silt and clay) or alternatively, the fractions passing various sieve sizes. Visual evaluation in the field, using these standard classifications, and/or laboratory tests, can therefore be employed to assess a material's potential.

Gravel and sand that are low in fines will be porous, lack stability when dry and will unravel under traffic. However, fines in the form of a sand–clay may be incorporated into these materials to give added stability.

The least desirable materials are those with silty fines, lacking gravel-sized particles, i.e. silts and silty-sands. These materials are likely to be porous and unstable and will unravel under traffic. They also tend to generate considerable dust.

Predominantly clay soils can provide a good dry-weather surface but will be slippery and/or will rut when wet. Sand–clay or sand–silt–clay mixtures can provide a satisfactory surface course for low traffic volume roads.

Either the plasticity index (PI) or the linear shrinkage (LS) can be used to evaluate whether the clay content of a material is appropriate. The PI or LS should desirably fall within minimum and maximum values, depending on climatic conditions, grading of the material and traffic conditions.

Malekula

Tanna

Particle strength and susceptibility to weathering will affect the ultimate grading and plasticity of a paving material. In general, it can be said that the easier a rock is to rip, the more it is likely to break down in construction and service. A material, which breaks down readily or has a history of weathering, should be thoroughly evaluated before use. It may be necessary to expose the material to the elements over a short section of roadway for a while to test its suitability.

The specifications proposed, have been developed to comply with the requirements of “ideal” wearing course materials which also performs as base course, with in mind that the specifications should:

- Be kept as simple as possible, with as few requirements or different test methods as possible.
- Have limits as wide as possible and not restricted to a narrow range of a significant property (e.g. a tight grading envelope), but comprehensive enough to accept suitable materials and reject unsuitable materials.
- Require inexpensive, quick, simple tests, which are repeatable and reproducible and need minimal sophisticated equipment and a relatively low level of operator training.
- Be practical to implement and apply to the total area for which they are intended.
- Adequately define important properties (indirectly if necessary) such as cohesion and strength and eliminate obvious problems such as oversize material.
- Should be in terms of existing test methods or combinations of results from existing methods, although scope exists for the development of simple new methods.
- Be based on performance related studies.
- Be rigidly adhered to; however, the user should appreciate the consequences of use of non-complying materials e.g. increased construction, maintenance and road user costs, increased dust and poor safety standards.

The choice of the gravel surfacing material is most often a compromise between a material, which possesses sufficiently high plasticity to prevent gravel loss in the dry season and sufficiently low plasticity to prevent serious rutting and deformation in the wet season. Choice of materials will also depend, when possible, on haul distances, since this will greatly affect construction costs and rate of progress.

Specifications emphasise the need for these properties combined with a mechanically stable grading with higher fines content for binding action to result. Selection of a suitable range of plasticity is dependent on climate.

The figure below illustrates wearing material quality zones.

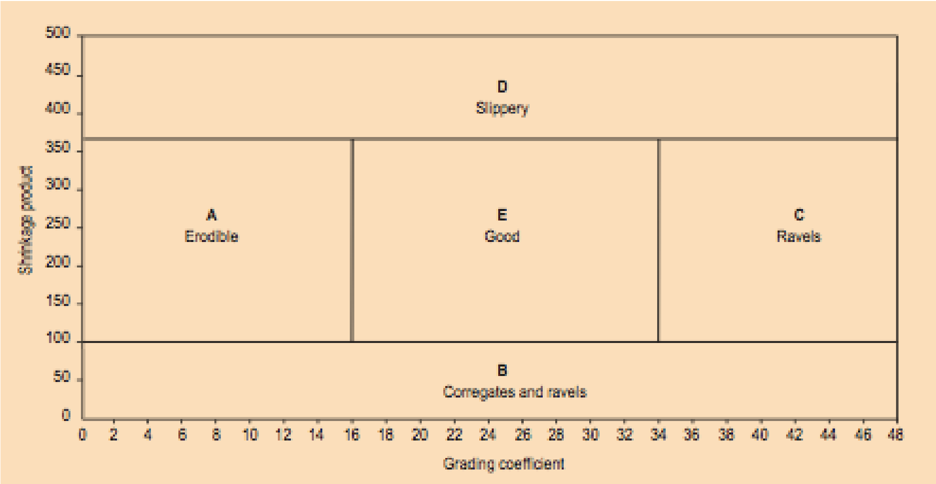


Figure 49 Wearing material quality zones

The characteristics of materials in each zone are as follows:

a) Materials in this area generally perform satisfactorily but are finely graded and particularly prone to erosion. They should be avoided if possible, especially on steep grades and sections with steep crossfalls and super-elevations. Roads constructed from these materials require frequent periodic labour intensive maintenance over short lengths and have high gravel losses due to erosion.

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

c) Materials in this zone generally comprise fine, gap-graded gravels lacking adequate cohesion, resulting in unravelling and the production of loose material.

d) Materials with a shrinkage product in excess of 365 tend to be slippery when wet.

e) Materials in this zone perform well in general, provided the oversize material is restricted to the recommended limits.

Dust: Dust is the loss of fines put in suspension by the action of traffic. To reduce the dust as much as possible near community villages, the material content may have a reduced fine content.

Gravel loss

Dusty road

Gravel loss: Gravel loss is the single most important reason why gravel roads are expensive in whole of life cost terms and often unsustainable, especially when traffic levels increase. Reducing gravel loss by selecting better quality gravels or improving the construction procedures or modifying the properties of poorer quality materials is one way of reducing long-term costs. Gravel losses can vary from 10 to 45 mm/year/100 vpd for the first phase of the deterioration cycle lasting possibly two or three years. Beyond that period, as the wearing course is reduced in thickness, other developments, such as the formation of ruts, will also affect the loss of gravel material. However, the rates of gravel loss given can be used as an aid to the planning for re-gravelling in the future. A more accurate indication of gravel loss for a particular section of road can be obtained from periodic measurement of the gravel layer thickness.

12.2 Requirements for Concrete and/or Masonry

Concrete material includes coarse and fine aggregates along with cement and water. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, account for 60 to 75 percent of the total volume of concrete.

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process.

12.2.1 Coarse Aggregate

Although some variation in aggregate properties is expected, characteristics that are considered include:

- Grading
- Durability
- Cleanliness
- Particle shape and surface texture
- Abrasion and skid resistance
- Unit weights and voids
- Absorption and surface moisture

Grading refers to the determination of the particle-size distribution for aggregates. Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate used as well as cement and water requirements, workability, pump-ability, and durability of concrete. The required amount of cement paste is dependent upon the amount of void space that must be filled and the total surface area that must be covered. When the particles are of uniform size the spacing is the greatest, but when a range of sizes is used the void spaces are filled and the paste requirement is lowered. The more these voids are filled, the less workable the concrete becomes. Therefore, a compromise between workability and economy is necessary. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength.

Cleanliness is an aggregate free of dirt or clay sticking to the particles. Dirt weakens the bond between paste and aggregates. If aggregates are used in reinforced concrete (using steel bars or wire mesh), the aggregates should be free of salt.

Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

The shape and texture of aggregate affects the properties of fresh concrete more than hardened concrete. Concrete is more workable when smooth and rounded aggregate is used instead of rough angular or elongated aggregate. Most natural sands and gravel from riverbeds or seashores are smooth and rounded and are excellent aggregates. Crushed stone produces much more angular and elongated aggregates, which have a higher surface-to-volume ratio, better bond characteristics but require more cement paste to produce a workable mixture.

