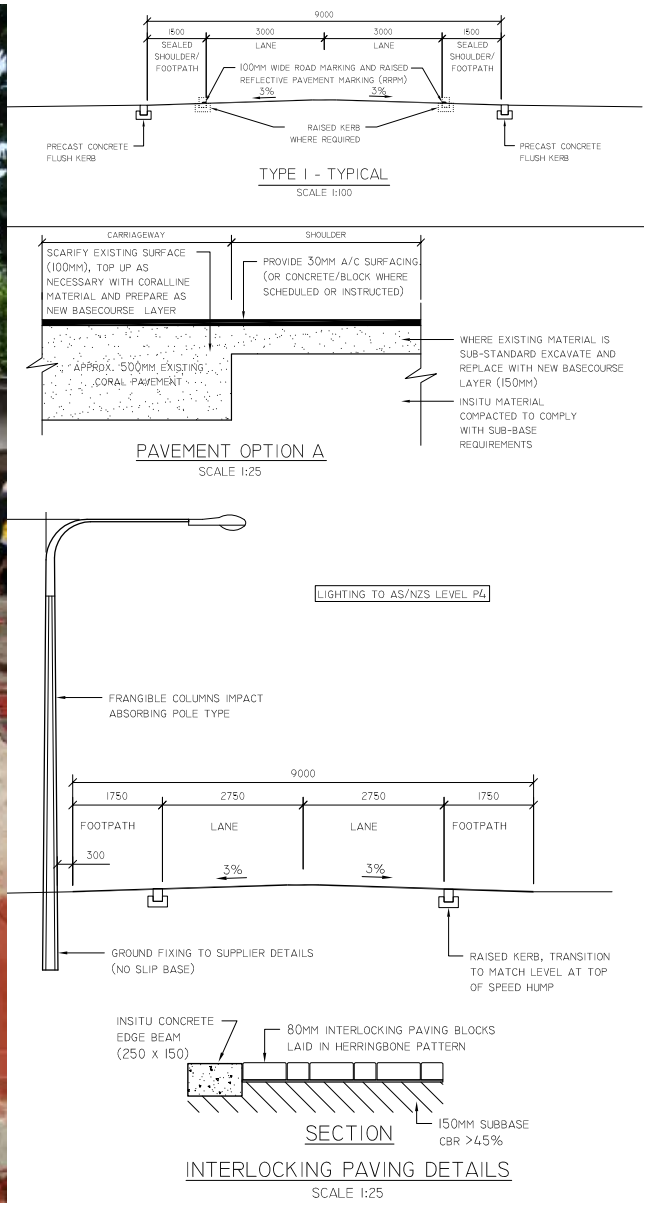
Road Pavement Design for the Pacific Region

Desk Research on the Use of Locally Available Materials



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List of Key Acronyms

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphaltic Concrete
ADB	Asian Development Bank
ASANRA	Association of Southern African National Roads Agencies
BS	British Standard
BB	Benkelman Beam
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DESA	Design Equivalent Standard Axle
DFAT	Department of Foreign Affairs and Trade (Australia)
DN	Penetration of Cone Penetrometer (in mm/blow)
EEZ	Exclusive Economic Zones
EIB	European Investment Bank
ESA	Equivalent Standard Axle
EU	European Union
FSM	Federated States of Micronesia
FWD	Falling Weight Deflectometer
HCV	Heavy Commercial Vehicle
IFC	International Finance Corporation
ITS	Indirect Tensile Strength
JICA	Japan International Cooperation Agency
JMF	Job Mix Formula
LSD	Layer Strength Diagram
LVCR	Low Volume Commercial Road
LVUR	Low Volume Unsealed Road
LVVR	Low Volume Vulnerable Road
MESA	Million ESA
NZMFAT	New Zealand Ministry of Foreign Affairs and Trade
NZTA	New Zealand Transport Agency
OPC	Ordinary Portland Cement
PAIP	Pacific Aviation Investment Program
PCO	PRIF Coordination Office
PI	Plasticity Index
PICs	Pacific Island Countries
PNG	Papua New Guinea
PRIF	Pacific Region Infrastructure Facility
RCC	Roller Compacted Concrete
RLT	Repeat Load Triaxial
RMI	Republic of the Marshall Islands
RN	Road Note
SN	Structural Number
TSWG	Transport Sector Working Group (PRIF)
UCS	Unconfined Compression Strength
UFC	United Facilities Criteria
US (or USA)	United States (of America)
vpd	Vehicles per day
WWII	World War Two (1939 to 1945)

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Executive Summary

The objective of this study is to investigate options to engineer the use of locally available pavement materials to improve pavement quality, resilience and sustainability and to reduce the overall whole-of-life cost of road construction and maintenance. This report represents the desk research phase of the study. It was requested through the Transport Sector Working Group within the Pacific Region Infrastructure Facility (PRIF) and managed by the PRIF Coordination Office. The report explores the extent to which locally available pavement materials can be used to construct resilient low-volume roads. It also sets out factors to ensure success, which include ongoing training and support, coupled with use of appropriately-scaled and resourced pavement investigation, design, material supply and processing; sound road construction practices; and knowledge of local materials and their applicability and limitations.

The locally available pavement materials used in road pavements in the Pacific region are largely sourced from coralline or igneous rocks. Countries where the central volcanic core remains (e.g. Fiji and Papua New Guinea) have access to inland and coastal igneous rock formations, with associated residual or tropical soil intrusions. Inland coronus reserves, coral and coral sand from the adjoining reef also contribute to the pavement aggregate options. In such countries, which are typically not low-lying, access to fresh water supply also enables more conventional earthworks engineering processes to be used.

Smaller low-lying island countries e.g. Kiribati and the Republic of the Marshall Islands often retain only the coastal coral reserves and, given concerns about environmental sustainability, probably only the coralline sand (cascajo) deposits inside the reef itself. Here access to fresh water is limited, so construction with salt water is more likely. Experience dating from World War II has shown that pavement construction using coralline materials with salt water can provide some benefits, assisting with self-cementation of the compacted coral aggregate. Investigations of failing airfield pavements sections have shown that the failure can be confined to the more recent overlying asphalt bound surfacing, and not the underlying, more resilient coral-based pavement layers.

The pavement design and construction principles used around the Pacific study area vary, and appear from anecdotal evidence to be largely based on recognised, published empirical methods including some local country-based variations. To be successful, whichever design and construction method is used, the pavement designer needs access to relevant and accurate information about future traffic loading, in-situ foundation conditions and material characterisations, and environmental constraints. Questions about pavement project reliability should be raised first with the pavement owner, because reliability, cost and the importance of the project in the wider context (e.g. small local road versus main highway) sometimes need to be traded off to achieve the best for project outcomes.

Pavement aggregate stabilisation is a proven technique around the Pacific region. The improvements in pavement layer stability, strength and load bearing capacity can be utilised from the subgrade up, throughout the pavement structure.

On low-lying coral atolls, cement, foamed or emulsified bitumen or cement/polymer stabilisation would appear better suited to the sand grained, unprocessed and compacted coral reef aggregate materials. Self-cementation in constructed coral aggregate roads is a recognised, beneficial outcome, with proven and tangible pavement performance benefits in low volume sealed and unsealed roads.

For road aggregates prepared from volcanic source rock, or weathered inland coronus deposits, lime and cement stabilisation would help to mitigate the adverse effects of high plasticity, water sensitivity, and high natural water contents.

Generally aggregate stabilisation with cement and/or foamed bitumen can be used with both volcanic and coronus materials to successfully mitigate the adverse effects of plasticity and enhance layer strength and load bearing capacity, provided that when a bound or lightly bound layer is prepared that the potential adverse effects of cracking are considered and proactively managed.

Pavement aggregate materials processed using local coralline or volcanic sources and added to using recycled material from other waste streams (e.g. recycled crushed glass, tyres or plastic for example), with or without existing or new polymer or other additives, presents an opportunity. The economics of using waste material need to be carefully considered, taking into consideration the whole-of-life costs of sourcing aggregate, especially the cost of collection, storage processing and transport. Small island states will probably not generate enough waste glass, used tyres and plastics on their own, except perhaps in one-off project situations. This raises the opportunity perhaps for wider regional collaboration.

All the options described above are technically feasible in the Pacific region. However, investigations in this study indicate that, whilst larger one-off capital projects may justify the establishment of external plant, resources and even materials, what is needed at a country level is appropriately trained and resourced local contractors, staffed by people who understand what can be achieved with local materials, with or without modification. With this knowledge, local contractors may be more credible and competitive when bidding for pavement construction and rehabilitation works across the region, thereby improving local productivity and, ultimately, supporting poverty reduction.

The study focuses on effective use of local materials and resources for improvement of low volume roads (both unsealed and sealed). However, it is stressed that while the use of more robust, cost effective and stable materials is important, proper asset maintenance is also needed to minimise whole-of-life costs and ensure sustainability.

The use of proven modifiers/stabilisers (lime/cement) with existing coral or volcanic source aggregates, and suitable in-country waste stream materials, by means of simple, repeatable production and construction techniques, appears to offer exciting opportunities, provided that the wider economics associated with collection, processing and utilisation of locally available aggregate materials incorporating such materials are understood. This would include understanding of the fixed and/or mobile plant needs to process aggregate materials, and the longer term plant and pavement maintenance expectations.

The ideas presented in this report require corroboration from in-field trials and performance monitoring to determine the long-term sustainability of the pavements. The resulting information database containing relevant feedback on processes and costs that can be linked to ongoing project performance reviews will enable local engineers to reasonably evaluate material and design options, and to develop and implement ongoing country-based training and support for pavement design and maintenance.

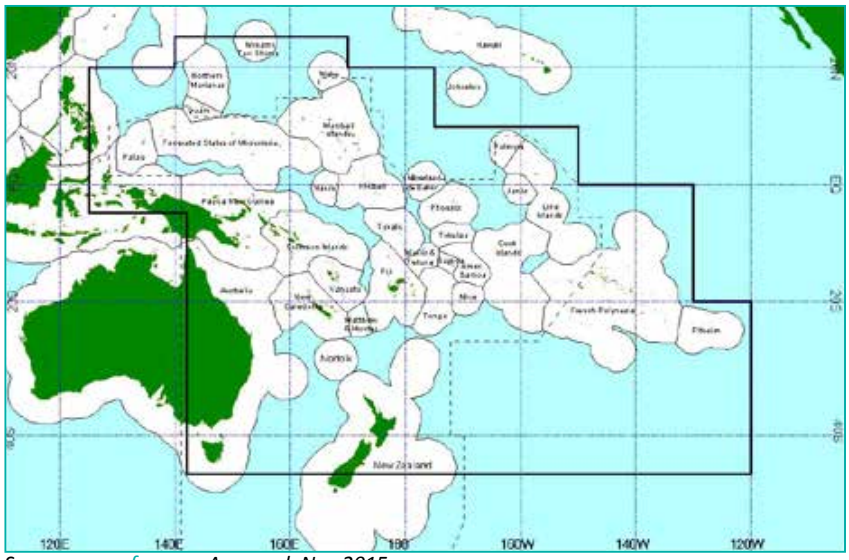
1 Introduction

1.1 Background

This study was proposed by the Transport Sector Working Group (TSWG) in the Pacific Region Infrastructure Facility (PRIF)[1]. It is being managed by the PRIF Coordination Office (PCO) and consists of two phases: a research phase and a trial phase (still to be confirmed).

The study is designed to investigate options to engineer the use of locally available pavement materials to improve pavement quality, resilience and sustainability and to reduce the overall whole-of-life cost of road construction and maintenance. The context is the Pacific Island Countries (PICs) in which PRIF operates[2]. The location of these countries, and their geographic and Exclusive Economic Zones (EEZ) settings within the wider Pacific Ocean are depicted in Figure 1.

Figure 1. Pacific Islands: Geographic and Exclusive Economic Zones[3]



Source: www.fao.org; Accessed: Nov 2015.

1 The PRIF Partners include the Asian Development Bank (ADB), Australian Department of Foreign Affairs and Trade (DFAT), the European Union and European Investment Bank (EU/EIB), Japan International Cooperation Agency (JICA), New Zealand Ministry of Foreign Affairs and Trade (NZMFAT), and the World Bank Group including the International Finance Corporation (IFC).

2 At present these are: the Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Nauru, Niue, Palau, Republic of the Marshall Islands (RMI), Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu, with monitoring for Papua New Guinea (PNG) and Timor-Leste.

3 The source for all Figures and Tables in this report is Opus NZ unless indicated otherwise.

1.2 Scope of Overall Study

This report has been developed during the research phase of the study. It brings together contemporary global research about a variety of pavement design and material options available to PRIF agencies working in the Pacific, including the potential use of pavement construction additives that can be reasonably sourced in the region and are appropriate for application in the Pacific context[4]. The use of in-country waste stream materials (e.g. recycled glass or crumbed tyre rubber) have been considered as an additive to support granular stabilisation. In addition, when comparing the whole-of-life costs of various pavement rehabilitation opportunities, a number of issues have been taken into account, including:

- logistics and likely costs associated with contractor, plant and material establishment
- future maintenance needs of the rehabilitated pavement, and
- what equipment is required to support future rehabilitation and maintenance works.

Even so, while these latter points are mentioned in general terms in this report, they will also be developed further during the remainder of the study. This may involve Net Present Value analysis, using likely unit rate/quantity construction cost profiles, agreed discount factors and supporting information to enable in-country engineers to make informed decisions. A field trial (or trials) will be proposed, with implementation likely to occur during 2016 and 2017.

This report is being released as a knowledge product for engineers and project managers to refer to, as needed, in conducting design and construction work in the Pacific. Further reports will also be prepared during the remainder of the study.

1.3 Structure of Report

The report addresses four topic areas in regard to locally available material for pavements:

- geological setting in the PICs
- aggregate materials in use in the Pacific
- specifications and standards in use, and
- aggregate stabilisation.

Each topic area is discussed in separate sections of the report. The material is broad-ranging in parts, whilst remaining 'on topic' technically. At the end of each section, a conclusion considers how the findings could be relevant to the current and future use of locally available aggregate materials. A list of references is at the back of the report.

1.4 Application of Report Findings

Given the nature of the overall study, it is not expected that all the issues will be applicable to future use of locally available aggregate materials in the Pacific. For example, when discussing pavement design standards (Section 4), applicable engineering test methods that could be used to define pavement material properties may not all be suitable for use in the Pacific region under current conditions. Also, the scale of plant and materials needed to undertake large-scale pavement aggregate stabilisation projects in an established PIC with access to a range of aggregate and recycling sources may not be applicable to a smaller, atoll-based island state, or for use on low volume roads. Where possible, suitable applications and solutions are identified that are feasible for a range of countries.

4 The principles of pavement investigation, design and construction described herein could be applied in other pavement infrastructure areas (e.g. airports and ports) with appropriate consideration of design traffic loads, load configurations, in service stress and strain conditions and surfacing requirements.

2 Geological Setting in the Pacific Context

2.1 Introduction

The Pacific is the world's largest ocean, representing about 20% of the Earth's surface area.

The Pacific Basin landforms are geologically young features. The margins of the basin are characterised by deep ocean trenches with their associated tectonic activity. The ocean basin floor also contains broad topographic 'swells' above the surrounding sea floor and is accentuated by volcanic structures, many of which rise above sea level, part of the so-called 'Pacific Ring of Fire'. Elsewhere, low-lying atolls (the eroded remnants of previous volcanic structures) are characterised by both dead and living coral formations.

Research shows that the location and geological makeup of the individual countries affects what and how locally available aggregate materials are, or could be, used.

2.2 Pacific Island Physical Environment Profiles

2.2.1 Introduction

A description of how geography and geology affects pavement material supply for each of the countries follows and is summarised here in Table 1.

Table 1. Expected Local Aggregate Options in Pacific Islands

Country	Coral Aggregate	Coronus Aggregate	Volcanic Aggregate
Cook Islands	✓	✓	✓
FSM	✓	✓	✓
Fiji Islands	✓	✓	✓
Kiribati	✓	✗	✗
Nauru	✓	✓	✗
Niue	✓	✓	✓
Palau	✓	✗	✓
PNG	✓	✓	✓
RMI	✓	✗	✗

Country	Coral Aggregate	Coronus Aggregate	Volcanic Aggregate
Samoa	✓	✓	✓
Solomon Islands	✓	✓	✓
Timor-Leste	✓	×	✓
Tonga	✓	✓	✓
Tuvalu	✓	×	×
Vanuatu	✓	✓	✓

Source: Lal & Fortune (Eds.), 2000.

2.2.2 Cook Islands

Located in the central southern Pacific, the Cook Islands form two distinct geographic groups. In the north are six coral atolls, while the southern islands are mostly of volcanic origin, usually with distinct central cores. Most have an elevated coral reef platform adjacent to the coast as well as recent coral reefs. The maximum height above sea level is 652 metres.

2.2.3 Federated States of Micronesia

Located in the west central Pacific, FSM comprises more than 600 tiny islands and atolls. There is a mixture of mountainous islands of volcanic origin, low coral atolls and isolated reefs. The maximum height above sea level is 751 metres.

2.2.4 Fiji Islands

Located in the central Pacific, Fiji comprises more than 320 islands, islets and reefs. The two main islands and many of the others are of volcanic origin. They are ruggedly mountainous with limited alluvial plains, uplifted limestone and raised shorelines, and extensive coral reefs in shallow areas. The maximum height above sea level is 1324 metres.

2.2.5 Kiribati

Kiribati comprises three island groups, which lie across the equator. Apart from Banaba, which rises to 80 metres above sea level, the islands are low-lying coral atolls often enclosing a central lagoon. The thin layer of sandy coral supports only sparse vegetation. The maximum height above sea level for most of the islands is only two metres and, therefore, Kiribati is one of the lowest-lying countries in the Pacific.

2.2.6 Nauru

A single island in the southern Pacific Ocean, Nauru is an uplifted coral limestone atoll, with a terraced rim containing caves and sinkholes, and an inland plateau of phosphate bearing rock. The maximum height above sea level is 70 metres.

2.2.7 Niue

A raised atoll southeast of Samoa, with its former reef and lagoon uplifted to about 60 metres above sea level. The central plateau in the middle of the island is edged with steep slopes. A coral reef fringes parts of the coastline. The maximum height above sea level is 68 metres.

2.2.8 Palau

Palau is an archipelago of about 340 islands in the North West Pacific. Only nine of them are inhabited. There are two volcanic islands with high centres but most of the remaining islands are raised coral atolls. The maximum height above sea level is 214 metres.

2.2.9 Papua New Guinea

Located just below the equator in the western South Pacific, PNG has 600 islands and coral atolls which are mostly of younger volcanic origin, but the mainland is a massive rugged cordillera (the Central Highlands) with wide and very fertile alpine valleys, and ice-capped peaks. There are at least 100 volcanoes, with 14 of them still active. The maximum height above sea level is 4697 metres at Mount Wilhelm.

2.2.10 Republic of the Marshall Islands

RMI consists of scattered, low-lying coral atolls forming the eastern-most group of the Micronesian archipelago. Some atolls enclose very large lagoons. Reference literature refers to the maximum height above sea level being somewhere between three to 10 metres so it is low-lying and considered vulnerable to rising sea levels.

2.2.11 Samoa

Located to the west of American Samoa, Samoa has two large islands and six smaller islets formed from volcanic cones, with several peaks and deeply eroded canyons. Coastal beaches ring the main islands. The maximum height above sea level is 1860 metres.

2.2.12 Solomon Islands

Located southeast of Bougainville (in PNG), the Solomon Islands are a series of high, rugged islands located along a northwest/southeast trending fault system, with some raised coral reefs. Soils range from extremely rich volcanic soils to relatively infertile coral limestone. The maximum height above sea level is 2447 metres.

2.2.13 Timor- Leste

Timor-Leste is part of the island of Timor, the largest and eastern-most of the Lesser Sunda Islands. Most of the country is mountainous. The climate is tropical and generally hot and humid. The maximum height above sea level is 2963 metres.

2.2.14 Tonga

Tonga comprises 169 islands in an archipelago in two almost parallel chains. The eastern islands consist of low coral islands with a covering of volcanic ash. The western islands consist of tall, recently formed volcanic islands. The maximum height above sea level is 1030 metres.

2.2.15 Tuvalu

Located north of Fiji, the islands and atolls of Tuvalu are of coral formation. Tuvalu is a low-lying country located south of the Equator, with a maximum height above sea level of five metres.

2.2.16 Vanuatu

The young volcanic islands of Vanuatu, some of which are still active, were formed from belts of older sedimentary rock that were repeatedly uplifted. The maximum height above sea level is 1877 metres.

2.3 Geological Influence on Pavement Aggregates

2.3.1 Introduction

The pavement materials discussed in this report are generally one, or a combination of:

- igneous rock, combined with tropical and residual soils, and/or
- coralline material (Bullen, 1984), which refers to material procured from a live or dead offshore reef.

Coralline material can then be subdivided as follows:

- coral – live or dead material from either fringing, barrier or atoll reef formation (Bullen, 1989)
- cascajo (Duke, 1949) – lagoon sediments, talus, incomplete material from associated reef, and
- coronus[5] (Belkum & Djou, 1982) – uplifted coralline deposit (inland limestone).

2.3.2 Igneous Rock, Tropical and Residual Soils

In their paper titled *Effects of Tropical Soils on Palau Airport Design* the authors describe the geology of Palau as being "similar in many respects to the geology of a convergent plate margin…basic characteristics in such a tectonic environment include explosive volcanism; regional uplift of the island producing coralline plateaus hundreds of feet above sea level and the characteristic andesitic composition of the rocks . . . the upper surface soils on Palau are the result of very long periods of weathering . . . the rock is a hard, well-cemented, massive volcanic breccia"[6]. This description is highly relevant to the range of PICs considered in this study.

On Pacific islands where the central volcanic core remains, associated residual soils are silt and sand sized, of varying consistency. Alluvial soils (valley infill washed from the adjoining slopes) may well contain more organic material. High ground water levels, and water infiltration as a result of storm events, are prevalent. Such conditions influence the plasticity levels and water sensitivity in naturally occurring and processed road aggregate.

In Fiji, for example, 'dirty' vesicular basalt breccia is quarried for aggregate and sealing chip. Aggregate and subgrade behaviour is known to be adversely affected by plastic fine soil fractions. The behaviour of these materials is significantly improved by stabilisation. They can be used successfully in road development.

Table 2 compares the behaviours of temperate and residual soils. This is relevant to the discussion about pavement aggregates on Pacific islands, as the residual soil (silt/clay) component of quarried volcanic materials will be influenced more by the residual soil component behaviours.

5 sometimes spelt "coronous"

6 Belkum & Djou. (1982) - Effects of Tropical Soils on Palau Airport Design, p668.

Temperate soils are those found more in central/southern Australia and New Zealand. This distinction is important because the aggregate specifications used in New Zealand and in central and southern States of Australia are more aligned to the temperate environment, and perhaps less suited to the Pacific than the specifications used in Northern Territory, Queensland and northern parts of Western Australia where the tropical soil influence is expected to be more pronounced.

Table 2. Differences between Temperate and Residual Soils

Property	Temperate Sedimentary Soils	Tropical Residually-Weathered Soils
Climate	Temperate to cold	Arid, tropical, warm temperate
Composition	Natural or crushed	Varies from rock to clay
Aggregate	Solid, strong rock	Sometimes porous, weakly cemented fines
Fine-grained Soil Fraction	Rock particles with or without clay	Cemented, coated and aggregated clay and/or silt fines
Clay Minerals	Mostly illite or smectite	Wide variety, e.g. halloysite, attapulgite (palygorskite)
Cement	None (usually)	Iron oxides, aluminium hydroxide, calcium carbonate, etc.
Chemical Reactivity	Inert	Reactive
Particle Size Grading	Stable	Sensitive to drying and working
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering
Consistency Limits	Stable	Sensitive to drying and mixing
Salinity	Non-saline	May be saline
Self-stabilization	Non-self-stabilizing	May be self-stabilizing
Variability	Homogeneous	Extremely variable

Source: Pinard & Netterberg, 2012, p3.

A number of the properties described in Table 2, most notably the expected plasticity in the weathered residual soil component, make these materials more suitable following modification either in-situ or during manufacture, as discussed further in Section 5.

2.3.3 Coralline Materials

Technical papers have been published since World War Two (WWII) about the geological setting and engineering origins of the use of coralline materials. Anecdotal evidence has highlighted the enduring performance of the in-situ coral aggregate materials. The following discussion points outline some useful research findings within the context of this study:

- coral-based materials (organic limestone) have been used extensively for road and pavement construction since the WWII (1939 – 1945) in the Pacific
- during WWII, the coral materials were largely obtained destructively by the combined American forces from the adjoining reef structures and, hence, were less influenced by silt/clay/organic intrusions
- for largely environmental protection and sustainability reasons, coral-based deposits used now are more likely to be inland quarry-based coronus materials, although smaller atoll-based states only have the reef materials and cascajo available to them as naturally-occurring materials
- coral-based materials used as pavement aggregates can be classified as poorer quality according to conventional pavement industry laboratory testing (e.g. crushing strength, weathering index)
- these conventional engineering tests do not, it appears, respond adequately to the self-cementation, improved compacted density, porosity and internal strength observed in practice for well managed coralline aggregate materials
- coralline materials, when used as pavement aggregates, are believed to perform well for low-volume sealed and unsealed roads that have been designed and built to meet the expectations of published empirical design methods
- consultancy work at the Bauerfield Airport in Vanuatu (Opus NZ 2015) suggests that the overlying bitumen bound surfacing is distressed and the coronus base is continuing to provide good support despite its age (circa. 1940s), and
- airport runway investigations in Tonga under the World Bank-financed regional Pacific Aviation Investment Program (PAIP) describe the enduring capability of the coral limestone basecourse materials, provided these are protected from water, noting though that the fine grained nature of some materials could adversely affect within pavement drainage or pore pressure mitigation.

The photographs shown below (Figure 2) give impressions of the construction processes and plant used by the US Navy 'SeaBees' during World War II on roads and large airfields.

Figure 2. Airfield and Road Construction on Pacific Atolls in World War II

Source: www.112thseabees.org and www.classicdozers.wordpress.com; Accessed: Nov 2015.

During this time, the typical extraction of materials was by blasting either from the reef or inland uplift. The material was then picked up and spread, followed by high impact compaction, which resulted in further breakdown of the aggregate material and (by all accounts) contributed to the in-situ density, self-cementation and subsequent durability of the resulting pavement layers.

2.4 Conclusion

The geological setting of the Pacific Island states included in this study influences modern day life and road infrastructure development at the individual country level.

Countries on smaller atolls and smaller isolated islands within larger island states rely on coral or coral-based lagoon sediments as in-situ source materials for engineering works or, alternatively, on imported materials for larger projects.

Coralline material has a proven performance history on sealed and unsealed lower traffic volume roads and in military-based 'hands on' airport pavement construction and maintenance conditions. In the modern day context, greater environmental awareness of the fragile state of the in-situ coralline and cascajo materials, combined with the need for pavements to carry higher traffic volumes and commercial traffic loads means that for some projects imported aggregate materials have been and will be used. Coralline materials remain a credible pavement material source, provided these can be obtained sustainably and they are protected from water by drainage and surfacing.

For the larger islands with residual highlands, the inland coronus and igneous rock materials appear to be used in preference to the environmentally sensitive coralline materials. These are suitable for pavement construction, but require informed consideration of the adverse effects of residual soil plasticity, deleterious materials and strength variability in order to avoid costly, unplanned reactive maintenance.

3 Aggregate Materials in the Pacific

3.1 Introduction

This section of the report considers how pavement aggregates made from locally available materials are likely to perform when used with local pavement design and construction practices.

3.2 Reported Aggregate Behaviour

Bullen[7] reports that pavement aggregate materials must be able to:

- be placed, compacted, and formed to the required condition and shape: ***Workability***
- be available and workable at an acceptable cost: ***Economy***
- resist loads without unacceptable deformation or crushing: ***Strength***
- be unsusceptible to volume changes because of moisture content changes: ***Volume Stability***
- be able to resist erosion, abrasion, and polishing: ***Wear Resistance***.

In the context of road aggregate specifications in current use in Australasia, the understanding of good aggregate behaviour could be expanded as follows:

- ***strength*** – crushing strength of the source stone needs to be sufficiently high to resist uncontrolled breakdown in service, either as a result of load or weathering/abrasion
- ***grading*** – the grading of the processed aggregate needs to support good construction outcomes, and associated benefits as needed such as permeability and stable density
- ***fine fraction stability*** – the processed aggregate needs to have sufficient fine fraction to enhance density and workability, whilst at the same time not exposing the finished aggregate product to risk associated with fine soil plasticity or water sensitivity
- ***crushed faces*** – processed aggregates used as near-surface basecourse materials demonstrate enhanced shear strength when processed with crushed faces
- ***economic sustainability*** – the aggregate materials need to be able to be processed sustainably.

3.3 Reported Aggregate Material Properties

The literature shows that aggregates from either igneous or coralline origins (either naturally or modified) are used in unbound or modified pavement structures throughout the Pacific.

The aggregate material derived primarily from coral sources can deliver a range of performance outcomes.

Table 3 shows the strength properties of coronus materials based on California Bearing Ratio (CBR) at varying compaction levels. The CBR peaks at well over the optimum target of 100%, at an optimum moisture content of 6.8% under modified compaction, and can be expected to perform well in this condition.

7 Bullen, F. (Transportation Research Record 1819). Use of Coral-Derived Aggregates for Construction of Low-Volume Roads, Paper No. LVR8-1115. p1

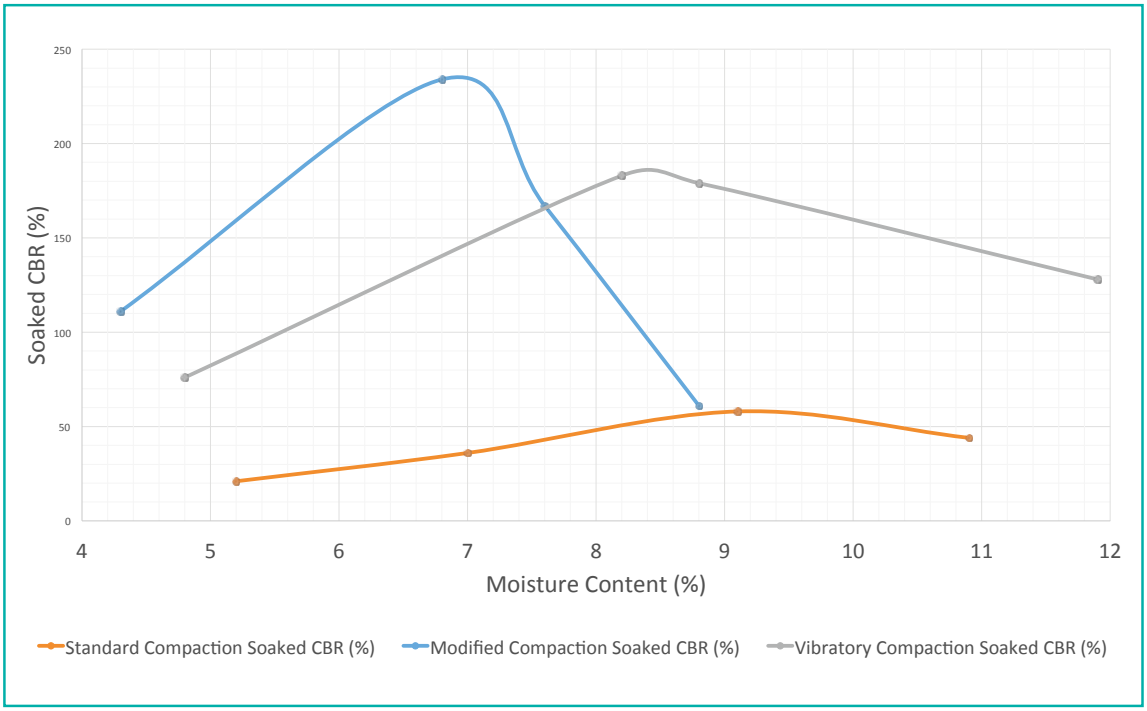
Table 3. Strength Properties (CBR) of Coronus Aggregate Materials

Standard Compaction		Modified Compaction		Vibratory Compaction	
Compaction Moisture	Soaked CBR (%)	Compaction Moisture	Soaked CBR (%)	Compaction Moisture	Soaked CBR (%)
5.2	21	4.3	111	4.8	76
7	36	6.8	234	8.2	183
9.1	58	7.6	167	8.8	179
10.9	44	8.8	61	11.9	128

Source: Bullen, Transportation Research Records 1819, p137.