The surface texture of aggregate can be either smooth or rough. A smooth surface can improve workability, yet a rougher surface generates a stronger bond between the paste and the aggregate creating a higher strength.

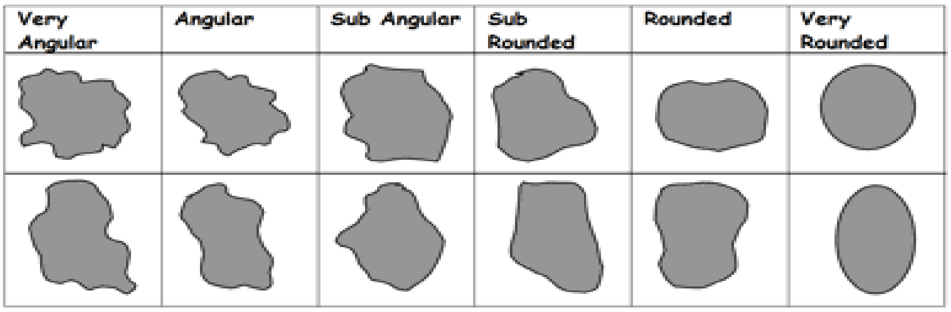


Figure 50 Shape and texture

13 Usage of Coronous in Road Works

13.1 Coronous as a Wearing Course

Coronous material is the best widely found material in Vanuatu for wearing course. However, as it is variable in its properties (grading, hardness, plasticity, etc.), proper care when selecting can improve the final result. In addition, handling and construction procedures and equipment are very important to ensure the best possible quality of the final work.

13.1.1 Advantages of Coronous Material

- Can be found almost everywhere within ±10 km.
- "As dug" pavement aggregate may be exploited to considerable depths by ripping.
- When "as dug" material contains an excessive proportion of oversize particles, it can often be effectively treated with a mobile crusher or 'Rockbuster' type machine.
- "As dug" coronous which contains less than 30% of fines, often get CBR > 100.
- There is good interlock between angular particles and a hard pavement 'crust' may develop.
- Carbonate clay is an excellent binder, which produces a good pavement running surface with 'normal' compaction. Significant breakdown of oversize particles may occur during compaction.
- When well compacted, the surface is hard with minimum dust and impermeable.

13.1.2 Disadvantages of Coronous Material

- A variable proportion of coronous particles are fairly weak.
- Rate of pavement wear/loss is typically higher than for alluvial gravel pavements. This may become significant on more heavily trafficked roads (> 800 vpd).
- Material quality/performance deteriorates as sand content exceeds gravel content.
- Potholes may form where pavement 'crust' is broken or softened.
- Material quality/performance deteriorates if carbonate clay (fine matrix) content is excessive.
- Quarry pit materials with high natural moisture content (damp/wet) are difficult to handle and compact, and tend to form a weak pavement when first laid.

13.1.3 Recommended Specifications on the Use of Coronous as Wearing Course

The following specifications are based on the available general research and knowledge of coronous material adapted to the local environment found in Vanuatu. It was also considered that all roads are low volume and that there is often only one layer above the subgrade. Therefore, to make it simpler and probably more realistic, the proposed specifications apply to all "traditional" layers. (sub-base, base and wearing course).

Grading: Coronous

Sieve (mm)	Envelope
53	100
37.5	90-100
19	70-100
2.36	35-65
0.425	15-50
0.075	10-30

Note on grading specification
This envelope is assuming that some of the largest particle (37.5-53mm) will break down during compaction. It is also assuming that the spread-water-compact operation is performed adequately. Some quarries may also have harder particles, which wouldn't break down. This could make the wearing surface to become fairly rough after few months of heavy traffic and rain. In that case, it is advised to revise the grading specifications in order to reduce (or eliminate) the coarser content (37.5-53mm), at least for the wearing course. A smaller nominal size would ease spreading and compaction and smoother ride.

Table 18 Grading specification for pavement materials

Considering the variation in the characteristics of the coronous between quarries and even within the same borrow pit, it is suggested to regularly perform visual assessments of the fine content of the material during the extraction process and to sample the quarry to build the knowledge of the material. It is also important to sample different zones within the borrow pit.

Other characteristics that can be relevant to verify are PI, LS and CBR. Therefore, the specifications would ideally be the following.

Characteristics	Specification	
Grading Coefficient	16 – 34	(%passing 26.5 mm - %passing 2 mm) x %passing 4.75 mm / 100
Grading Modulus	1.5 – 2.5	(200 – (%passing 2 mm + %passing 0.425 mm + %passing 0.075 mm)) / 100
Fine to sand ratio	0.25 – 0.24	5 passing 0.075 mm / % passing 2.36 mm
Plasticity Index (PI)	Max 15	If CBR in unknown or < 8 %
Plasticity product	300 - 400	PI x % passing 0.425 mm
Shrinkage Product (Sp)	100 - 365[1]	LS x % passing 0.425 mm
Soaked CBR	Min 30%	

[1] 240 Preferable

Table 19 Other desirable properties for coronous pavement material

There is a fairly good relationship between a high fine content and a low CBR. Therefore, it is believed that in having a good grading, limiting the fine content and in verifying its plasticity (especially if the passing 0.075 mm is higher than 20%), the material is more likely to conform to the CBR requirement.

The limits stated for the characteristics above come from general overseas studies and experiences. These may or may not be suitable for Vanuatu. In order to develop specific requirement for local material, a better knowledge of the material properties are needed. The actual information is almost non-existent and sometimes irrelevant. Therefore, sampling and testing must be done on the local material. Local experience may indicate changes to limits that better distinguish between local materials and their capability of fulfilling requirements for different rural road standards.

13.1.4 How to Improve Coronous as a Wearing Course?

In the borrow pit

	Action to improve	How	Why
p1	Avoid material with fine content higher than 30%.	Visual. Perform grading test.	High fines content normally indicate a low CBR. It also indicates a higher plasticity and plasticity modulus, which will make the pavement less stable. It will also generate more dust.
p2	Remove gravel size greater than 50 mm.	Manually or with screen and/or crushing,	Coarser material in the wearing course may lead to poor compaction as the interlocking will be harder to achieve around large gravel and may result in premature potholing. The larger the gravel, the coarser the wearing surface will become during the wearing process due to the lose of fines.
p3	Prevent segregation during stockpiling.	Stockpile in a continuous layer. Do not push materials over an existing pile.	If segregated material is spread on site and compacted as is, the performance expected will not be met.; there will be either mainly coarser gravel with a lack of fines or little gravel in a matrix of fine material.