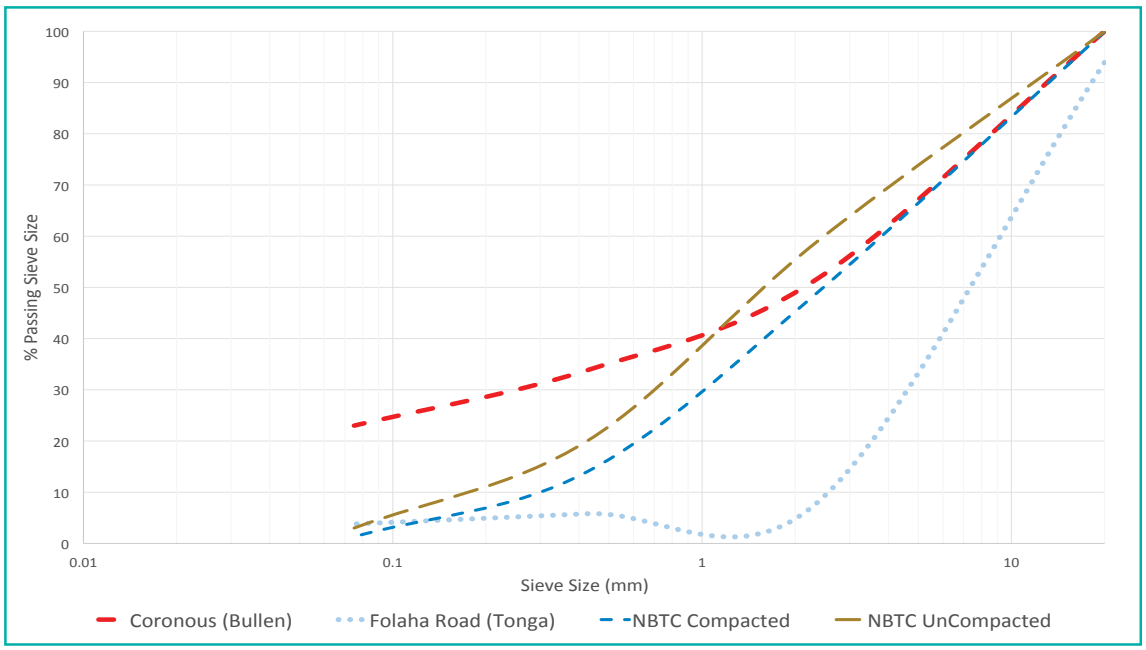
Plotting the results from Table 3 (Figure 3 below) shows that moving from Standard to Modified Compaction results, as expected, in a decrease in apparent optimum moisture content and increase in CBR. Moving then to Vibratory Compaction results in an increase in apparent optimum moisture content and decrease in CBR, probably as a result of accelerated aggregate material breakdown.

Figure 3. Soaked CBR of Coronus Material for Different Compaction Efforts



The particle size grading of coronus materials reportable varies widely and would be influenced by the location of the rock source and the extent of processing/compaction. Four grading results from cited references demonstrate this finding in Figure 4.

Figure 4. Particle Size Grading Comparisons for Coronus Materials



Sources: Bullen, (1984) and National Building Technology Centre (1988).

Fine grained soil property tests for the naturally-occurring coronus materials (Table 4 and Table 5) are indicative of highly variable, source rock location specific, low/moderate to high plasticity levels, and CBR strengths.

Table 4. Fine-Grained Soil Properties from Various Locations Compared with those of Coronus Aggregate

Material Conditions	Liquid Limit (LL) %	Plasticity Index (PI) %	Shrinkage %
Unsealed wearing course, moist temperate and wet tropical	35	4 to 9	2.5 to 5
Seasonal wet tropical	45	15 to 30	8 to 15
Base crushed rock, Queensland Main Roads (QMR)	25	4	-
Average of coronus pits	31	14	>5

Source: Bullen, Transportation Research Record 1819, p136.

Table 5. Various Coronus Aggregate Material Properties

Liquid Limit %	Plasticity Index %	Dry Density (t/m^3)	Max CBR %	Lower Bound CBR %
12 to 56	0 to 29	1.75 to 2.08	20 to 250	17 to 195

Source: Cardno & Davies, 1993.

Volcanic aggregate source materials (e.g. igneous rock such as basalt and andesite) are used for road aggregate production (Tawake, A.K., March 2007; Tawake & Maoate, April 2009). The particle size grading of crushed by products from igneous rock will depend on the quality of the crushing, screening and washing processes used. Whilst the large stone aggregate components can be made up of competent rock, unwashed aggregate materials can contain high quantities of water sensitive finer grained materials (silt and clay). In-situ igneous aggregates can suffer from in-service breakdown and weathering, with the subsequent release of plastic fines. Therefore, the materials properties may well appear similar to those shown in Tables 4 and 5, displaying considerable variability.

3.4 Implications of Using Locally Available Materials in the Pacific

Within the Pacific Islands context, the literature (example evidence shown above) suggests that the implications of using road aggregates made from locally available materials include:

- natural or processed road aggregate materials can be fine grained (maximum stone size less than 20mm)
- plasticity levels in the soil fraction can vary and are expected to be higher in the rock products of inland coronus or igneous rock origin, and following construction (compaction)
- potentially adverse effects of plasticity can be mitigated by stabilisation
- coral-based aggregate products are known to benefit from 'self-cementation' which enhances pavement performance for low volume roads
- coral based aggregates perform well for a long time provided these are kept dry
- volcanic and coronus aggregates can suffer from in-service breakdown and weathering, with the subsequent release of plastic fines
- strength properties (usually measured as soaked CBR) vary significantly, and will again depend on the origin of the rock, the nature and origin of the component soil fractions, and the effects of construction (notably particle breakdown during construction), and
- production and subsequent use of aggregate materials from either principal source (i.e. volcanic or coralline) can be adversely affected by a number of factors including land ownership and access restrictions, quantity and location of source rock, environmental constraints (e.g. access to and use of either live coral beds or cascajo from sensitive or highly visible lagoon areas), material properties of the source rock, finer-grained material intrusions, cost of production, modification and transport, reliability of production (quarrying, crushing, blending), reliability of on-road construction and maintenance, and contractor and operator skill levels and experience.

3.5 Conclusion

The geology of the PICs influences how local pavement aggregate materials are sourced and their production and in-service performance. Whether the pavement aggregate is of coral, coronus or volcanic origin, to perform well under modern road traffic conditions it must combine strength, coarse and fine particle fraction stability, resilience and be reasonably priced.

On the larger islands, where a combination of coral and volcanic materials is available (e.g. Fiji and PNG), the quarrying, crushing and use of local pavement aggregates can be successful if factors are taken into account such as in-service stone breakdown, variable (often plastic) fines, and moisture sensitivity.

On islands where coral rock is the prevalent local aggregate source (e.g. Kiribati, Tuvalu and smaller isolated atolls across the Pacific), the design and construction of successful road pavements will make best use of self-cementing finer aggregates (even sand aggregates) and mitigate the possible adverse effects of aggregate break down during construction and strength loss when wet if it uses robust sealing and drainage methods. The practice of shipping aggregates from countries such as Fiji to other parts of the Pacific may be justified on some of the larger projects; however, on routine road construction and maintenance, this is unlikely and local materials should provide a viable alternative.

Whilst the apparent limitations of locally available materials (as described above) can be daunting, the research in this study shows that these aggregates can be used successfully in the Pacific for both construction and maintenance of pavements – when used in combination with good local pavement design and construction practices – providing that at the individual country level, the local variances in source material properties are well understood and taken into account by means of methods including stabilisation and robust sealing.

4 Specifications and Standards

4.1 Introduction

Within the Pacific study area, research combined with relevant anecdotal evidence shows that the pavement design, material supply and construction specifications used are still largely based on empirical methods. The empirical methods in use include those developed within or by: Road Note (RN) 31, AASHTO, AUSTROADS, and US Army Corps of Engineers. There is also evidence of the use of relevant mechanistic methods: Austroads, AASHTO.

This section of the report considers the relevance of the design and construction specifications and standards in use in the Pacific Islands, as a way to support the effective use of locally available aggregate materials.

4.2 Empirical Methods

4.2.1 Road Note 31

Features of this design method from TRL in the United Kingdom include:

- basis is to limit vertical strains on subgrade, thus control wheel track rutting
- pavement design solutions are derived from charts that assume aggregate materials that are subsequently used within the pavement structure meet prescribed performance targets including strength, grading and plasticity limits
- climate-related deterioration often dominates: drainage, temperature, rainfall, and
- design traffic based on traffic classes, as a function of the number of equivalent standard axles (ESA), up to 30 million ESA (30MESA), as shown in Table 6.

Table 6. Traffic Classes as a Function of Number of MESA

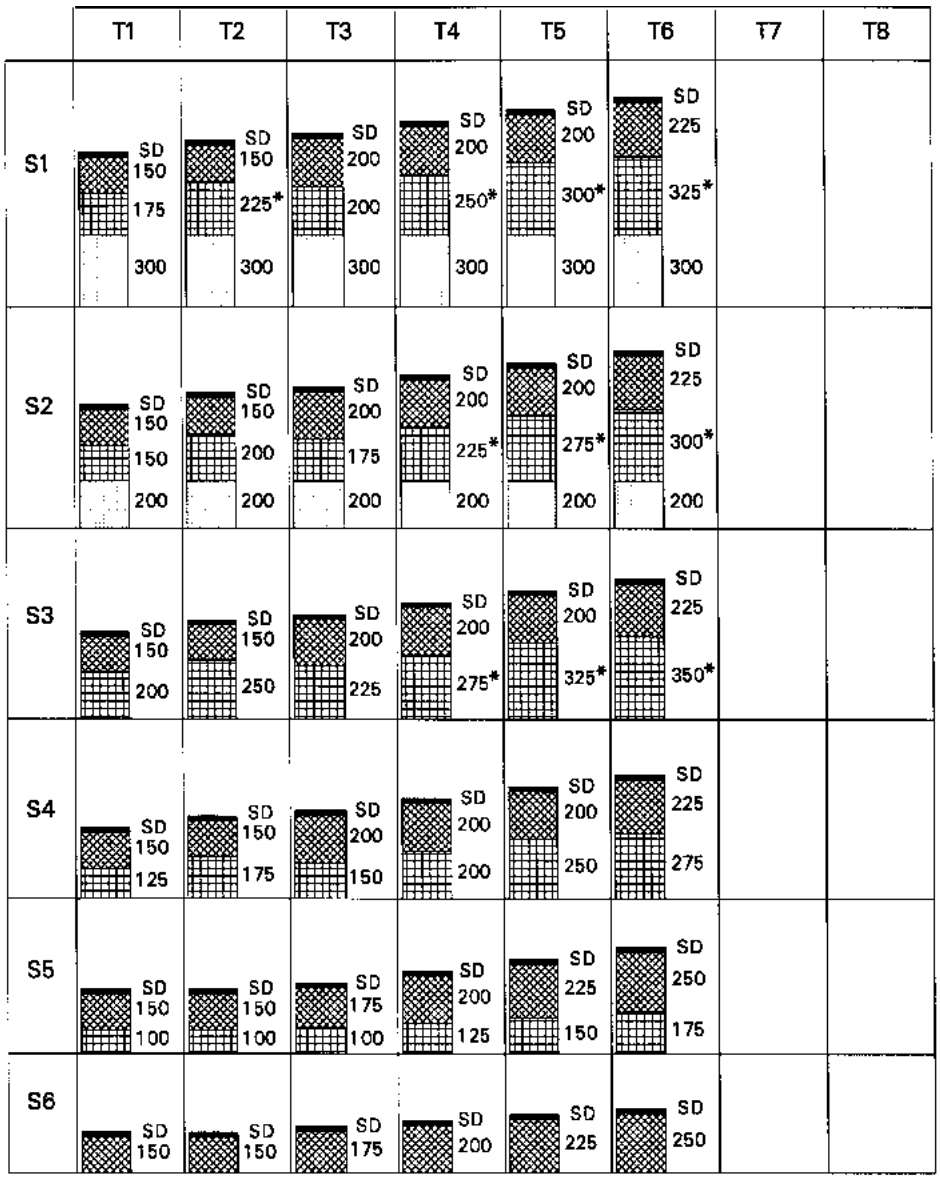
Traffic Classes	Range (MESA)
T1	<0.3
T2	0.3 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30

Source: Transport Research Laboratory, 1993, p9.

Evaluation of traffic loading should then be based on measured annual average daily traffic (AADT), annual growth, design life, percentage of heavy commercial vehicles (HCV) and number of standard axles (8.2 tonne dual tyre single axle) per HCV.

Then a catalogue solution is used to confirm the required pavement layer depths, refer Figure 5.

Figure 5. Catalogue Design for Granular Road Base with Surface Dressing



Source: Transport Research Laboratory, 1993, p53.

The potentially adverse effects of overweight traffic are assessed by converting the movement of an overweight axle to an equivalent number of ESA, using equivalence factors shown in Table 7.

Table 7. Axle Load Equivalence Factors

Wheel Load, Single and Dual (10^3kg)	Axle Load (103kg)	Equivalence Factor
1.5	3	0.01
2.0	4	0.04
2.5	5	0.11
3.0	6	0.25
3.5	7	0.5
4.0	8	0.91
4.5	9	1.55
5.0	10	2.5
5.5	11	3.83
6.0	12	5.67
6.5	13	8.13
7.0	14	11.3
7.5	15	15.5
8.0	16	20.7
8.5	17	27.2
9.0	18	35.2
9.5	19	44.9
10.0	20	56.5

Source: Transport Research Laboratory, 1993, p8.

Pavement overloading is a common occurrence across the Pacific and poses a problem in defining expected traffic to design adequate pavement systems accordingly. With the lack of monitoring and enforcement, it can be difficult to project future traffic loading levels. Anecdotal evidence from current design/ build contracts in Fiji indicates that recent pavement designs for the Fiji Roads Authority are to be based on 16 tonne dual tyre axles loads (compared to the 8.2 tonne standard ESA). On-site weight in motion measurements in Fiji have recorded dual tyre axle loads up to 38 tonnes. Confirmation of project specific design traffic loads is an essential component of successful pavement design. Unplanned overweight traffic will result in accelerated deterioration in most pavement structures utilising locally available aggregates, if they are not designed appropriately.

Relevant World Bank project work (Opus International Consultants, 2012) on pavements in northern India has highlighted the uncertainty often associated with effects of overloaded axles in developing countries and largely agricultural areas, refer Figure 6. In the two vehicles shown the number of equivalent Standard Axles per vehicle (Vehicle Damage Factor, VDF) was unable to be measured at the time, but was evidently very high.