At the worksite

	Action to improve	How	Why
s1	Prevent segregation when loading.	Always load a full depth of material and not only the surface or the edge.	If segregated material is spread on site and compacted as is, the performance expected will not be met; there will be either mainly coarser gravel with a lack of fines or little gravel in a matrix of fine material.
s2	Prevent segregation when spreading.	Continuous discharging. Limit passage and vibration of the uncompacted material.	
s3	Remove gravel size greater than 50 mm.	Manually or mechanically.	See p2 above.
s4	Break large particles.	Use of a grid rollers can be beneficial under certain circumstances.	If breaking of particles is desirable.
s5	Moisture the material uniformly to the optimum moisture content (OMC).	Evaluate the natural water content and add the quantity of water needed to bring it to the OMC (normally between 8 and 11). Use water tank, manual pressure sprayer, watering can, etc.	To achieve the optimum compaction. To be able to use the fines as paste and binder. Water will help to bring all particles as tight as possible.
s6	Compact to refusal.	Use the most suitable equipment available. Compact with vibration. Minimum of 10 passes or when the roller leaves, no more prints.	Increase load-bearing capacity. Provide better stability. Reduce permeability for water. Improve traffic resistance.
s7	Keep carriageway clean of organics.	Avoid putting grass and leaves on carriageway when cutting grass during routine maintenance.	It will become humus and may become slippery.

Table 20 Proposed improvement actions in the work site

13.1.5 Proposed Further Actions or Study on the Use of Coronous as Wearing Course

1. Develop further actions or study on the use of coronous as wearing course.
2. Help develop a quarry management system (or borrow put inventory) including all test results for each pit to be sampled.
3. Perform at least 2 complete sets of tests for each borrow pit (grade, MDD, CBR, limits, shrinkage, LA, etc.)[3]. This will greatly help in the material selection.

13.2 Coronous as Concrete Aggregate

An aggregate is normally 60-70% of the concrete along with cement and water. If the adherence between the aggregate and the cement paste is strong, the coarse aggregate will help give strength to the concrete. The fine aggregate (sand) will make the concrete flowing and workable.

3 Only a few laboratory test results have been found for each island. They were all performed since 2011 by the PWD material testing laboratory. However, it was found that two important tests were not performed correctly (sieve analysis and CBR). The material was not tampered and washed during the sieve analysis, leading to an important undervaluation on the fine content. The compaction of the material for the CBR was not at the optimum moisture content leading to under compaction and the surcharge was removed during the test performance loading. This all leads to an under evaluation of the CBR. Therefore, all laboratory test results available could not be trusted to report on the properties.

Coronous is used as concrete coarse aggregate in ready-mix plants in Port Vila. It is also occasionally used in outer island for small scale house building or other uses. However, most of the concrete made manually for small quantities will use beach and stream aggregates.

13.2.1 Advantages of Coronous Material

- Can be found almost everywhere within ±10 km.
- Can be sieved manually or with equipment (sieve, crusher, etc.).
- Often a better environmental option (compared to the gravel from a beach/stream).
- Angular particles, if hard, help interlocking and improve strength.

13.2.2 Disadvantages of Coronous Material

- Fairly weak particles without an operation of crushing may remain as coarse aggregates and weaken the concrete.
- Must be well washed to eliminate the fines sticking to the gravel (not with seawater if used in reinforced concrete).
- Angular particles will reduce workability and may require more paste (cement).

13.2.3 Recommended Specifications using Coronous Aggregates

In the absence of information regarding the properties of coronous aggregates (particularly the mechanical properties) for use in concrete, it is suggested to use the specifications stated in the PWD or in the Australian Standard AS 2758.1 "Aggregates and rock for engineering purpose – Part 1: Concrete aggregate".

However, as the material from the most significant quarries are to be sampled and tested, the knowledge of the coronous properties should enable the selection of a more adapted specification. The normal properties required are

- Aggregate strength (LA, ACV and/or SSS)
- Aggregate grading
- Impurity, fines and organics

13.2.4 Proposed Further Actions or Study Use of Coronous as Concrete Aggregate

1. Better knowledge of the characteristics of the aggregates in different quarries. Perform hardness tests on particles size 5 mm – 20 mm of coronous from several borrow pits (LA, etc.). This will greatly help to determine if a given material is suitable and if it needs crushing.
2. Knowing that coronous is generally suitable as concrete aggregate, the biggest challenge will be to process the material efficiently on a small scale. Therefore, options should be analysed to find the most cost-effective, realistic and applicable way to process the material, which would be accepted by the local community.

14 Volcanic Scoria

14.1 Scoria as a Wearing Course

Volcanic scoria as wearing course is a less performing material than coronous. All particles (from fine to coarse) are vitreous and therefore, there are no plastic fines to bind the material. In Ambae and Ambrym, there are no coronous deposits and scoria is the only material easily available for roadwork. Therefore, as it is variable in its properties (grading, hardness, plasticity, etc), proper care when selecting can improve the final result. In addition, handling and construction procedures and equipment are very important to ensure the best possible quality of the final work.

1 l

- Can be found everywhere on Ambae and Ambrym.
- May occur in large relatively uniform exploitable deposits.
- Typically easily excavated by backhoe, wheeled loader or bulldozer.
- Angular gravel produces good interlock of particles when well graded.
- “As dug” materials may often be well graded.
- Larger particles tend to breakdown under normal compaction and may improve the grading by creating sand and silt size particles, which may reduce the need of quarry processing.

14.1.2 Disadvantages of Scoria Material

- Typically lack good plastic binder.
- If the “as dug” materials are uniformly graded and have a significant lack of fines ,adequate compaction will be difficult to achieve.
- Completely weathered volcanic ash residual soils may form thick overburden deposits.
- Due to vesicular nature of these deposits, weaker materials may breakdown rapidly under compaction and in-service on the road to produce a dusty surface in dry conditions.
- Workable deposits may occur within a sequence, in-bedded with tuff / clayed silt and hard basaltic lavas. Selective extraction at the pit is then necessary.
- Very susceptible to rain. Will tend to ravine and erode.
- Susceptible to corrugate under traffic.
- Dusty.

14.1.3 Recommended Specifications for the Use of Scoria as Wearing Course

The following specifications are based on the available general research and knowledge of scoria material adapted to the local environment found in Vanuatu. It was also considered that all roads on Ambae and Ambrym are low volume and that there is often only one layer above the subgrade. Therefore, to make it simpler and probably more realistic, the proposed specifications applied to all “traditional” layers (sub base, base and wearing course). Grading is proposed below.

Sieve	Envelope
53	100
37.5	90-100
19	70-100
2.36	35-65
0.425	15-50
0.075	10-30

Note on grading specification
This envelope is assuming that some of the largest particle (37.5-53mm) will break down during compaction. It is also assuming that the spread-water-compact operation is performed adequately. Some quarries may also have harder particles, which wouldn't break down. This could make the wearing surface to become fairly rough after a few months of heavy traffic and rain. In that case, it is advised to revise the grading specifications in order to reduce (or eliminate) the coarser content (37.5-53mm), at least for the wearing course.

Table 21 Grading specification for pavement materials

Considering the visual variation in the characteristics of the scoria between quarries and even within the same borrow pit, it is suggested to perform regular visual assessments of the material during the extraction process and to sample the quarry for testing to build the knowledge of the material. It is also important to sample from different zones within the borrow pit.

Other important characteristics to verify are:

- Los Angeles
- Soaked CBR min 30

Note: As this type of material does not normally have plastic fines, plasticity limits have not been specified. But if the material happens to have some plasticity, its behaviour would be improved.