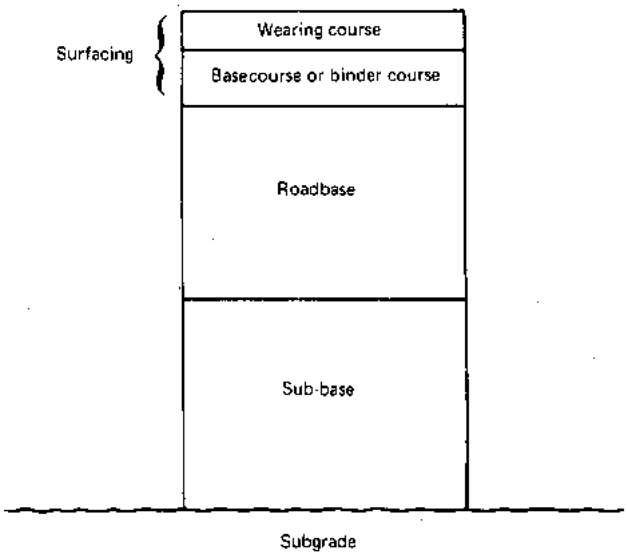
Figure 6. Examples of Overweight Vehicles on Rural Road Network in the Punjab

VDF > 25, aggregate transport

VDF unknown, sugar cane trailer

Key pavement layer descriptions are as shown in Figure 7. This shows the differentiation between the basecourse and roadbase (the top surface layers beneath the seal or wearing course with load bearing capacity and shear strength), the sub-base with load bearing capacity and permeability, and the subgrade, which can also include a subgrade improvement layer.

Figure 7. Definition of Key Pavement Layers



Source: Transport Research Laboratory, 1993, p3.

The desirable material properties of the pavement layers are then in turn prescribed, using conventional fine soil and aggregate test properties including particle size grading, CBR and PI, as shown in Tables 8 and 9.

Table 8. Prescribed Properties of Unbound Aggregate Materials, RN31

Code	Description	Summary of Specification
GB1, A or B	Fresh, crushed rock, gravel or boulders	Dense graded, unweathered crushed stone, non-plastic fines (A) or PI<6 (B)
GB2, A or B	Dry-bound macadam (A) or water-bound macadam (B)	Aggregate properties as for GB1 (B)
GB3	Natural coarsely graded granular material including processed and modified gravels	Dense grading, PI <6 Soaked CBR >80%
GS	Natural gravel	Soaked CBR >30%
GC	Gravel or gravely-soil	Dense graded Soaked CBR >15%

Source: Transport Research Laboratory, 1993, p21.

Table 9. Grading Envelopes for Crushed Stone Roadbase Materials, RN31

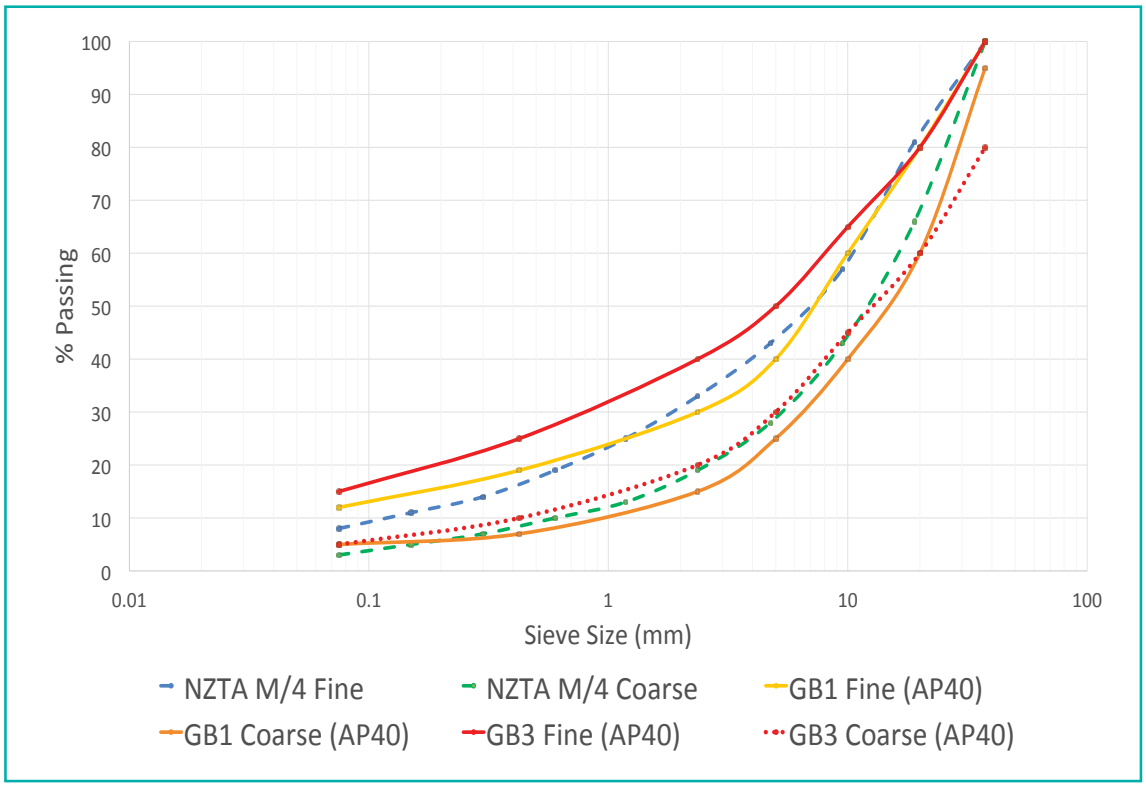
BS test sieve (mm)	GB1 (AP40)	GB3 (AP40)
50	100	100
37.5	95 – 100	80 – 100
20	60 – 80	60 – 80
10	40 – 60	45 – 65
5	25 – 40	30 - 50
2.36	15 – 30	20 - 40
0.425	7 – 19	10 - 25
0.075	5 - 12	5 - 15

Source: Transport Research Laboratory, 1993, pp22 and 24.

Figure 8 compares graphically the specified aggregate grading for the GB1 and GB3 AP40 materials with the NZTA basecourse M/4. Interestingly, as the M/4 specification includes limits on CBR (>80%) and PI (<5%) it aligns it the GB3 material. However, from a grading perspective, the M/4 material has a more closely spaced envelope (i.e. tighter control than either of GB1 or GB3), and permits less fine material passing the 0.075mm sieve. The GB1 and GB3 materials could therefore be more moisture sensitive. Anecdotal evidence from recent Fiji projects on the main island of Viti Levu confirms that mitigation of the moisture sensitivity by stabilisation remains a key factor needed for project success[8].

8 pers. coms. Allen Browne (15th December 2015)

Figure 8. Comparison of Basecourse Grading



Source: Transit New Zealand, 2006 and Transport Research Laboratory, 1993.

RN31 is a credible design method in the Pacific region. In order to deliver successful pavement outcomes, local engineers must have a good understanding of project-specific traffic loadings and the local pavement environment and be confident that the aggregate materials and construction processes will achieve the minimum standards expected by the RN31 method.

4.2.2 AASHTO 1986

The American Association of State Highway and Transportation Officials (AASHTO) design model (AASHTO, 1986) is similar in principal to RN31. Design structure models and design catalogues are used.

In AASHTO the Structural Number (SN) of the pavement is a method of describing the strength of a road pavement, based on the cumulative sum of depth of individual pavement layers (D) and the layer coefficient (a).

The layer coefficients are aligned to elastic (resilient) modulus (E), are assigned to each layer (e.g. asphalt bound and granular layers) and may vary with thickness, underlying support condition and position in the pavement. The derivation of layer coefficients is chart and table based from within the AASHTO guide. The strength of the subgrade is related to subgrade resilient modulus or modulus of subgrade reaction, k. Also included in the AASHTO model are pavement reliability factors, environmental factors and others.

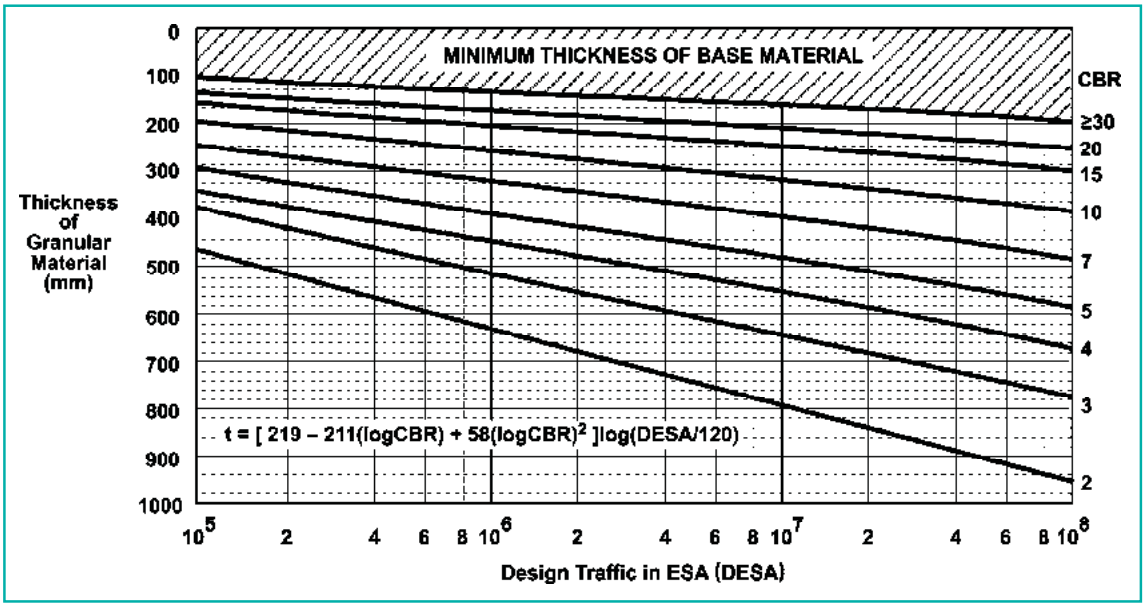
In addition to having a good understanding of project-specific traffic loadings and the local pavement environment, the effective use of the AASHTO method in the Pacific context relies on being able to apply the layer coefficients to the locally available aggregate and subgrade materials. This not only requires local knowledge and experience, but also field and laboratory testing.

4.2.3 Austroads Empirical

The Austroads model (Austroads, 2008) relates the design traffic in equivalent standard axle loads (ESA) to subgrade CBR.

Designers use Figure 9 to determine the minimum depth of unbound pavement required. A minimum thickness of 'premium' base material (AP40 or AP20 basecourse) is required to provide adequate top layer shear strength. Pavement design solutions derived from Figure 9 assume aggregate materials that are subsequently used within the pavement structure meet prescribed source and production property performance targets including strength, grading and plasticity limits.

Figure 9. Design Chart for Granular Pavements with Thin Bituminous Surfacing



Source: Austroads, 2008, p107.

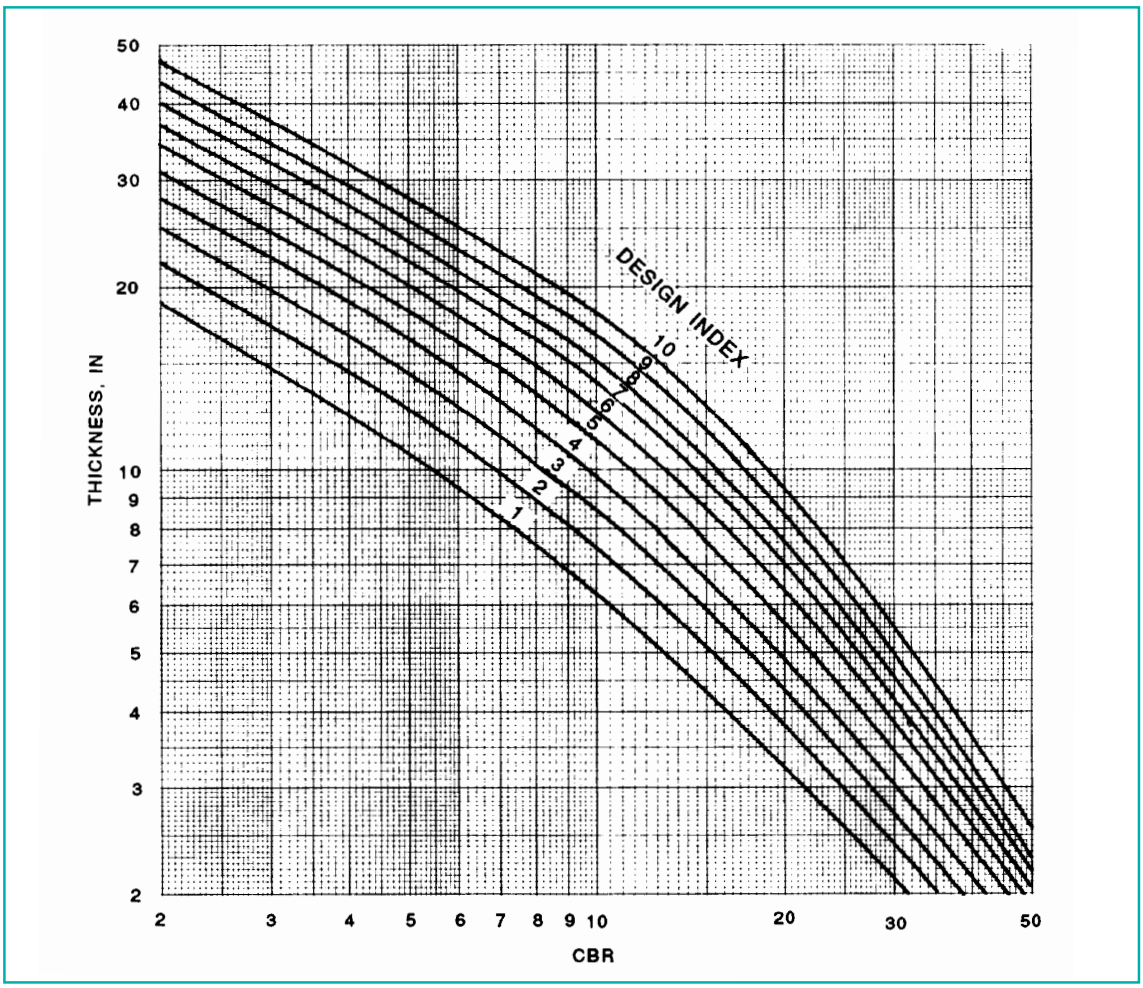
In addition to having a good understanding of project-specific traffic loadings and the local pavement environment, the effective use of the Austroads empirical method in the Pacific context relies on being able to characterise the strength and long-term behaviour of the subgrade (CBR). As with the AASHTO method, this not only requires local knowledge and experience, but also field and laboratory testing.

4.2.4 UFC Pavement Design Guide: Empirical

The United Facilities Criteria Pavement Design Guide has been developed for the American Joint Armed Forces (United Facilities Criteria - UFC, 2004). It provides guidance on the design of pavements for roads, streets, walking and storage areas.

Empirical subgrade CBR based designs for flexible pavements utilise a chart like Figure 10, with the design index based on traffic loading. Modified pavement materials are modelled using pavement layer equivalence factors. This potentially offers local engineers more options than would be the case with other methods, such as the Austroads method (see above), provided they can characterise the strength and long-term behaviour of the subgrade (CBR) and the various modified (stabilised) materials. This would usually require laboratory testing. The method also allows for the design of rigid pavement structures (e.g. reinforced concrete).

Figure 10. Flexible Pavement Design Curves for Roads and Streets



Source: United Facilities Criteria, 2004, p8-2.

4.2.5 Dynamic Cone Penetrometer Method

Pavement asset development in Southern Africa includes the use of the Dynamic Cone Penetrometer (DCP) design method (Association of Southern African National Roads Agencies – ASANRA, 2014). This uses a test method to characterise the in-situ pavement structure with depth, and then compares this with an expected pavement profile, based on DCP based values, with depth based on expected design traffic.

Table 10 shows the various traffic classes used.

Table 10. DCP Design Catalogue for Different Traffic Classes

Traffic Class E80 x 10^6	LE 0.01 0.003 – 0.010	LE 0.03 0.010 – 0.030	LE 0.1 0.030 – 0.100	LE 0.3 0.100 – 0.300	LE 0.7 0.300 – 0.700	LE 1.0 0.700 – 1.0
150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade 93% MAASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23

The design catalogue for this traffic category is only valid if low moisture conditions can be guaranteed in the pavement in service. If there is a risk of moisture ingress the pavement design should be based on the soaked condition.

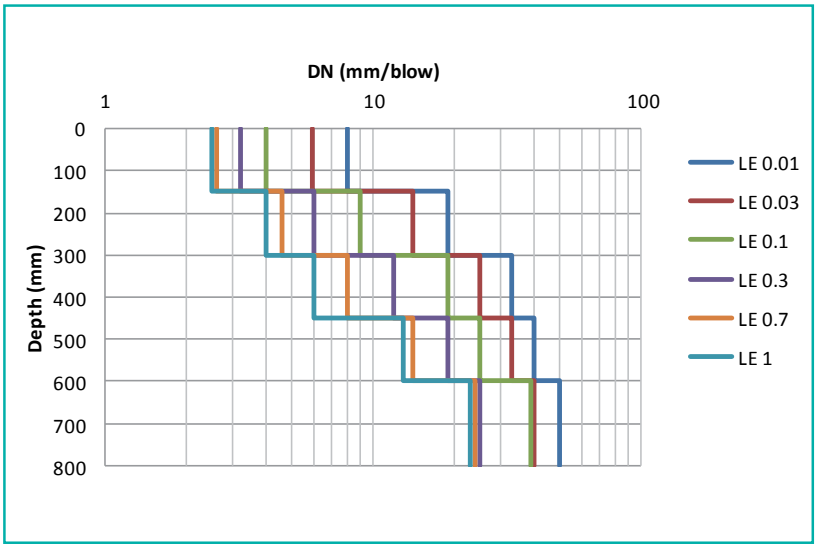
Source: ASANRA, July 2014, p51.

The DCP method offers opportunities for the smaller island states in the Pacific context. Local engineers can characterise the strength and behaviour of the subgrade and overlying pavement using a single test, then design the pavement treatment using knowledge and experience in the local context – providing that the future traffic loading conditions are well understood.

Figure 11 shows the layer strength diagram (LSD) for various traffic categories (refer Table 10) in terms of the DN values (penetration of penetrometer in mm/blow) at a specified density and moisture content.

The LSD for a particular traffic category indicates the required material properties, as represented by the DN values for each 150 mm layer to a depth of 800 mm. As illustrated in Figure 11, the comparison between the in situ strength profile of the existing pavement structure and that of the designed pavement is used to determine the appropriate design requirements.

Figure 11. DCP-Based Pavement Structures for Various Traffic Classes



Source: ASANRA, July 2014, p52.

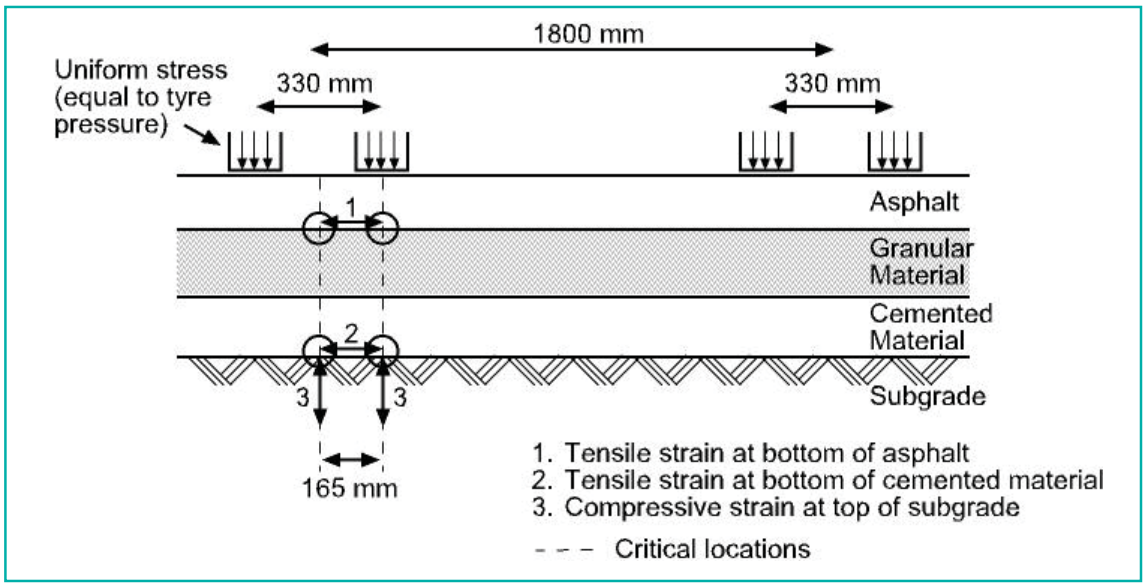
4.3 Mechanistic Methods

With improved understanding of the behaviours of pavement components and computer models, it is possible to apply mechanistic principles to pavement design. Anecdotal evidence suggests that increasing use is being made of these methods in the Pacific, notably on current large-scale pavement projects in Fiji and Vanuatu.

4.3.1 Austroads

The Austroads mechanistic design approach (Austroads, 2008) considers the stresses/strains within the pavement structure, based on combinations of applied load, layer strength, layer depth and subgrade strength, to determine the minimum depth and configuration of the pavement structure. Strains considered are tensile strains within asphalt or cement bound layers, and compressive strains within the subgrade (refer Figure 12).

Figure 12. Pavement Model for Mechanistic Procedure Used in Austroads



Source: Austroads, 2008, p98.

The pavement designer will use computer programmes such as CIRCLYW[9] to calculate the expected strain (and stress) levels within the pavement structure (based on circular load on an elastic half space principles) and then in a separate process compare these predicted strain levels with the strain levels expected to be tolerated by the pavement layer based on the number of repetitions of the design traffic load and layer/material specific performance relationships. Currently the performance relationships used in Austroads are based on Australian in-service road and highway data and long term testing.

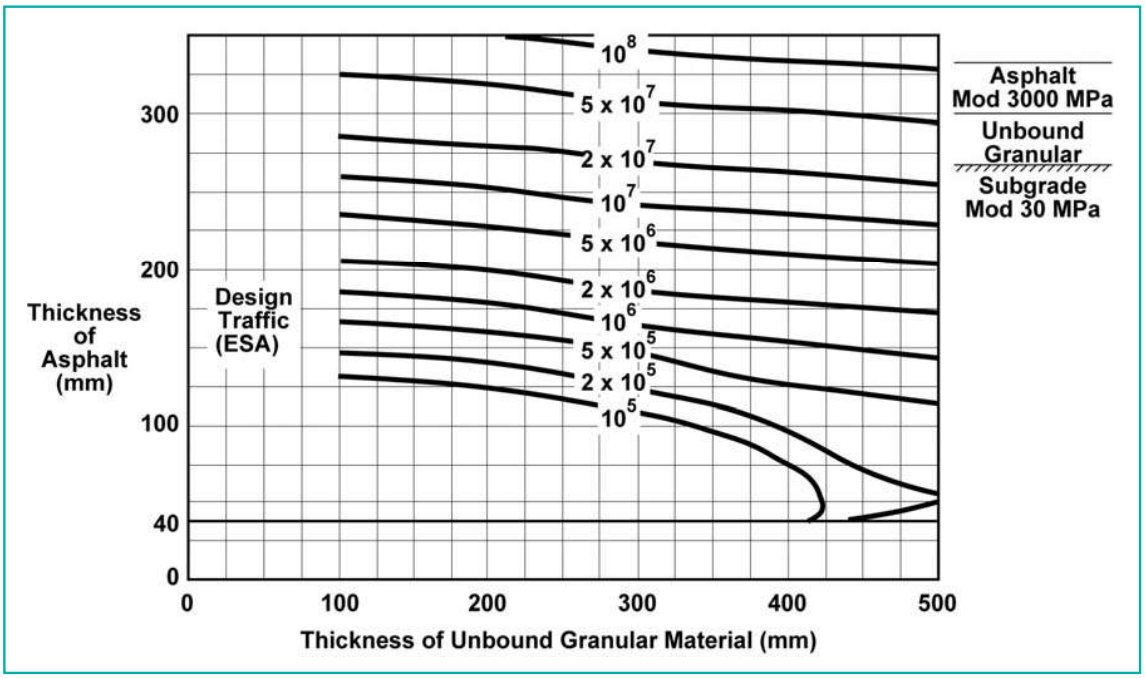
Pavement design solutions derived from mechanistic models assume that aggregate materials and properties which are subsequently used within the pavement structure meet prescribed performance targets including strength, grading and plasticity limits. If local materials do not meet these performance targets, material modification can be achieved through stabilisation (refer Section 5).

9 CIRCLYW, MINCAD Systems

A key design input is the pavement layer resilient modulus. In the absence of reliable test data, the resilient modulus is based on published presumptive values.

In the situation where a designer does not have access to computer support, Austroads publishes a number of design charts based on mechanistic principles (refer Figure 13). The published design charts allow designers to consider both unbound and bound (structural asphalt) pavement solutions.

Figure 13. Mechanistic Design Chart



Source: Austroads, 2008, p111.

In addition to having a good understanding of project-specific traffic loadings and the local pavement environment, the effective use of the Austroads mechanistic method in the Pacific context relies on being able to characterise the mechanistic material properties of the subgrade and pavement layers. Whilst presumptive values from the literature can be used, this requires care and local knowledge/ experience as well as laboratory testing.

4.4 Material Specifications

Whether using empirical or mechanistic pavement design methods, the contractor responsible for the production and supply of materials to pavement construction is usually bound by separate material specifications. For example in New Zealand, the NZTA specification M/4 specifies source and production property expectations for crushed basecourse materials. This material is processed, crushed stone with a maximum stone size of 37.5mm (AP40). The subbase layers may will be separately specified, usually starting with a larger maximum stone size.

In Australia, whilst the requirement to supply processed, crushed stone remains, the maximum stone size is more often a maximum stone size of 19mm (AP20). Material specifications can also be found in RN31, AASHTO and US Army Corps of Engineers guidelines.

In most material specifications, source property tests are included to provide controls on stone crushing strength and weathering resistance, primarily to limit unplanned and damaging in-service breakdown. Such tests are appropriate to the use of volcanic stone on the Pacific, because the fine materials produced by particular breakdown can be plastic, and hence will lead to accelerated in-service pavement deterioration often within the basecourse layer.

The well-documented in-service breakdown of the coralline materials can assist self-cementation, provided that the material is then subsequently kept dry. The literature review for preparation of this report found a number of commentators who support making best use of self-cementation. This should be taken into account when specifying the supply of such materials.

Production property tests include checking for limits on: particle size grading; sand equivalent; plasticity.

4.5 Pavement Material Characterisation

Pavement material characterisation applies to bound surfacing, pavement aggregate layers, modified materials and subgrade materials. AASHTO, British Standard and Austroads guidelines can be applied.

A key input to pavement design is subgrade strength and/or subgrade layer performance. Strength is usually characterised by either CBR or subgrade modulus exponent (k). For mechanistic design methods the layer material performance properties needed include Resilient Modulus (*E)* and Poisson's ratio (μ).

The CBR value is frequently inferred from the DCP, or from laboratory based testing on either disturbed or remoulded samples. Resilient modulus of the subgrade, a key input to mechanistic design, can be based on presumptive values, or empirical relationships.

The characterisation of the properties of the pavement layer materials (unbound aggregate basecourse and subbase) will by preference utilise laboratory test data (e.g. particle grading, plasticity indices, CBR), presumptive values for E, and where the facilities can be accessed, laboratory based Repeat Load Triaxial (RLT) testing. The characterisation of the properties of stabilised materials (either bound, lightly bound or modified) should now, to be credible, involve laboratory testing of Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS).

For surfacing materials, specifically dense or gap graded asphaltic concrete products, laboratory based testing is required to provide property characterisation, based on a pre-construction Job Mix Formula (JMF) and then post construction verification tests.

The variation in key test outcomes over some various test methods needs to be taken into account during design and construction. For example, when the design of the pavement structures is based on CBR, usually the reported 10th percentile value of test results. Table 11 shows how CBR values can vary, in this case based on changes in test method. Table 12 shows that the coefficient of variation for a number of routine tests can be very high. This needs to be taken into account in design and construction.

Table 11. CBR Determinations by Different Methods

CBR Penetration depth (mm)	TMH1 and AASHTO		BS	
	Oversize compensation	No oversize compensation	Oversize compensation	No oversize compensation
2.54	80[1]	35[2]	140[3]	65[4]
5.08	100[5]	45[2]	180[3]	80[1]

Notes: 1- Assumed soaked CBR value of 80% as measured by the prescribed testing standard
2- Based on a CBR reduction factor of 0.45 to compensate for removal of oversize (ref. Section 2.5.2)
3- Based on a CBR increase factor of 2.2 to compensate for addition of oversize (typically 45% compensation)
4- Based on $CBR_{2..54} = 0.79\ CBR_{5.08}$
5- Based on $CBR_{5.08} = 1.27\ CBR_{2.54}$

Table 12. Co-efficient of Variation for Common Soil Tests

Test	Reported CV (%)	Recommended CV (%)
CBR	17-58	25
Compaction (OMC)	11 - 43	20, 40
Compaction (MDD)	1 - 7	5
Linear shrinkage	57 - 135	100
Liquid limit	2 - 48	10
Moisture content	6 - 63	15
Plastic limit	9 - 29	10
Plasticity index	7 - 79	30, 70

Source for tables above: Pinard & Netterberg, 2012, pp12-13.

The significant variation in reported CBR for laboratory tests based on material preparation and test method, and the reported coefficient of variation for results from laboratory-based soil characterisation tests, requires the designer to consider carefully the associated risks. How often this is done well in practice is questionable, and needs ongoing support and training.

4.6 Investigations and Tests in Support of Good Design

Good pavement design is dependent on good investigations. From a 'best practice' perspective, good investigations should include:

- total traffic counts, heavy vehicle counts, and in some circumstances traffic load surveys
- test pit or pavement pit investigations to assist the designer to characterise the in-situ ground and pavement conditions, and to sample materials for laboratory testing
- in-insitu strength testing for subgrade strength, and
- in-situ testing for groundwater and surface water design conditions.

The extent of these investigations could vary according to the project size, complexity and location. It is unwise to ignore investigations altogether, as even when working with the most experienced local practitioners, often the weakest link in a pavement design and construction outcome can be the 'unrecognised' localised soft ground or drainage deficiency.

Engineering laboratory and field tests used to support project investigations come in a variety of forms. For lower volume road pavement rehabilitation empirical design can be based on in-situ testing with DCP (e.g. Scala penetrometer), Drop Impact Hammer (Clegg Hammer), Shear Vane, and test pit and hand auger investigations to help with material characterisation (refer Figure 14).

Figure 14. Hand-Held Site Investigation Tools

For larger capital projects, investigation utilising tests such as the Falling Weight Deflectometer (FWD), Benkelman Beam (BB), Cone Penetrometer, and In-Situ CBR test can be used to assist the designer to characterise and where appropriate section areas of the pavement works with respect to characteristics including subgrade strength, ground settlement and need for surface or subsurface drainage etc., as shown in Figure 15. These are more applicable to the mechanistic design methods.

Figure 15. Larger Project Site Investigation Tools

4.7 Project Reliability

Project reliability is the probability that the pavement, when constructed to the chosen design, will outlast the design traffic before major rehabilitation is required. When considering the level of project reliability expected from a pavement project or projects, the asset owner and pavement designer must appreciate that this will be affected by both immediate construction and longer term maintenance achievements.

For pavement works on isolated PICs, reliability of outcome is important, as is the need to balance reliability with cost effectiveness.