14.1.4 How to Improve Scoria as a Wearing Course?

In the borrow pit

	Action to improve	How	Why
1	If possible, select material with more fines.	Visual. Perform grading test.	More fines content will tend to compact better.
2	Remove gravel size greater than 50 mm.	Manually or with screen and/or crushing.	Unless coarser particles are weak and will break under compaction, coarser material in the wearing course will make the compaction more difficult as the interlocking will be harder around large gravel and would normally require heavier compaction equipment. The bigger the gravel is, the rougher the surface pavement will become during the wearing process due to the lose of fines.
3	Prevent segregation in the stockpiling.	Stockpile in a continuous layer. Do not push materials over an existing pile.	If segregated material is spread on site and compacted as is, the performance expected will not be met; there will be either mainly coarser gravel with a lack of fines or little gravel in a matrix of fine material.

Table 22 Proposed improvement actions in the pit

At the worksite

	Action	How	Why
1	Prevent segregation when loading.	Always load a full depth of material and not only the surface or the edge.	If segregated material is spread on site and compacted as is, the performance expected will not be met; there will be either mainly coarser gravel with a lack of fines or little gravel in a matrix of fine material.
2	Prevent segregation when spreading.	Continuous discharging. Limit passage and vibration of the uncompacted material.	
3	Moisture the material uniformly to the optimum moisture content (OMC).	Evaluate the natural water content and add the quantity of water needed to bring it to the OMC (normally between 8 and 11) Use water tank, manual pressure sprayer, watering can, etc	To achieve the optimum compaction. To be able to use the fines as paste and binder. Water will help to bring all grains as tight as possible.
4	Compact to refusal.	Use the heaviest equipment available. Compact with vibration. Compact with a minimum of 10 passes or when the roller leaves no more prints.	Increase load-bearing capacity. Provide better stability. Reduce permeability for water. Reduce setting of soil. Improve traffic resistance.
5	Stabilized with plastic fines.	Add plastic fines as clayed material and mix it	It will greatly improve the binding of the material and the compaction. Therefore, will have a better resistance to traffic weathering, be less dusty and corrugate less.

Table 23 Proposed improvement actions in the worksite

14.1.5 Volcanic Scoria as Base or Sub-base

As base or subbase, scoria is confirmed as having good results in overseas studies and trials on low volume roads, particularly on sealed roads. The layer was stable and had an acceptable bearing capacity.

14.1.6 Proposed Further Actions or Study for the Use of Scoria as Wearing Course

1. Develop an easy method to evaluate the water content in the material for compaction purpose (same as for coronous)
2. Help develop a quarry management system (or borrow pit inventory) including all test results for each pit (same as for Coronous) to be used.
3. Perform at least 2 complete sets of tests for each borrow pit (grade, MDD, CBR, limits (?), shrinkage (?), LA, etc.). This will greatly help in the material selection.
4. Look for clayey deposit in Ambae and Ambrym and perform trial in stabilising scoria with plastic fines. This was done as a research on 2 sections in Ethiopia and it showed a great improvement in the behaviour of the scoria.

14.2 Volcanic Scoria as Concrete Aggregates

An aggregate is normally 60-70% of the concrete along with cement and water. If the adherence between the aggregate and the cement paste is strong, the coarse aggregate will help give strength to the concrete. The fine aggregate (sand) will make the concrete flowing and workable.

There is no known use of scoria aggregates in concrete in Vanuatu but there are references from overseas where scoria aggregates were use in lightweight concrete. Information (test results) couldn't be found on the properties of scoria from Ambae or Ambrym, which would be relevant for concrete aggregates (densities, water absorption, durability, etc.). However, to be considered, particles would need to be at least as strong as the concrete.

14.2.1 Advantages of Scoria Aggregates

- Can be found everywhere on Ambae and Ambrym.
- Can be sieved manually or with equipment (sieve, crusher, etc.).
- Often a better environmental option (compared to the gravel from a beach/stream).
- Angular particles, if hard, help interlocking and improve strength.

14.2.2 Disadvantages of scoria aggregates

- Fairly weak particles without an operation of crushing may remain as coarse aggregates and weaken the concrete.
- Angular particles will reduce workability and may require more paste (cement).

14.2.3 Recommended Specifications for the use of Scoria as a Concrete Aggregate

In the absence of information regarding the properties of scoria aggregates (particularly the mechanical properties) for use in concrete, it is suggested to use the specifications stated in the PWD Standard Technical Specification for Road and Bridge Works or in the Australian Standard AS 2758.1 "Aggregates and rock for engineering purpose – Part 1: Concrete aggregate".

However, as the material from the most significant quarries are yet to be sampled and tested, the knowledge of the scoria properties should enable the selection of a more adapted specification.

14.2.4 How to Improve Scoria as a Concrete Aggregate

In the absence of any test results to assess the raw material, it is hazardous to propose any improvement. However, grading is surely essential.

	Action	How	Why
1	Ensure grading as specified.	Sieve (and crushed) manually or with equipment (sieve, crusher, etc.).	To ensure workability in respecting the water/cement ratio. The formula took in account the grading of aggregates and its proportion.

Figure 51 Sieving scoria in Ambae 2012

14.2.5 Proposed Further Actions or Study to Improve Scoria as Concrete Aggregate

1. Build basic knowledge of the properties of the scoria aggregates. Perform lab tests relevant to concrete aggregates on several samples, at least from Ambae. This will greatly help to determine if a given material has the basic properties to be considered, and if so, what are its limitations and how can it be improved.

2. Perform trial mixes using scoria aggregates.

3. If the scoria gravel happened to be appropriate for concrete aggregates, the biggest challenge will be to process the material efficiently on a small scale. Therefore, options should be analysed to find the most cost-effective, realistic and applicable way to process the material, which would be accepted by the local community.

15 Stabilisation

Pavement stabilisation is employed in unsealed roads usually to reduce maintenance costs, improve material properties and to provide a better all-weather surface. By rectifying deficiencies in materials, stabilisation allows otherwise unsuitable materials to be used to advantage in road pavements.

Stabilisation has the benefits of improved surface condition through less dust, rutting, potholes and corrugating. In addition to reduced maintenance costs, vehicle-operating costs may also be reduced. However, some forms of stabilisation may be inappropriate or too costly for use in unsealed road construction. Problems can arise from either the selection of a stabilisation method, which is inappropriate for the local material and conditions, or the use of incorrect techniques in an appropriate application.

The principal factors to be considered when selecting the most suitable method of stabilisation are as follows:

- Type of material to be stabilised.
- Proposed use of the stabilised material .
- Relative costs.

Cost is a particularly important factor in relation to unsealed roads. Stabilisation is therefore only worthy of consideration if it is economical when compared to all other alternatives. For unsealed roads, it is more likely to be justified at particular problem locations. Other factors that influence the choice of method of stabilisation include:

- The capabilities and experience of the construction personnel.

- Availability of the specialised stabilisation equipment.
- The availability of testing facilities for investigations and subsequent quality control.

The most common methods of stabilisation used in roadworks include:

- Mechanical stabilisation
- Lime stabilisation
- Cement stabilisation
- Bituminous stabilisation including emulsions
- Geotextiles
- Chemical stabilisation

The proposed addition of clayed soil (plastic fines) to scoria as wearing course is a mechanical stabilisation.

16 Summary of Actions to Improve Materials Suitability

16.1 Immediate Actions

As mentioned above, many actions can be taken in the borrow pit or at the source to improve the material.

1. Sieve gravel or coral (coarse aggregate) for concrete.
2. Sieve sand (fine aggregate) for concrete.
3. Wash sand and/or gravel/coral if appropriate to remove salt.
4. Take note of each mix proportion and behaviour of the concrete (for further adjustment).
5. Remove manually or build/buy a screen to remove particles bigger than 50 mm (can be built with old steel bars).
6. Prevent segregation in the quarry by ensuring adequate stockpiling procedures.
7. Take regular samples and have them analysed by PWD lab (refers to TN04_Sampling/Testing of Borrow Pits).
8. Ensure proper operation in the field when compacting pavement materials: spread / shape / moisture / compact (refers to Appendix 2 “Better Control of Compaction”).
9. Look for clayey deposit on Ambae, sample and perform tests (grade, LL, PL, IP, LS).

16.2 Further Actions

1. Develop an easy method to evaluate the water content in the material (refer to Appendix 3 “Possible Methods to Evaluate Moisture Content of Material On-Site”)
2. Help develop a quarry management system (or borrow pit inventory including all test results for each pits). Department of Geology & Mines are currently working to develop a GIS module on the matter.
3. Analyse test results for coronous material as pavement and revise recommendation.
4. Analyse test results for coronous material as concrete and revise recommendation.
5. Analyse test results for scoria material as pavement and revise recommendation.

6. Analyse test performed in clayed deposit from Ambae and perform trial in stabilising scoria with plastic fines. This was done as a research on 2 sections in Ethiopia and it showed a great improvement in the behaviour of the scoria.
7. Analyse test results for scoria material as concrete and give recommendation
8. If scoria gravel gives good test results, perform trial mixes using scoria aggregates
9. Analyse options to find the most cost-effective, realistic and applicable technique to process the material (coronous and/or scoria), which would be accepted by the local community (refer to Appendix 5 “Quarry Materials Process Options”)
10. Develop Test/Check forms to record quality activities, process and results (Quality control/Quality assurance).

17 Conclusion

Vanuatu has a particular context in which it is an archipelago formed with 80 relatively small islands and therefore, they are not linked with a “main” road from one to each other. They are rather isolated from each other. This context makes the use of imported material and/or equipment very expensive.

Fortunately, there are satisfactory materials for construction purposes in abundance on most islands. Sometimes, the materials may not be “ideal” or “perfect” but it is affordable and acceptable for low volume roads.

Care and a few sensible actions can realise properties of the local material at its best and/or improve. As most islands are relatively small, it could be very costly to have heavy equipment available and in a working state on all of them. Therefore, compromise and adapted actions are necessary.

Immediate actions and further actions are proposed to improve local materials. These proposed actions are mainly based on the overall knowledge of the material type in general. However, as the knowledge of the specific properties of the local materials becomes better known, the improvement action possibilities and requirements may be refined or revised.

Coronous is a good material for base and wearing course as long as some care is taken in grading and compacting adequately. It can also be a good concrete aggregate but would probably need heavy processing (crushing, washing and sieving). Test results will be used to assess the potential of the material. Further, an economic study will be needed to evaluate the options and suitability for small-scale operation.

Scoria has a good bearing capacity but it is medium material for pavement wearing course as it lacks of plastic fines. However, it can be suitable as base course when the road is sealed (bitumen or concrete). There is potential in stabilizing scoria with plastic fines to improve it (more stable, less wear, less dust, less chance to corrugate). The behaviour of scoria in concrete in unknown but if the gravel size has enough strength (which could be the case as VTSSP Phase 1 used it on the Otta Seal trial in Ambae), there is a possible use.

There is little evidence to suggest problems with the other local materials. Sand and coral/gravel from beach/stream for concrete would require the correct size in sieving and ensure removal of salt by washing when used in reinforced concrete. Together, they have the ability to make very good concrete.

18 Appendices

Appendix 1	Summary of Material Suitability
Appendix 2	Better Control of Compaction
Appendix 3	Possible Methods to Evaluate Moisture Content of Material On-Site
Appendix 4	Better Control of Concrete
Appendix 5	Quarry Materials Process Options

18.1 APPENDIX 1

18.1.1 Summary of Material Suitability

18.1.1.1 *Knowledge and Local Experience on the Use of Various Materials*

Unconsolidated natural deposits where available have been historically used on the islands for various purposes. Most of these natural materials are designated as: coronous (or raised reef), scoria (or cinder gravel), basalt cobble, beach coral, volcanogenic and coral sand. They were and can be used for

	Coronous	Scoria	Cobble	Beach coral	Sand
Embankment	Green	Green	Dark blue	Dark blue	Dark blue
Subgrade	Green	Green	Dark blue	Dark blue	Dark blue
Subbase	Green	Green	Dark blue	Dark blue	Dark blue
Base (if sealed)	Green	Green	Dark blue	Dark blue	Dark blue
Base wearing course	Green	Yellow	Dark blue	Dark blue	Dark blue
Surfacing (Otta seal)	Yellow	Yellow	Orange	Orange	Dark blue
Surfacing (other)	Orange	Orange	Orange	Orange	Yellow
Concrete aggregate	Green	Yellow	Orange	Green	Green
Masonry	Orange	Yellow	Dark blue	Dark blue	Green
Gabion	Green	Yellow	Green	Dark blue	Dark blue
Stone pitching / grouted stone	Yellow	Yellow	Green	Dark blue	Green

Green	Successfully used in the past
Yellow	Good potential with some processing but needs further study
Orange	Would need major processing (crushing, etc) or extensive research
Dark blue	Not suitable

18.1.1.2 *Use of Coronous*

Coronous material or raised coral reef deposits are found on all islands having public roads except on Ambae and Ambrym. It can be described as a poorly consolidated rip-able rock producing moderately to well graded, irregular to angular carbonate GRAVEL with some to many cobbles of sandy plastic 'putty' CLAY or sandy SILT. The status of the knowledge on its use is mapped in the table below.

		General comment on usage	Issues or precaution needed – material selection	Issues or precaution needed – construction	Proposed study
Embankment		Makes suitable and stable fill.	Larger size of gravel not more than 2/3 of the thickness of the compacted layer.	Needs to be shaped and compacted properly to refusal.[1]	No
Subgrade		Makes a good and stable subgrade.	Not applicable.	Needs to be shaped and compacted properly to refusal.[2]	No
Sub base		Makes a good and stable sub base (as long as the subgrade is stable).	Material with high fine content may not be stable and have low CBR. Need less than 30% fines. If too plastic, stability may decrease. Need to remove gravel larger than 53 mm and keep not more than 10% larger than 37.5 mm. May be improved by processing in the quarry. Almost all deposits suitable for "as dug" or screened sub base material.	Good construction procedure is a MUST. Cross fall of 5% minimum to drain water, spread, shape and compact properly to refusal [2].	No
Base [1]		Can make a good and stable base.			No
Base/ Wearing		Can make a good base/wearing course for low volume roads. Stable, "waterproof" and traffic resistant. Proper proportion of plastic fines will "bind" the material. "As dug" and screened materials typically compact well to form a dense interlocking structure. Some breakdown of particles.			Need to monitor the performance and to relate it with the particle characteristics. Search for option of processing in the quarry and the possible use of a small crusher.
Surfacing (Otta seal)		Has been used successfully in Tonga.	Would need some processing. Screening and perhaps crushing.	Knowledge, experience and equipment also needed.	Yes
Surfacing (other sealing)		Used in Efate and Santo.	Particles strength could be an issue.		If need arises.
Concrete / coarse aggregate		Currently used in batch plant in Port Vila and Santo. Also used in many islands to build houses.	Need processing: screening and perhaps crushing for large volume. Need to care for fines that could stick on aggregates.		Cost of processing options.
Masonry		Not recommended. Need non plastic sand and fine gravel < 5mm.	Would need too much processing.		No

Gabion filling material		Suitable but needs processing.	Important screening need to be done 100-250 mm needed.	Some particles could be week and break down with interlocking.	Cost of processing options.
Stone Pitching or grouted stone		Suitable but need processing	Important screening need to be done 150-450 mm needed	Some piece could be week and break down.	Cost of processing options.