4.8 Conclusion

Pavement investigation, design construction and maintenance works in the Pacific are able to make use of a range of empirical or mechanistic pavement design and construction guidelines. It appears the historical context of the country in question will influence the origin of the guideline used (e.g. RN31 in PNG, US Army Corps of Engineers guidelines in RMI).

Whether using empirical or mechanistic pavement design and construction methods, the access to and accuracy of investigation information is important, as this will affect the reliability of the pavement project design and construction outcomes. This information should include:

- future traffic loading data and overweight load conditions
- foundation conditions and strength
- drainage conditions, and
- in-situ and imported material characterisation.

Based on the research in this study, empirical design methods have been used successfully in the Pacific, and continue to offer PICs with practical and repeatable approaches based on test methods that can be successfully and sustainably used in country (e.g. the DCP or field laboratory based Sand Equivalent test). However, the successful use of these methods does need the designer engineer (and asset owner) to understand the assumptions upon which these methods are based. Empirical design methods based on subgrade CBR strength for example assume that this important characteristic strength can be reliably measured in the field or nearby laboratory, and that CBR characterisation will take into consideration future drainage limitations (if any), localised groundwater conditions and future maintenance aspirations (e.g. reseal frequency).

5 Aggregate Stabilisation

5.1 Introduction

Stabilisation of pavement aggregate materials (hereafter called aggregate stabilisation) is carried out for a number of reasons, these being to:

- change the natural material properties of the fine fraction in a crushed or uncrushed aggregate to reduce the pre-existing plasticity and sensitivity to water
- improve the strength or load bearing capacity of the aggregate
- make better use of potentially lower quality local materials when producing crushed or uncrushed aggregate to reduce dependency on imported materials, and
- enable aggregates to be used in different layers and for different purposes (e.g. unbound or bound) within a pavement structure.

This section of the report describes how stabilisation could assist with the effective utilisation of locally available pavement aggregates in PICs. In this context, aggregate stabilisation only makes sense if the net cost of importing and mixing the stabilising agent (e.g. lime, cement, bitumen or polymer) with the local aggregate is less than the alternative of using local product in a different way, for example by thickening the pavement, or less than importing aggregate from a nearby source. Aggregate stabilisation can be effective in a wide range of situations.

5.2 Generally Accepted Stabilising Agents

The generally accepted stabilising agents include:

- lime: in forms of hydrated lime (CaOH) or Quicklime (CaO)
- cement: normally general purpose Ordinary Portland Cement (OPC)
- other cementitious stabilising agents including fly ash
- bitumen: in forms of bitumen emulsion or foamed bitumen
- polymer: usually products of acrylate-based co-polymers, in water mixed liquid or pellet form, and
- stabilisation using geosynthetics.

Figure 16 provides guidance on the use of the various stabilising agents in practice. Of the most commonly used materials:

- lime stabilisation is best suited to aggregate materials with higher proportions of clay fines and hence plasticity (the lime acts to reduce the plasticity and strength/water content sensitivity, and would appear better suited to the volcanic aggregate materials), while
- cement stabilisation works well across a wider range of material fine fractions and plasticity indices, and more often results in measurable strength increase, and would appear better suited to the coral materials, although useful for the volcanic materials as well.

Health and safety must be considered carefully when using these stabilising agents. For example, Quicklime will burn the skin on contact. Hydrated lime, cement and fly ash will be easily disturbed, and contaminate the air nearby and adjoining homes etc. Bituminous and polymer based agents are chemical compounds that must be respected (refer to Austroads, 2006).

Figure 16. Guidance on the Use of Stabilising Agents

Particle size	MORE THAN 25% PASSING 0.425 mm			LESS THAN 25% PASSING 0.425 mm		
Plasticity index	PI ≤ 10	10 < PI <20	PI ≥ 20	PI ≤ 6 WPI ≤ 60	PI ≤ 10	PI > 10
Binder type						
Cement and cementitious blends*						
Lime						
Bitumen						
Bitumen/ cement blends						
Granular						
Polymers						
Miscellaneous chemicals**						
Key	Usually suitable		Doubtful or supplementary binder required		Usually not suitable	

* The use of some chemical binders as a supplementary addition can extend the effectiveness of cementitious binders in finer soils and higher plasticities.

** Should be taken as a broad guideline only. Refer to trade literature for further information.

Source: Austroads, 2006, p17.

5.3 Types of Stabilisation

Table 13 describes the type of stabilisation work completed in practice, linking this to the expected strength of the stabilised material.

The distinction between granular, modified and bound behaviour shown is important. When designing for bound behaviour, whilst the support offered by a bound layer can be helpful within the overall pavement structure by providing enhanced load bearing capacity, careful checks need to be made of in-service fatigue performance to prevent cracking. During and following construction, pre-cracking of bound materials using heavy rollers can be used to mitigate the risk of uncontrolled future cracking in initially bound layers.

Crack control in both modified and bound layers is vitally important.

The New Zealand Transport Agency (NZTA) has reported the long term behaviour of lightly bound aggregate materials in near surface recycled pavement layers over time (Gray et al, 2011). Pavement layers with even modest amounts of cement additive (>1% by dry mass) were found to display lightly bound or bound behaviour for about 5 years after construction. Then when micro-cracking occurred, the stiffness of the cemented layer reduced over time to approach the unbound aggregate condition. The key to the ongoing good performance of near surface cement stabilised basecourse was found to be well informed design/construction backed by proactive surface dressing or sealing, and proactive maintenance crack sealing as needed.

Table 13. Types of Stabilisation Work Used in Practice

Category of Stabilisation	Indicative Laboratory Strength after Stabilisation	Common Binders Adopted	Anticipated Performance Attributes
Subgrade	BR1 > 5% (subgrades and formations)	▪ Addition of lime ▪ Addition of chemical binder	▪ Improved subgrade stiffness ▪ Improved shear strength ▪ Reduced heave and shrinkage
Granular	40% < CBR1 < +100% (subbase and basecourse)	▪ Blending other granular materials which are classified as binders in the context of this Guide	▪ Improved pavement stiffness ▪ Improved shear strength ▪ Improved resistance to aggregate breakdown
Modified	0.7 MPa < UCS2 < 1.5 MPa (basecourse)	▪ Addition of small quantities of cementitious binder ▪ Addition of lime ▪ Addition of chemical binde	▪ Improved pavement stiffness ▪ Improved shear strength ▪ Reduced moisture sensitivity, i.e. loss of strength due to increasing moisture content ▪ At low binder contents can be subject to erosion where cracking is present
Bound	UCS2 > 1.5 MPa (basecourse)	▪ Addition of greater quantities of cementitious binder ▪ Addition of a combination of cementitious and bituminous binders	▪ Increased pavement stiffness to provide tensile resistance ▪ Some binders introduce transverse shrinkage cracking ▪ At low binder contents can be subject to erosion where cracking is present

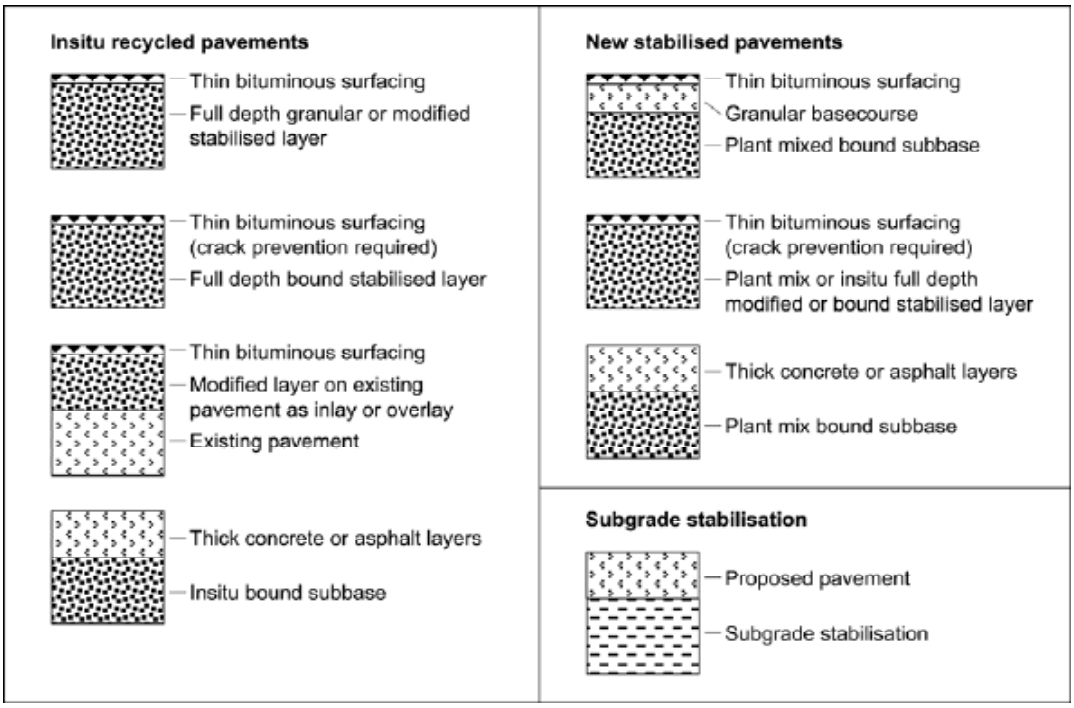
Notes:

1. *Four day soaked CBR.*
2. *Values determined from test specimens stabilised with GP cement and prepared using Standard compactive effort, normal curing for a minimum 28 days and 4 hour soak conditioning.*

Source: Austroads, 2006, p 4.

Figure 17 shows how stabilised materials of different types (refer Figure 16) can potentially be used in existing and new pavements, including how pavement recycling options can now include stabilised materials.

Figure 17. Methods of Incorporating Stabilised Materials into Pavement Structures



Source: Austroads, 2006, p 6.

Aggregate stabilisation with bitumen emulsion or foamed bitumen can now be routinely completed, has been used internationally for a number of years, and is being used currently in Fiji. The process requires specialised construction plant and material (Writgen Ltd) and a high level of quality control to be successful consistently. The bitumen stabiliser is usually added together with some cement, the latter providing short term strength gain.

Another opportunity for using bitumen (either hot bitumen or bitumen emulsion) on lower volume roads is the use of Otta seals (Norwegian Public Roads Administration, 1999). This involves the use of bitumen formulated to be mixed/absorbed into the upper levels of the road pavement to produce a stable, flexible, sealed surface. First developed in the Otta Valley in Norway, the process has been successfully used in Africa, Australia, New Zealand, Scandinavia and Tonga.

Polymer stabilisation has been used on pavement aggregate surfaces in developing countries as a dust palliative on unsealed roads in Africa and South America. Aggregate stabilisation using polymer, water and approximately 3% by dry mass of cement is known to deliver encouraging results with poorer quality mixed aggregate materials (including some pre-existing bitumen surfacing materials). This outcome has compared favourably with observed on-road performance where no cracking in the polymer and cement stabilised surface was observed. In an adjoining cement-only stabilisation pavement repair, however, terminal cracking and subsequent shallow shear failure occurred in a relatively short time (< six months). The inclusion of polymer appears to act across the micro-cracks in the lightly bound material under load, improving the stabilised layer resilience.

Aggregate stabilisation can also utilise mixing in new aggregate components (e.g. larger gap-graded crushed stone, recycled crushed glass and potentially other recycled materials from the waste stream) to modify the overall aggregate grading and internal structure and, thereby, to improve the resultant shear strength and load bearing capacity of the improved pavement layer. Research has shown that this can be effective from a technical perspective in New Zealand (NZTA/Pavespec, 2008).

If recycled materials from waste streams are to be used, the quantity of material would need to be considered carefully. For example, enquiry regarding the potential use of recycled crushed glass in Tonga suggests that up to 220 tonnes of recycled glass may be available (refer P Kelly, 2015). To put this opportunity in Tonga into perspective, a pavement rehabilitation of 0.5 kilometres (kms) of 6m wide pavement involving a 150mm aggregate overlay would need approximately 450m3 of new solid in place material. This represents approximately 1000 tonnes of aggregate. If it is assumed that crushed glass could make up 20% of the aggregate demand, the 220 tonnes currently available would just satisfy this one project.

To be sustainable in the long-term, the collection and management of waste stream materials would need to be well organised either in-country or across country groups, so that the quantity of recycled materials is available when required.

5.4 Plant and Equipment

Effective and successful aggregate stabilisation is supported by: a well-organised, specialist array of plant and machinery; skilled staff/operators supported by skilled laboratory testing support; accurate delivery of stabilising agent and water; accurate depth and efficiency of mixing; proactive material delivery, compaction, and shaping.

Discussions with New Zealand-based contractors currently working in Fiji show that projects requiring extensive stabilisation are usually planned well in advance, and of sufficient scale to justify 'importing/exporting' a well-resourced stabilising 'road train', as shown in Figure 18.

Figure 18. Pavement Stabilising 'Road Train'

Whilst highly effective at a large project level, in the PICs the specialist operator skills and resources may not remain in-country. Thus the legacy from the work experience can be limited. Experience shows that plant left in-country will deteriorate when not used enough for construction, rehabilitation

or ongoing road maintenance work (the 'build-neglect-rebuild' paradigm[10]) and therefore is not being regularly serviced. Contractors working in PICs have reported finding 'old' derelict plant just 'parked up'.

Within the PICs, construction using smaller well-equipped plant and labour teams warrants further consideration. Recent reported experience of highly successful polymer/cement near surface aggregate stabilisation using a small, motivated work crew equipped with bobcat mounted stabiliser, small truck, and certified small sized bitumen sprayer is illustrated in Figure 19. This approach, or something similar, may have potential for further application.

Figure 19. In-situ Aggregate Stabilisation with Small Plant and Skilled Work Crew

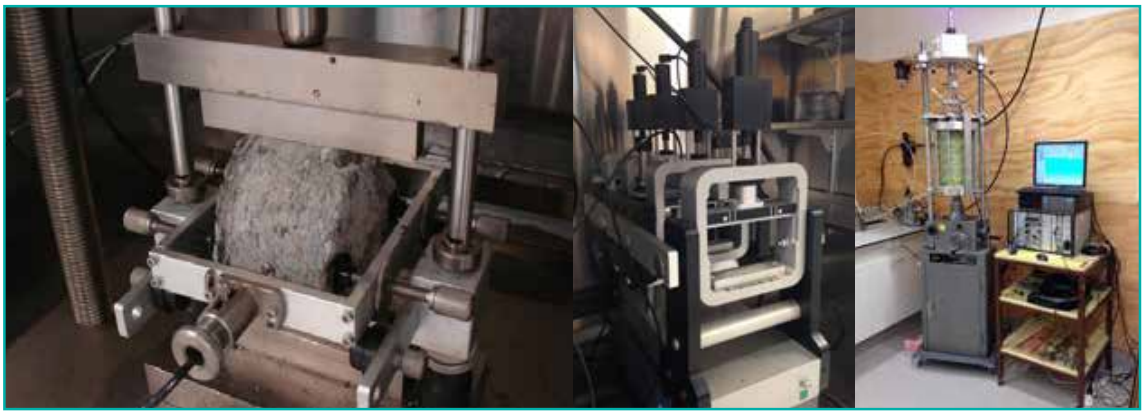
Engineering laboratory and field test support for aggregate production, supply and stabilisation varies. At the basic level, for example cement or lime modification of existing or imported aggregate, in-situ testing with DCP (e.g. Scala penetrometer), Drop Impact Hammer (e.g. Clegg Hammer) can be supported by local laboratory based soil/aggregate moisture/density curve, linear shrinkage, CBR and stabilised material reactivity tests (Figure 20).

Figure 20. In-Country Capable Field and Engineering Laboratory Tests

10 Pacific Infrastructure Advisory Centre. 2013. Infrastructure Maintenance in the Pacific: Challenging the Build-Neglect-Rebuild Paradigm. PRIF: Sydney, Australia.