[1] Base course for sealed roads

[2] Layers not exceeding 150 mm, respect OMC (± 2%), compact with heavy roller with 8 to 12 passes depending on the weight of the roller. Refusal is when an extra pass leaves no imprint.

18.1.1.3 *Use of Scoria*

Scoria or cinder gravel or volcanic cinder is found on a few islands, but on Ambae and Ambrym it is the only “gravelly” material available. It can be described as a loose natural gravel – typically comprising variably graded silty sandy to very sandy angular to subangular vesicular GRAVEL with some to many cobbles (volcanic bombs) and with a lack of plastic fine.

The status of the knowledge on its use is mapped in the table below.

	General comment on usage	Issues or precaution needed – material selection	Issues or precaution needed – construction	Proposed study
Embankment	Makes suitable and stable fill but slope should be reduced as the cohesion is low.	Size of gravel larger than 2/3 of the compacted layer has to be removed.	Needs to be shaped and compacted properly.	No
Subgrade	Makes a good and stable subgrade.	Not applicable.	Needs to be shaped and compacted properly.	No
Sub base	Makes a good and stable sub base (as long as the subgrade is stable).	The grading and particle strength properties of coarse deposits may be significantly improved by crushing. The more uniformly graded fine to medium gravel deposits are typically unsuitable for use in base construction but will represent useful sources of selected subgrade fill and sub base.	Good construction procedure is a MUST. Spread, shape and compact properly to refusal [2]. Mechanical stabilization with plastic fines can greatly help.	No
Base [1]	Can make a good and stable base in lightly trafficked roads.			Monitor the performance and to relate it with the particle characteristics. Processing in the quarry and the possible use of a small crusher. Perform trial in adding plastic fines.
Base/ Wearing	Gives a suitable support but can corrugate and wear very quickly. Considering its poor “as dug” grading, relatively low particle strength and lack of plastic fines, this material can rate poorly when used for base/wearing course and needs higher maintenance.			
Surfacing (Otta seal)	Trial performed in Ambae in 2012. Results were promising.	Would need some processing. Screening and perhaps crushing.	Knowledge, experience and equipment also needed.	Continue trial to build on experience.
Surfacing (other sealing)	Trial performed in Ambae in 2012. Results were average.	Particles strength could be an issue.	Knowledge, experience and equipment also needed.	Need to know the particles strength.
Concrete / coarse aggregate	No known use on Vanuatu. Used overseas in lightweight concrete.	Would need processing (screening and perhaps crushing).		Cost of processing options.
Masonry	No known use on Vanuatu.			Need to investigate the grading of fine content.

Gabion		No known use on Vanuatu.	Important screening needs to be done (100-250 or 150-450).	Some pieces could be week and crumble	Particle strength would need to be investigated.
Stone Pitching or grouted stone		Where there is scoria, there is basalt cobble which are preferred.			

[1] Base course for sealed roads.

[2] Layers not exceeding 150 mm, respect OMC (± 2%), compact with heavy roller with 8 to 12 passes depending on the weight of the roller. Refusal is when an extra pass leaves no imprint.

18.1.1.4 *Use of Basalt Cobbles*

	General comment on usage	Issues or precaution needed – material selection	Issues or precaution needed – construction	Proposed study
Embankment	Not applicable.			
Subgrade	Not applicable.			
Sub base	Not applicable.			
Base [1]	Not applicable.			
Base/ Wearing	Not applicable.			
Surfacing (Otta seal)	Not applicable.			
Surfacing (Other sealing)	Never been tried.	Would need crushing. Usually good strength. Crushed basalt is known to make elongated shape.		If need arises. Would need to crush and perform various testing.
Concrete / coarse aggregate	Never been tried.	Would need crushing. Usually good strength. Crushed basalt is known to make elongated shape.		If need arises. Would need to investigate for crushing.
Masonry	No known use in Vanuatu.			Need to investigate the grading of fine content.
Gabion	No known use in Vanuatu.	Important screening needs to be done (100-250 or 150-450).	Some pieces could be week and crumble.	Particles strength would need to be investigated.
Stone Pitching or grouted stone	Where there is scoria, there is basalt cobble which are preferred.			

[1] Base course for seal roads

18.1.1.5 *Use of Beach Coral and Gravel*

		General comment on usage	Issues or precaution needed – material selection	Issues or precaution needed – construction	Proposed study
Embankment		Not applicable.			
Subgrade		Not applicable.			
Sub base		Not applicable.			
Base [2]		Not applicable.			
Base/ Wearing		Not applicable.			
Surfacing (Otta seal)		May be possible, but never tried.			If need arises.
Surfacing (other sealing)		Never been tried.	Would need crushing. Could have variable strength.		If need arises. Would need to crush and perform various testing.
Concrete / coarse aggregate		It is the primary source of concrete coarse aggregates on the islands.	Need to be sieved and washed.		No.
Masonry		Not applicable.			
Gabion		Not applicable.			
Stone Pitching or grouted stone					

[2] Base course for seal roads

18.1.1.6 *Use of Sand (Beach and Volcanogenic)*

	General comment on usage	Issues or precaution needed – material selection	Issues or precaution needed – construction	Proposed study
Embankment	Not applicable.			
Subgrade	Not applicable.			
Sub base	Not applicable.			
Base [2]	Not applicable.			
Base/ Wearing	Not applicable.			
Surfacing (Otta seal)	Not applicable.			
Surfacing (other sealing)	Never been tried. Could maybe be used in sand seal.			If need arises.
Concrete / coarse aggregate	It is the primary source of concrete fine aggregate.	Need to avoid fine sand. Needs to be sieved and washed.		No.
Masonry	Suitable for use in masonry.	Need to avoid fine sand.		No.
Gabion	Not applicable.			
Stone Pitching or grouted stone	Suitable for use in mortar or grout.	Need to avoid fine sand. Needs to be sieved and washed.		No.

[2] Base course for seal roads

18.2 APPENDIX 2

18.2.1 Better Control of Compaction

To be used whenever pavement material is to be imported, spread, watered and compacted (for all roadwork including Island Based Contracts (IBC's), National Competitive Bidding (NCB) and Force Account (FA)).

18.2.1.1 *Work Specification*

(If applicable, ensure to include the following requirement in the existing Work Specification)

- Gravel and gravel source to be approved by the supervisor prior to spreading.
- Gravel must be free of particles larger than 50 mm (remove or crush oversize).
- Spread uniformly at the required thickness (+25 to 35% before compaction) and ensure there is no segregation.
- Evaluate the initial moisture content of the material and select the amount of water to add per square metre (m^2).
- Water the material to its Optimum Moisture Content (OMC) before compacting.
- Compact with at least 8 passes by an approved compactor equipment or until no roller imprint on the surface can be recognised.

18.2.1.2 *Quality Control*

Test / Check	Measure	Method	Frequency	Tolerance
Gravel source approved	Quarry Permit required	Check document	Each source	N/A
Gravel material approved	Max. 50 mm	Visual (or sieve or tape)	Each day	± 5 mm
Spread uniformly, no segregation	N/A	Visual	All	N/A
Thickness of the layer	As required	Tape / gauge	Each 20 m or each spot	± 10 mm
Evaluate initial moisture content	N/A	Hand test, hydrometer, speedy	Every 10 -15 m or at least 3 location	± 2 %
Add water to OMC [1]	Amount of water needed per m^2	Tape, volume of water	Each section	N/A
Compact gently with no vibration	N/A	Visual	All	N/A
Leave it for 2-3 h	2 - 3 h	Time	Each section	_
Ensure material at OMC	Target OMC 8-11 %	Hand test, hydrometer, speedy	Every 10 -15 m or at least 3 locations	± 2 %
Compact with roller vibrating	8-10 passes or to refusal [2]	Visual count, check imprints of roller	All	N/A

[1] Check initial moisture and add amount needed to reach 12% if dry and sunny weather (10% if wet and cloudy weather)

[2] Compaction to refusal is when the roller leaves no more imprints on the material.

Table 24 Quality control checks

Water to add to the granular material to bring the moisture at its optimum for compaction (addition in litre of water per square metre – L / m^2)

Target Moisture: 12% (Dry and sunny weather)

Initial state	Increase in MC	Thickness of the layer to compact (mm)				
		50	75	100	125	150
Dry (2 %)	+ 10	10	15	20	25	30
Slightly Moist (5 %)	+ 7	7	10.5	14	17.5	21
Moist (8 %)	+ 4	4	6	8	10	12

Target Moisture: 10% (Wet and cloudy weather)

Initial state	Increase in MC	Thickness of the layer to compact (mm)				
		50	75	100	125	150
Dry (2 %)	+ 8	8	12	16	20	24
Slightly Moist (5 %)	+ 5	5	7.5	10	12.5	15
Moist (8 %)	+ 2	2	3	4	5	6

Table 25 Moisture test targets

18.3 APPENDIX 3

18.3.1 Possible Methods to Evaluate Moisture Content of Materials on Site

It is very important to ensure that the material is close to its Optimum Moisture Content (OMC) when compacting on site. Therefore, simple methods are proposed below.

Method	Pros	Cons	Note
Sampling and lab test	Accurate	Takes too long. No facilities on outer islands.	
Moisture Roll Meter (Speedy)	Accuracy ± 1%; fast on-site result (10 min); fairly easy to use (1 h training)	Need to manage equipment and supply of reagent powder. Some cost.	1
Agricultural Moisture Meter	Easy and fast. Direct reading	Accuracy and durability unknown. Cost unknown.	2
Hand squeeze test	Fast and no cost.	Not accurate. Very subjective.	3

Table 26 Evaluate moisture content

1. Four Moisture Roll Meters were bought during VTSSP Phase 1. Reagent lost. Needs to be supplied.
2. More research should be done regarding this method. Could be promising.
3. Experience and much "calibration" with known moisture content to ensure reasonable estimates. Also depends greatly on the fines content.

Out of these methods, the **Moisture Roll Meter** has proven its efficiency and its use is recommended.

However, an interesting suggestion to use an **Agricultural Moisture Meter** came late in the study. Considering the low cost and simplicity of the equipment, this method would definitely need further research.

18.4 APPENDIX 4

18.4.1 Better Control of Concrete

To be used for all roadwork including IBC, NCB and Force Account.

18.4.1.1 *Work Specification*

(Ensure to include the following requirement in the existing Work Specification)

- Sand for concrete mixing shall be clean river/beach sand free from dust, salt, lumps, soft or flaky particles or organic material.
- Aggregates shall be well graded and free from organic material and salt.
- Water shall be clean, free of oil, free of salt and shall not contain any impurity that may affect concrete durability.
- The water / cement ratio shall not be more than 0.5.
- Compact of vibrate concrete (care must be taken regarding segregation).
- Cast elements shall be protected from direct sunshine for 14 days.
- Concrete slabs and walls crowns shall be kept wet for 7 days.
- No concrete shall be cast unless the formwork, reinforcement and hard-core bed have been checked and approved by the Supervisor.

Test / Check	Measure	Method	Frequency	Tolerance
Sand and Gravel/Coral source approved	Quarry Permits required	Check document	Each source	N/A
Sand material approved	5 mm	Visual (or sieve)	Each day	N/A
Gravel/Coral material approved	5 – 20 mm (unless instructed)	Visual (or sieve or tape)	Each day	+ 5 mm
Compliance with mix design[1]	Quantity	Visual	Each batch	N/A
Water/cement ratio	Max 0.5	Check	Each batch	
Time of mixing	2 min	Watch	Each batch	
Time for pouring	45 min	Watch	Each batch	+10 min
Workability (if required)	Normally 80-100 mm	Slump cone	As required	-
No segregation	N/A	Visual	All	N/A
Time for wet curing	7 days	Visual	Daily	N/A
Quality of cast concrete	No honey combs / no cracks	Visual	All	N/A
Concrete strength evaluation	As specified, 15, 20 or 25MPa	Schmidt Hammer	When needed	

[1] Unless otherwise specified, Concrete Mix by volume should be as follow

- Class 10 MPa: 1:4:4
- Class 15 MPa: 1:3:6
- Class 20 MPa: 1:2:4
- Class 25 MPa: 1:1.5:2.5

Table 27 Requirement for concrete mix

18.5 APPENDIX 5

18.5.1 Quarry Materials Process Options

Pavement material is actually the principal material extracted from quarries on outer islands. It has to be processed as the material should be free from particles bigger than 50 mm. This is addressed in options 1 and 2.

Concrete aggregates and cobbles come naturally from sources like beaches and streambeds. This type of extraction is not well accepted from an environmental point of view and therefore, opportunity to extract them from a coronous/scoria quarry need to be evaluated. In addition, from an environmental point of view, some islands may not agree to remove beach/stream material.

Therefore, technical options are given below. However, all islands would need a small-scale operation, which can be itinerant between islands. An economic evaluation will be essential to complete the study.