When working with bitumen stabilisation (foam or emulsion), or larger scale cement/lime stabilisation potentially using lightly bound or bound material layers, more sophisticated laboratory testing is required. Design guidelines from Australia, New Zealand, and South Africa use ITS, Flexural Beam and RLT tests as shown in Figure 21. This type of testing is more costly, requiring more technology and lead time.

Figure 21. Specialist Laboratory Tests Used to Support Stabilised Material Design



When moving on to construction, in addition to the quality assurance needed around the accuracy of pavement set out, construction depths and widths etc., and the delivery and mixing of stabilising agents, the compaction outcomes of pavement works should be measured on site using either the Nuclear Densometer, or other test methods such as the Sand Replacement method, refer Figure 22.

Figure 22. Field Compaction Density Tests

5.5 Stabilisation using Geosynthetic Materials

Geosynthetic materials in this context mean geogrids and geotextile. Geogrids are incorporated into pavement structures to enhance the tensile strength of the pavement. Anecdotal evidence from suppliers suggests that overall pavement thickness can be reduced if a pavement includes geogrid layer(s). Alternatively, the pavement depth can be retained as determined using the design methods considered in Section 4, and the geogrid employed to provide more certainty around fatigue and reflective crack control, particularly when overweight loads are expected.

Geotextiles are usually placed in a pavement to mitigate the risk of fines erosion and to assist with permeability controls. Some geotextiles can also provide tensile strength.

Geogrid/geosynthetic materials are combined in the reinforcement of structural asphalt pavement layers.

5.6 Conclusion

The test and construction processes described above and the design methods outlined in Section 4 can be used together to support aggregate stabilisation and improved pavement performance.

The generally accepted stabilising agents include:

- lime: in forms of hydrated lime (CaOH) or Quicklime (CaO), and
- cement: normally general purpose OPC.

Other material options potentially include: fly-ash, foamed bitumen/cement, various polymer additives, granular replacement additives including alternative stone sources, recycled glass, tyres and plastic, and geosynthetic (geogrid/geotextile) reinforcement.

All these agents and additives have been used successfully with the various locally available aggregates in the Pacific. Lime modification (of plastic fines in aggregate of volcanic origin) and cement/foamed bitumen modification (of higher sand content aggregates) offer particularly sound technical responses.

Geosynthetic reinforcement provides enhanced load bearing capacity and crack control within pavements, and can be linked with associated edge support (e.g. rock fill gabion baskets) to enhance the overall stability of the road embankment in vulnerable locations. The placing of geosynthetic reinforcement is labour intensive, and the whole of life cost implications of doing so would need to be compared with other stabilisation options. However the increased labour component could well suit labour-based construction methods (PRIF, May 2014).

Aggregate stabilisation in any form only makes sense if the net cost of importing and mixing the stabilising agent (e.g. lime, cement, bitumen or polymer or new graded aggregate or sand) with the local aggregate is less than the alternative of using more local product in a different way.

6 Practical Application of Study Research

6.1 Introduction

The materials, investigation, design and construction methods described in this report can be used in a variety of ways in the PICs. Table 1 (refer Section 2) describes the expected accessibility of local aggregate source materials in the PICs. Table 14 shows how these materials could be expected to be used to support the construction and maintenance of roads in those countries, based on the following low volume road categories:

- low volume unsealed roads (LVUR) with targeted traction seals
- low volume roads in vulnerable locations (LVVR) e.g. exposed coastal road sections, and the crest/run of mountainous/steep roads at grades greater than 8%, and
- low volume sealed roads expected to carry commercial traffic (LVCR), including overweight traffic.

Low volume is defined herein as <500vpd and up to 20% HCV.

Table 14. Availability and Use of Locally Available Pavement Aggregate Materials

Country	Coral Aggregate	Coronus Aggregate	Volcanic Aggregate	LVUR	LVVR	LVCR
Cook Islands	✓	✓	✓	✓	✓	✓
FSM	✓	✓	✓	✓	✓	×
Fiji Islands	✓	✓	✓	✓	✓	✓
Kiribati	✓	×	×	✓	✓	×
Nauru	✓	✓	×	✓	✓	×
Niue	✓	✓	✓	✓	✓	×
Palau	✓	×	✓	✓	✓	×
PNG	✓	✓	✓	✓	✓	✓
RMI	✓	×	×	✓	✓	×
Samoa	✓	✓	✓	✓	✓	✓

Country	Coral Aggregate	Coronus Aggregate	Volcanic Aggregate	LVUR	LVVR	LVCR
Solomon Islands	✓	✓	✓	✓	✓	✓
Timor-Leste	✓	×	✓	✓	✓	✓
Tonga	✓	✓	✓	✓	✓	✓
Tuvalu	✓	×	×	✓	✓	×
Vanuatu	✓	✓	✓	✓	✓	✓

Source: Lal & Fortune (Eds.), 2000.

The presentation in Table 14 is intended to show that the lack of locally available aggregate would preclude the use of certain materials in some of the PICs (e.g. igneous rock on Kiribati) or alternatively that the LVCR road category in particular is much less likely to feature in some locations (e.g. Kiribati), due to the nature of the low-lying atoll, port access controls and associated transport infrastructure (roads and in-country vehicle fleet).

Table 14 does not refer to high traffic volume rural or urban roads or purpose built commercial roads. The materials, investigation, design and construction methods likely to be used in such cases would be of such a scale that they would most likely be completed by specialist contractors, as is currently the case on the main islands in Fiji.

The design and construction of low volume commercial roads (LVCR) should assume that some overweight traffic loading will occur, because pavement overloading is a common occurrence across the Pacific due primarily to the lack of monitoring and enforcement. The likely scale of this overweight loading would be affected by the location of the road, and proximity to large traffic generators.

This discussion focuses on low volume roads as this is where the greatest benefit can potentially be derived for local communities, using locally available materials. Low volume roads make up a significant proportion of the transport infrastructure investments in the Pacific, in rural and peri-urban locations.

6.2 Low Volume Roads

6.2.1 Low Volume Unsealed Roads with Targeted Traction Seals

Unsealed roads traditionally use well-formed, well surface-drained pavement base (pavement depth would usually be determined using empirical methods, refer Section 4.2, and be based on project specific traffic loading and subgrade conditions) and overlying, sacrificial clay-rich wearing course to support effective pavement performance based on ongoing maintenance: routine surface grading, wearing course make-up, and side drain/culvert clearing. Maintenance grading should not disturb the stable base layer.

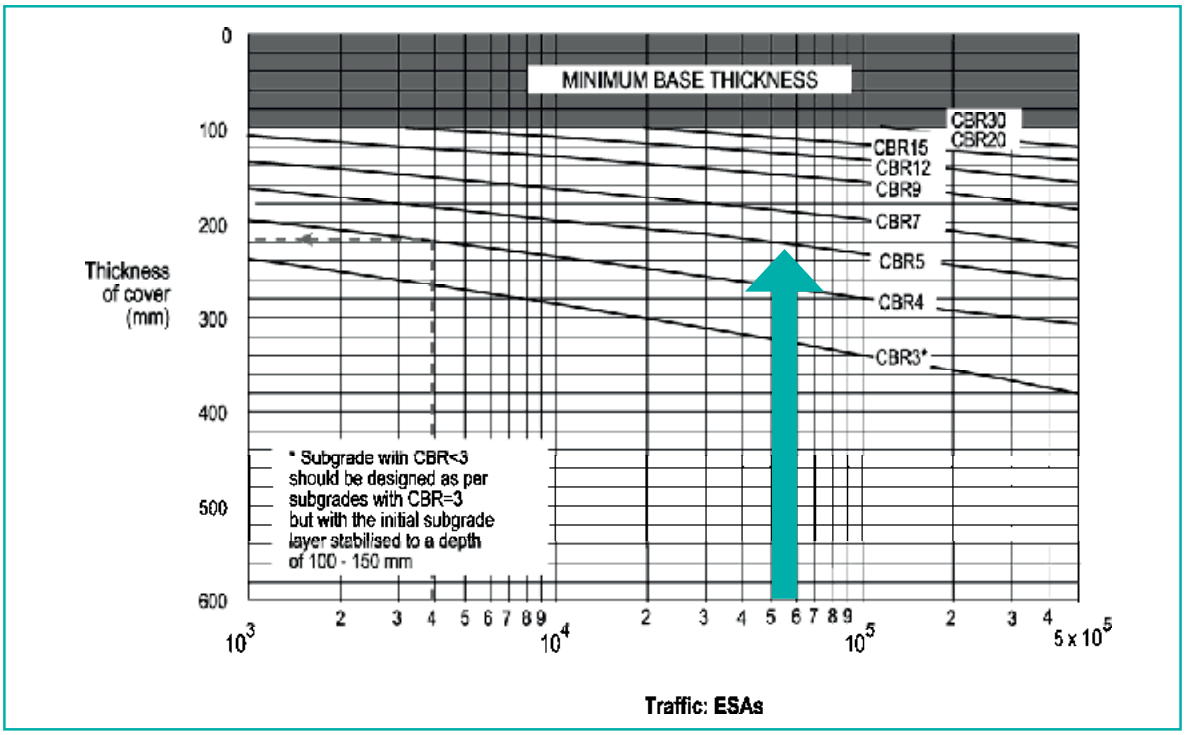
The depth of the pavement base would be determined using empirical methods (refer Section 4.2).

Pavement base materials could utilise locally available coral, coronus or volcanic aggregate sources, and can include larger screened uncrushed stone (up to 75mm), depending on the country. The performance of the base material would be assisted by self-cementation within coral based aggregates, provided that the cemented bonds are not subsequently damaged (broken) by unplanned overweight loads. The harder volcanic materials (e.g. vesicular basalt) could also be used. The presence of plastic fines in the base materials for both volcanic and coronus materials could affect the material shear strength of the base over time. Regular grading does efficiently mitigate the near surface effects of such failures, provided that the pavement depth is adequate to prevent deep seated failure down to or within the subgrade.

Stabilisation of the base material with cement/lime can be used to improve performance of the pavement structure beneath a suitable wearing course.

As an example, a single unsealed road carrying 200vpd, and 5% normal HCV (use 1.5 ESA/CV), for a ten year design period, gives a pavement design loading of $5.5*10^4$ ESA (0.055 MESA). Allowing for a subgrade strength CBR of 5% (this can be obtained on site using the DCP), requires a pavement > 250mm deep, with a minimum base thickness of 100mm, as shown in Figure 23. A potential solution could use a sand subbase >100mm thick overlain with >150mm of larger stone mixed base, shaped to give a 5% crossfall, and then capped with 50mm of fines rich wearing course.

Figure 23. Pavement Thickness Design, Unsealed Pavement



Source: Austroads, 2009, p21.

Traction sealing of unsealed roads, notably on steeper grades >8% or high stress corners carrying larger, heavy vehicles would typically involve the removal of the clay-rich wearing course, construction of a basecourse layer (depending on the layer depth using AP20 or AP40 crushed and processed basecourse) followed by chip seal, or by the use of an Otta seal. The basecourse could potentially be processed from a range of source rocks, with or without modification.

6.2.2 Low Volume Sealed Roads in Vulnerable Locations

LVVR in vulnerable locations occur across the Pacific, are often located near the coast and within 2-3 metres above sea level in normal conditions, and below the waves during storm events. Given the location on these roads, in-place drainage systems do not work efficiently during high tide events. Changes in climate and sea level rise will exacerbate the number of roads in this category on road networks.

Sealed roads in this context traditionally use well-formed, well-drained pavement base and sub-base (pavement depth would usually be determined using empirical methods, refer Section 4.2, and be based on project specific traffic loading and subgrade conditions), with a chip seal or thin lift AC surfacing. In the latter case, the use of thin-lift AC surfaces (up to 50mm) should mean that the underlying base/subbase combination does need to mitigate surface defection and curvature (D_0-D_{200}) to help prevent premature cracking in the AC. Ongoing maintenance would then normally involve routine proactive pothole repair, chip seal reseal and side drain/culvert maintenance.

The depth of the pavement base would be determined using empirical methods (refer Section 4.2), or in cases where different combinations of the pavement layers are used (e.g. stabilised material) by using mechanistic methods (refer Section 4.3).

In the highly vulnerable road environments (e.g. sea wave wash over pavement) the construction of low volume sealed road pavements could be enhanced using the following:

- basecourse modification to create lightly bound material (using cement, foamed bitumen/cement or polymer modification) to help hold the basecourse together, reduce top surface permeability, and enhance chip seal adhesion via primer seal
- free draining subbase, to allow water to leave the pavement structure effectively and mitigate the development of excess pore pressures in the basecourse
- roller compacted concrete (RCC)[11] pavement structure, particularly where there is coral or coral-sand material, and
- pavement reinforcement using geosynthetics linked to pavement edge constraint/support using aggregate enclosed within 'geocell', 'gabion' or geo-fabric reinforced rock rip-rap structures.

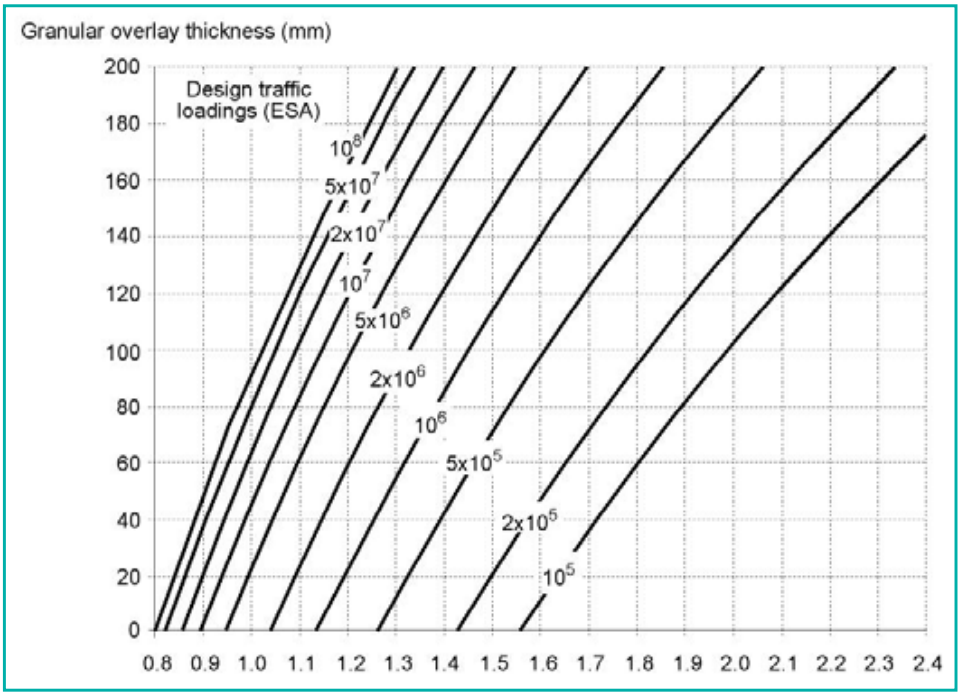
Depending on the country, these roads could be constructed out of coral, coronus or volcanic materials.

6.2.3 Low Volume Sealed Roads Carrying Commercial Traffic

Sealed roads for projects involving managed commercial traffic use traditionally use well-formed, well-drained pavement basecourse and sub-base (typically >125mm of basecourse and >150mm of subbase, depending on traffic loading and subgrade conditions), with a chip-seal or thin-lift AC surfacing or Otta Seal surfacing. The successful use of thin-lift AC surfaces (up to 50mm) does require management of surface defection and curvature (D_0-D_{200}) to help prevent premature cracking in the AC. Austroads provides some guidance on this matter, refer Figure 24.

11 Review of published design information for RCC (National Concrete Pavement Technology Centre, August 2010) suggests that the plastic fines in the volcanic source materials may need to be modified to allow for use in RCC.

Figure 24. Overlay Requirements on Sealed Pavement Surface



Source: Austroads, 2009, p152.

Stabilisation of the basecourse material with cement/lime is used to improve performance of the pavements. Anecdotal evidence from Samoa shows that cement stabilisation of the local vesicular basalt has been effective. Pavement rehabilitation projects in Samoa are now being carried out by local contractors using a machine stabiliser purchased from New Zealand. The paradigm remains how to encourage the local government pavement managers, material suppliers and contractors to consider the use of stabilisation in pavement maintenance works, as well as in the more traditional rehabilitation and pavement construction.

The depth of the pavement base could be determined using empirical methods (refer Section 4.2).

Ongoing maintenance would then normally involve routine, proactive pothole repair, chip seal reseal and side drain/culvert maintenance.

As an example, allowing for 500vpd, and 20% HCV, with 1.5ESA/HCV (this is normal commercial loading) gives a design traffic load for a single lane road over 10 years of $5.5*10^5$ ESA (0.55 MESA). Assuming a subgrade CBR of 5% (which could be, for example, dense beach sand) requires a pavement depth of 380mm, with minimum 125mm base material (refer Figure 25). This could potentially be made up of:

- >250mm of dredged sand
- >130mm of blended dredged sand and crushed stone, processed to achieve basecourse level performance with modification (stabilisation), and
- Otta seal surface.

Alternatively, it could comprise:

- >380mm of blended sand and crushed stone with surplus fines (e.g. coronus quarry)
- upper 200mm stabilised in-situ to create a modified pavement layer, and
- chip-seal surface.

Figure 25. Pavement Design Using Empirical Method

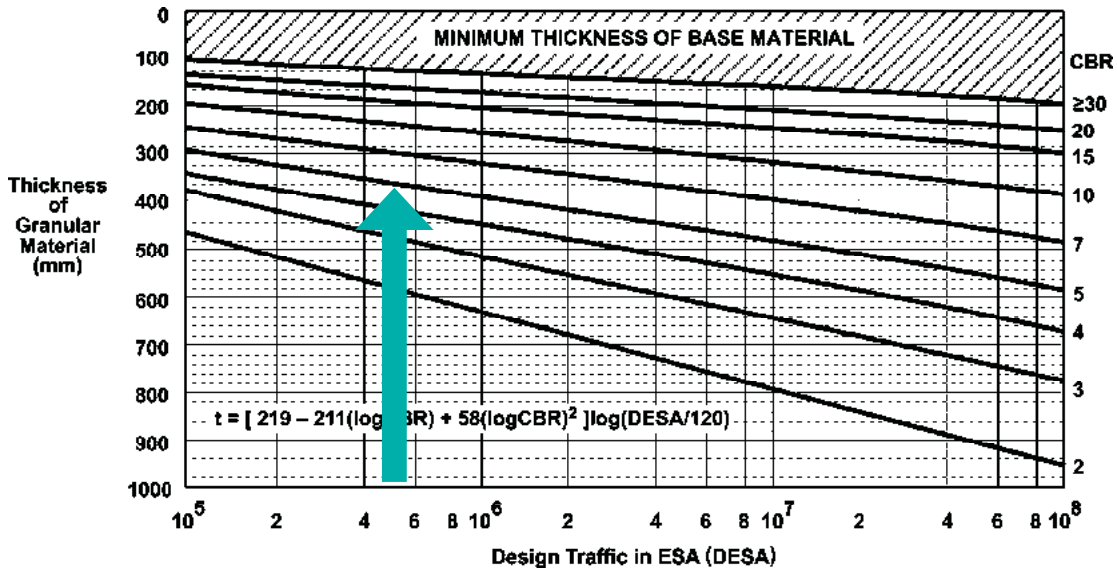


Figure 8.4: Design chart for granular pavements with thin bituminous surfacing

Source: Austroads. 2008, p107.

Pavement projects expected to carry overweight commercial traffic loads (either by design or because of lack of in-country control) can include one or a combination of the following:

- stabilised subgrade to provide a working platform (subgrade improvement layer) that contributes to a deeper pavement (without the need for even more imported aggregate) and enables the overlying pavement structures (sub-base and base) to be effectively placed and compacted
- stabilised sub-base (either modified or bound)
- stabilised basecourse (either modified or bound), with cement, foamed bitumen/cement or other additive
- pavement reinforcement using geosynthetics, potentially linked to pavement edge constraint/support, and/or
- deep lift structural AC or RCC.

Investigation and design of such pavement structures benefits from the use of well-researched mechanistic design methods. Laboratory-based material testing would be recommended in support.

For example, a recent project in Fiji involves a narrow sealed Port access road. The existing sealed pavement was heavily potholed, cracked and substandard, as shown in Figure 26. Deficiencies in seal quality and pavement drainage have contributed to the poor state of the road. The traffic on this road includes cars, buses, normal commercial vehicles and overweight vehicles, with recorded dual tyre axle loads from eight tonnes up to 14 tonnes.

Investigations have included on site test pits, laboratory testing of in-situ aggregate and imported quarry aggregate samples (in-country volcanic sources) and reactivity testing for cement stabilisation.

The rehabilitation treatment here involved overlay with processed aggregate, followed by in-situ cement stabilisation, shape and seal. The pavement design was prepared using mechanistic methods (Austroads principles and CIRCLY), and based on a clay subgrade strength of 4%. Improvements in roadside drainage were required.

Figure 26. Pavement Project Site in Fiji

6.2.4 Urban Road Context

The rehabilitation of urban roads is frequently complicated by the presence of underground and overhead utility services, proximity of kerb and channel or other transport infrastructure, and location of adjoining businesses/homes.

Conventional pavement rehabilitation options can be used. Near surface stabilisation of the existing basecourse layers with foamed bitumen/cement, undercut and replace with unbound or bound materials, or overlay with structural AC or RCC could be considered.

The depth of the pavement base would be determined using empirical methods. In higher traffic locations or where the use of more sophisticated stabilisation methods are planned the use of well-researched mechanistic design methods is recommended. Laboratory-based material testing would be recommended in support.

6.3 Future Research Testing

6.3.1 Introduction

This section of the report considers ideas for possible future testing of locally available solutions, within the context of low volume unsealed and sealed roads. Some of these may be developed further for field testing through PRIF during 2016 and 2017. The objectives of the field testing, if approved, would be to demonstrate practical application of the research ideas presented herein and to enable local engineers to develop more understanding about the value of working with local materials in pavement construction and maintenance.

6.3.2 Performance Monitoring of Pavement Rehabilitation Projects

Pavement rehabilitation projects of varying scales are currently being undertaken in Fiji (under the auspices of the Fiji Roads Authority) and in Samoa. Future performance monitoring of selected rehabilitation sites to consider how they perform over time and in relation to the design expectations could include:

- in-service pavement condition monitoring looking for cracking, shallow shear etc.
- in-service pavement structure testing including DCP tests (and comparison with DCP design methods) and sampling and laboratory testing of in-service materials
- pavement deflection testing (using BB or FWD), and
- traffic load monitoring.

All these works would be best suited for implementation by the respective Government's land transport authorities or divisions, with support from local or regional laboratories and pavement study specialists, thereby providing employment and ongoing training.

6.3.3 Blending of Local Processed Aggregate Materials

The existing coral and volcanic source rock materials have traditionally been used separately or in separate layers within a pavement structure.

These source materials could conceivably be blended to optimise the benefits of both. Processed local or regional waste stream materials (e.g. glass, tyres and plastic) could be blended with the local aggregates, and then incorporated into new pavement structures as natural or stabilised materials.

For example, dredged coral sand could be blended with crushed volcanic stone. The principal benefits here could be that the coral sand (limestone) could have a modifying effect on plastic fines within the processed volcanic aggregate, and provide the all-important stable sand fraction in the aggregate makeup.

Processed recycled waste stream materials (e.g. crumbed rubber or crushed glass) could be blended with coral sand on low lying atolls and coronus or volcanic stone materials on larger island states to produce improved, sustainable aggregate outcomes. This assumes that sufficient waste stream material is available to use in the longer term.

The processing and blending of aggregate materials to produce improved outcomes could be undertaken by private contractors using local stone and waste stream resources, with potential for regional sharing of larger processing equipment. The testing should consider the range of equipment available to process and blend aggregate materials and what equipment is best suited to the individual PICs.

Ongoing selection and testing of bended aggregate options could also be undertaken by local contractors or experts (with support from local or regional laboratories and pavement study specialists) providing employment and ongoing training.

6.3.4 Otta Seals

The ongoing success of Otta seals is reported internationally. Recent trials in Tonga have been useful. An outcome of these trials is that the short to medium term maintenance of the bitumen rich Otta seal is important, particularly during the immediate after care period. Maintenance or lack of it can affect

the local community's impressions of the new surface if not completed, particularly on commercial roads where flushing in the loaded wheel tracks can become problematic. Also noted in reports on the Tonga Otta seal trials is the forgiving nature of the technology where 'mistakes' in construction can be remedied easily without comprising the future performance of the pavement.

For example, in an Otta seal, if the binder application is too high initially, the error can be easily remedied through spreading additional aggregates on the surface. In contrast with a chip seal, inaccurate binder application can result in excess binder on the surface which could lead to surface defects, such as bleeding or stripping. In addition, unskilled labour and readily available equipment are utilised in the Otta seal technology.

Future Otta seal trial options include:

- incorporating blended aggregates (with and without waste stream components) in Otta seals
- Otta sealing using carefully targeted bitumen emulsion or low temperate bitumen binders, and
- supporting the training and use of safe, effective hot bitumen supply equipment.

Investigations of local aggregate use in Otta seals show that the selection and use of appropriate construction equipment for Otta seals including selection and testing of materials could be undertaken by local contractors (with support from local or regional laboratories and pavement study specialists) providing both employment and ongoing training opportunities.

6.3.5 Coral Sand-Based Pavements

Recent published research work in Southern Africa regarding the use of sand pavements has application in the Pacific, notably on low lying atolls. Sand pavement materials can be used modified or unmodified, usually depending on the traffic loading.

Options for sand pavement layer modification on low volume roads could incorporate imported additives including foamed bitumen/cement or polymers. Alternatively the natural cementation of the coral sand aggregates, with or without blending with other materials, and with or without geosynthetic reinforcement, could be researched further using trials and then utilised in the modern road design and construction context.

Investigations of local coral sand aggregate options, including selection and testing of materials could be undertaken by local contractors (with support from local or regional laboratories and pavement study specialists) providing both employment and ongoing training opportunities.

6.3.6 Labour-Based Construction Using Appropriate Technology

The use of local labour coupled with appropriately-scaled equipment has been reported in different parts of the Pacific (PRIF, May 2014) and continues to offer potential, both in pavement rehabilitation and maintenance. Improving local understanding of the real benefit of proactive and effective road maintenance would be particularly useful. Conceptually, a skilled (international or national) contractor would be matched with semi-trained or trained local labour, with further on-the-job training as needed.

The scale of the possible construction operations is illustrated in Figure 27. In this example, the use of the single, small specialised mechanical plant is only effective if the small labour crew working with it place the materials, and works over the surface with shovels and brooms effectively.

Figure 27. Labour-Based Local Construction Teams Using Appropriate Technology Support

The training and ongoing support of local Pacific-based engineers has the potential to involve the University of the South Pacific and University of Auckland. The most relevant opportunity appears to be in regard to evaluative studies and investigations on any trial work (Henning & Visser, 2012) in the follow-up phase. One or more trials could be mapped out to ensure funding security is established and managed, including oversight and reporting of outcomes (Wilkinson, Visser, Henning, Bennett, & Faiz, 2013).

7 Conclusions

The desk-based research undertaken for this study shows that it is possible to use locally available coral and igneous rock-based pavement materials to improve road pavement quality, resilience and sustainability and to reduce the overall whole-of-life cost of low volume road construction and maintenance in the Pacific region.

The science and technology exists now to source, extract, process and use local pavement materials effectively at whatever scale is necessary to best suit the local conditions. The properties of the local pavement materials can be improved by processing and stabilisation using a variety of stabilisation agents to suit the needs of unsealed and sealed pavements in the region.

The challenges to achieving the above are real and immediate:

- climate change-induced sea level rise and damage caused by major storm events
- poor regulation and control of overweight commercial and industrial traffic
- insufficient and poorly informed pavement investigation and design
- lack of maintenance of road pavement and drainage infrastructure, and
- lack of investment in any pavement resurfacing.

All of these contribute to the 'build-neglect-rebuild' paradigm evident on roads across the Pacific region.

As part of this current study, field trials will be proposed that will help determine the long-term sustainability and performance of road pavements built and maintained using locally available materials to meet current and future traffic demands. The manner in which the trials are developed and implemented will encourage involvement by and training of local engineers and contractors (as needed), using appropriately-scaled labour-based and equipment supported methods.

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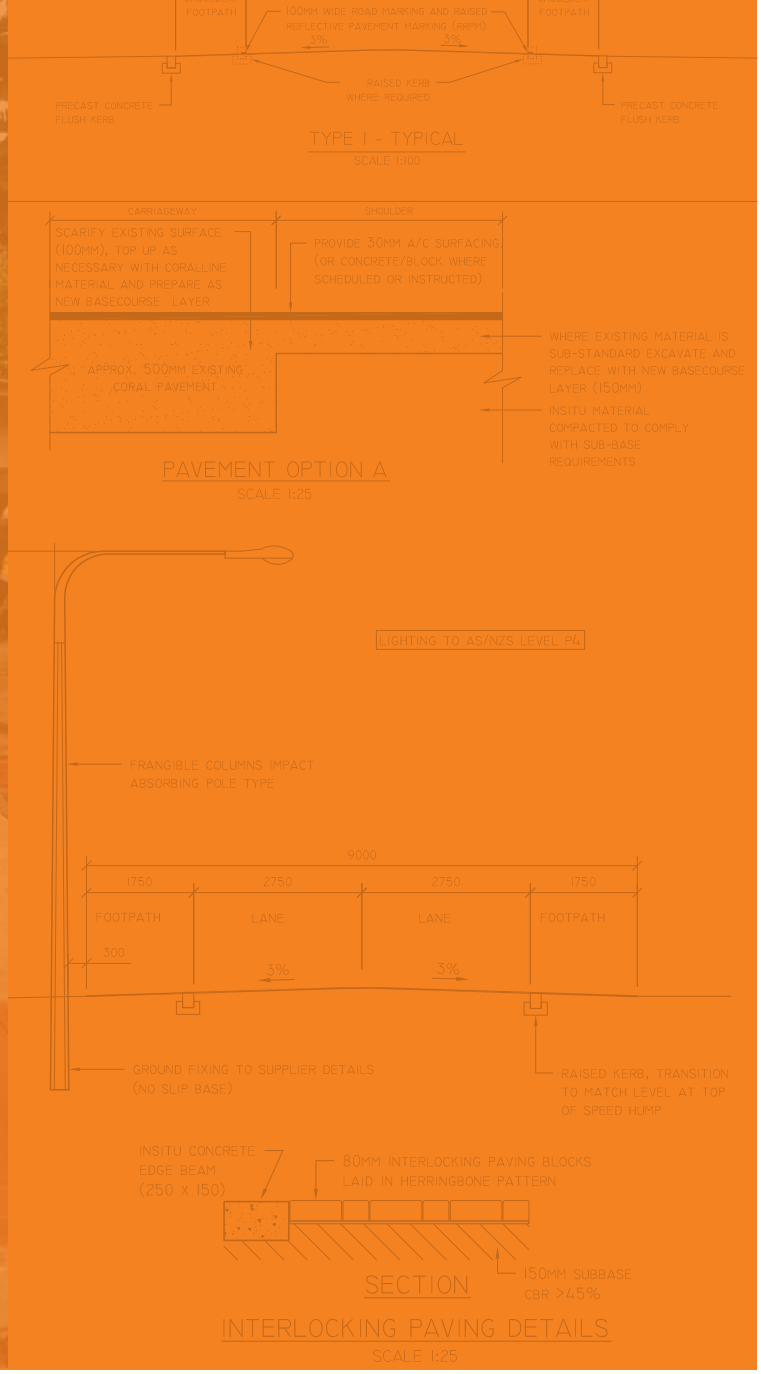

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