Size Definition

mm	0.005	0.075	4.75	76	300
CLAY	SILT	SAND	GRAVEL	COBBLE	BOULDER

Range of Material Size Needed

Pavement materials	Max. 50 mm
Concrete aggregates: min 5 / max 20 mm.	5-20
Cobbles for gabion: min 100 mm / max 250 mm.	100-250
Cobbles for grouted stone: min 150 mm / max 450 mm.	150-450

Table 28 Size definition of material

Option	Process	Local work	Machinery	Issues
1	- Try to remove > 50 mm as much as possible with the excavator. - Remove more > 50 mm with people when stockpiling. - When reloading, remove bigger pieces. - On site, have site workers remove big pieces before compacting.	Give work to 2 MD/100m^3. Removing big pieces on 50 m^3 / d Pavement material only, Ø < 50 mm	Use of excavator or loader. Move only once	Unused material > 50 mm (waste)
2	- Try to remove > 50 mm as much as possible with the excavator - Pass material through a grizzly (wire screen used to separate larger from smaller) (50 mm) - Stockpile	No manual workers Pavement material only, Ø < 50 mm	Use of excavator or loader. Move twice	Unused material > 50 mm (waste)
3	- Try to remove > 50 mm as much as possible with the excavator. - Pass material onto a double grizzly if possible (200 and 50mm) - Stockpile < 50 mm - Have workers manually crush gravel 50-100mm to incorporate onto pavement material < 50 mm - Stockpile the rest 100-200 for gabion/grouted stone, etc.	Give work to 75 MD/100m^3. Crushing 0.75 m^3/d. - Pavement material, Ø < 50 mm + - Cobble 100 – 200 mm	Use of excavator or loader. Move twice for pavement/cobbles.	Unused material > 200 mm (waste)
4	- Could sieve natural material to get the pavement material. - The oversize material can be crushed manually or with crusher to make concrete aggregates.	- Pavement material < 50 mm +		
5	- Use of big sieve or grizzly.	- Coarse concrete aggregates 5 -20 + - Cobble 100-200		

Grizzly can be bought for a few hundred thousand Vatu or can be homemade. Small crusher on tracks worth around UD$80,000 (less if not on tracks)

Table 29 Process of gravel selection

Further technical and economical research needs to be done of various options available.

1

2

3

4

Figure 52 Pictures from various worksites

1. Grizzly bar; 2. Sorting gravel; 3. Shifting gravel with an excavator; 4. Gravel sieve

PART C - Screening Infrastructure for Climate Resilience

19 Vulnerability Screening and Mitigation Measures for Coastal Roads

Roads in close proximity to the sea are generally associated with greater risks of degradation caused by adverse weather events, such as wave overtopping and erosion. During the design phase, special attention must be paid to identify and mitigate these potential hazards. General guidance on this process is provided below and within the flowchart below (*Figure 57*).

Identification:

a) Danger of wave overtopping
- Road located within 50 m of coastline - slightly vulnerable.
- Road within 20 m of coastline - moderately vulnerable.
- Road within 10 m of coastline - highly vulnerable.

b) Danger of erosion: visual evidence of beach retreat / sea advance
- Loss of trees.
- Tree stumps in sea.
- Interview local residents. Ask about situation 10, 20 years ago.

Figure 53 Evidence of coastal erosion

Although coastal erosion is not necessarily attributable to climate change, it makes coastlines more vulnerable to sea level rise and wave overtopping.

Figure 54 Wave run up and over topping

Mitigation:

- Realign inshore. Do not make minor re-alignments for example 10 m. Make major move, 100 - 200m inland.
- Raise road height above level of inundation by at least 0.5 m.
- If road raised on embankment, incorporate pipe culverts for cross drainage to allow water drainage back to sea.
- Provide beach protection. Place boulders, wire mesh gabions, or textile mesh gabions to form seawall on beach side of road. Provide concrete vertical seawall if funds allow.
- Select alignment to exploit natural protection such as mangroves.
- Check local residents are not removing mangroves for other purposes.
- Determine Highest Astronomical Tide (HAT) from hydrographic charts, tide tables for nearest port or highest high tide recorded.
- Check for tide gauge on wharf.
- For projections 50 years into future; assume SLR = 0.5m.
- Set freeboard (height above sea level) at 0.5 m.
- Take HAT + SLR + 0.5 as height of upper surface of platform.

Figure 55 Wharf with low freeboard at high tide

Figure 56 Tide gauge

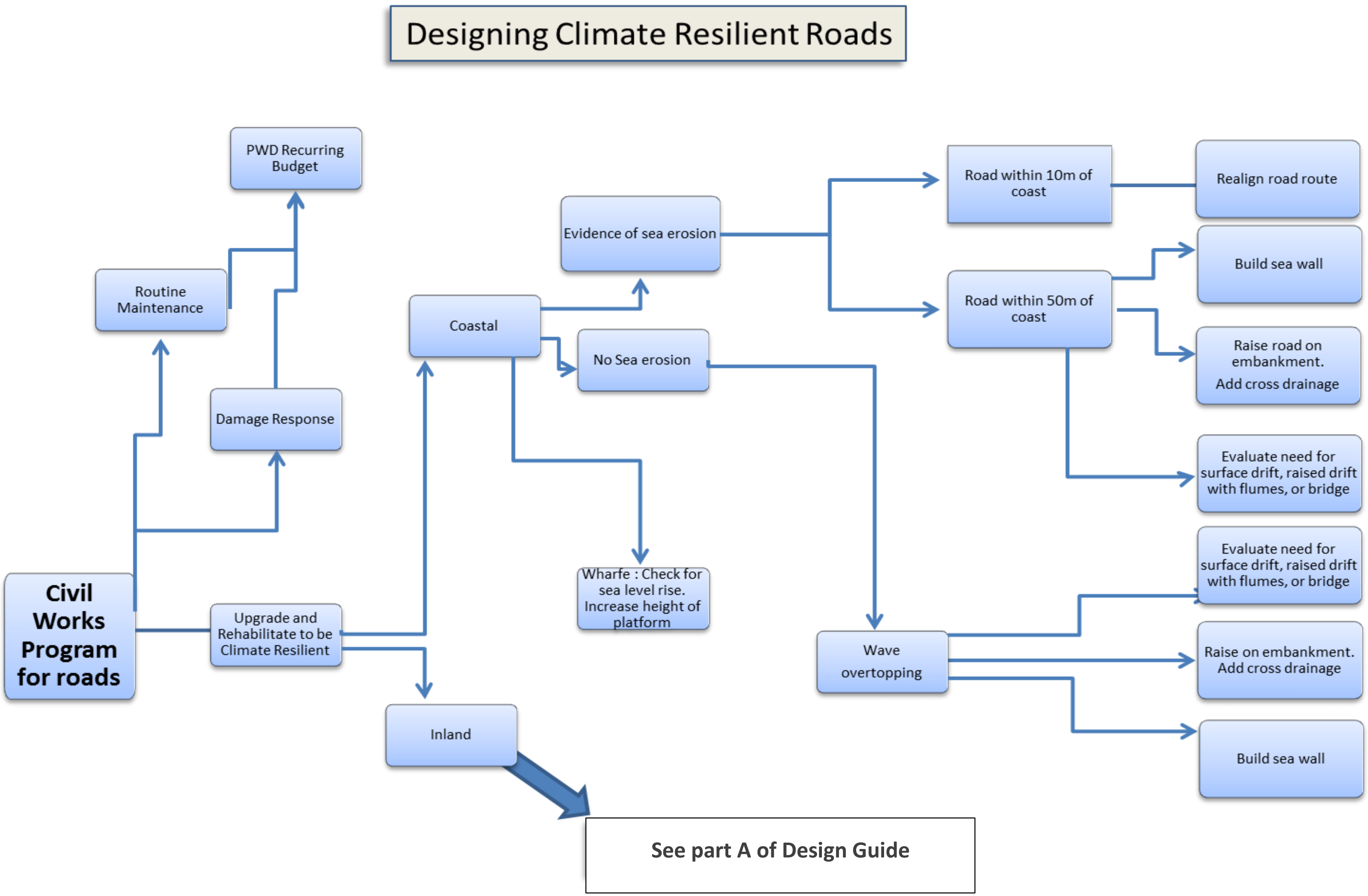


Figure 57 Designing climate resilient roads