Performance of volcanic ash in bituminous mixes

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Department of Public Works and Highways, Philippines

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Subsector:	Transport
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PREFACE

This report forms one of the deliverables from the DFID funded project on Promoting the Use of Volcanic Ash: Phase II, Use in Bituminous Mixes for Road Surfacings which is being undertaken as part of a co-operative research programme with the Bureau of Research and Standards, DPWH, Philippines. It also forms one of the deliverables under Project 3 within the overall Pavement Investigation Research project which is being undertaken with DPWH with the support of the Asian Development Bank.

The purpose of this component of the co-operative research project is to"

Reduce the costs of construction, rehabilitation and maintenance of road infrastructure to help reduce vehicle operation costs.

The objective of Project 3 is

> *To develop methods of using the indigenous marginal materials in the Philippines so that they can be used with confidence for road construction and other civil engineering purposes.*

Project 3 is divided into two parts namely: 'project 3/1 marginal materials for road construction', and project 3/2,' developing stabilised sub-base specifications for both flexible and rigid road pavements in the Philippines'.

The cost of road construction and associated environmental degradation can be greatly reduced if locally available materials, found near the road alignment, can be used in construction, thereby reducing the extraction and haulage of expensive high quality aggregates. Such materials may often be of marginal engineering quality in terms of standard specifications but, by modification and/or suitable design and construction methods, their use can be very cost effective. The methodology of the research is based on successful previous research on indigenous marginal materials in other countries.

Use of stabilized sub-bases for heavily trafficked roads, using materials of either marginal quality (originally) or those of better quality, can effectively counter: poor materials availability or selection; poor construction control; poor drainage and the general effects of the ingress of water. Used with unbound road bases in flexible pavements it can also prevent or reduce reflection cracking in the upper layers of the pavement and improve the overall service life of the pavement.

This report is one of 26 which are being delivered as part of this project. These reports are:

PROJECT 3.1

No	Title	Report code	Type
1	Identifying and mapping marginal materials in the Philippines		Project report
2	Distribution of gravel-sized and fine particulate materials from Mount Pinatubo, Philippines	PR/OSC/172/99	Project report
3	Outline design for pilot scale trial on the Zambales coastal road		Project report
4	Making good use of volcanic ash in the Philippines.	PA 3594/00	Conf. paper

5	The use of volcanic ash in bituminous mixes	PR/OSC/138/98	Project report
6	A study of the volcanic ash originating from Mount Pinatubo, Philippines	PR/INT/194/01	Project report
7	Investigation into the use of Lahar as fine aggregate in hot rolled asphalt and asphaltic concrete wearing courses	PR/INT/220/01	Project report
8	Specifications and guidance for construction: Pilot trials on the Nasugbu to Batangas City Road, Batangas Province: Lahar Asphaltic Concrete and Hot Rolled Asphalt (Station 96+665 to 96+994)		Project report
9	Outline design for pilot scale trials using weathered volcanic rock and soft limestone on the Malicboy to Macalelon road in Quezon Province.		Project report
10	Specifications and guidance for construction: Pilot trials on the Malicboy to Macalelon road, Quezon Province; site Agdangan		Project report
11	Agency estimate for a pilot trial on the Malicboy to Macalelon road, Quezon Province; site Agdangan		Project report
12	Construction report: Pilot trials on the Nasugbu to Batangas City Road, Batangas Province: Lahar Asphaltic Concrete and Hot Rolled Asphalt (Station 96+665 to 96+994)	PR/INT/273/2003	Project report
13	Construction report: soft limestones and weathered volcanics as roadbases trial (Agdangan)		Project report
14	Performance of volcanic ash in bituminous mixes	PR/INT/282/2004	Project report
15	Performance of marginal materials in roadbases: Soft limestones and weathered volcanics		Project report
16	Specification for using lahar and volcanic ash in bituminous mixes		Project report
17	Specifications for the use soft limestone		Project report
18	Specification on the use of weathered volcanics		Project report

PROJECT 3.2

19	Outline design for a pilot scale trial on the Nasugbu to Batangas City road.		Project report
20	Literature review: Stabilised sub-bases for heavily trafficked roads	PR/INT/202/00	Project report
21	Specifications and guidance for construction: Pilot trials on the Nasugbu to Batangas City Road, Batangas Province: Site B, Mabini Junction (Station 142+340 to 142 + 700)		Project report
22	Specifications and guidance for construction: Pilot trials on the Nasugbu to Batangas City Road, Batangas Province: Site A, Santa Teresita pilot trial (Station 135+450 to 135+610)		Project report
23	Construction report: stabilised sub-bases (Bauan/Balayong and Sta Teresita trials)	PR/INT/281/04	Project report
24	Performance report: stabilised sub-bases (Bauan/Balayong and Sta Teresita trials)		Project report
25	Final report		Final report
26	Guidelines on Stabilised Sub-bases		Project report

PERFORMANCE OF VOLCANIC ASH IN BITUMINOUS MIXES

CONTENTS

PERFORMANCE OF VOLCANIC ASH IN BITUMINOUS MIXES

1 INTRODUCTION

The eruption of Mount Pinatubo in The Philippines in 1991 resulted in large volcanic deposits, locally known as lahar. This material is presently used in the manufacture of concrete blocks destined for building purposes. It also has the potential for being a source of aggregate used in road construction.

The grading of lahar samples by sieve analysis from various sources in the Pampanga region has shown that it could possibly be used as fine aggregate in ‘gap-graded’ bituminous mixes, such as Hot Rolled Asphalt (HRA). Hot rolled asphalt has been used in the UK as both wearing course and roadbase materials for many years.

Hot rolled asphalt acquires its strength and stability from the bitumen/filler/fine aggregate mortar in the mix and therefore contains a high proportion of fine aggregates. The fine aggregate fraction can be as high as seventy per cent of the total aggregate in the mix. These types of mix are therefore ideally suited for the use of large quantities of lahar.

The primary objective of this project was to develop standards and specifications for the use of lahar in road construction. As part of this study, the lahar has been investigated as a fine aggregate in bituminous mixes.

The stages of the project comprised,

(1) A review of the location, classification and properties of lahar (reports 2 and 6 – see Preface)
(2) Laboratory testing of potential sources of lahar for use in road surfacings (report 6)
(3) A preliminary laboratory based study of bituminous mix design using lahar (reports 5 and 7)
(4) Design of a full scale trial (report 8)
(5) Construction of the full scale trial (report 12)
(6) Performance monitoring and interim assessment of the road surfacings (this report)

The report begins with some general background information to put the project in context but for comprehensive details the reader should consult the earlier reports, listed above.

2 GENERAL PROPERTIES OF LAHAR

2.1 Geological examination

When Mount Pinatubo erupted in 1991 three different mineral fragments were identified within the large volumes of pumiceous pyroclastic flows; mineral crystals (made in the magma prior to the eruption), glass (formed as the magma cooled in the atmosphere) and rock fragments (broken from the crater walls) (Campbell et al, 1982).

A geological examination by the Philippine Institute of Volcanology and Seismology (PhIVolcS) identified the materials as mostly gravel and sand-sized porphyritic, biotite-hornblende, quartz, latite pumice with a few boulder-sized fragments. A subsequent petrographic examination conducted by TRL in 1999 showed a predominance of plagioclase (35%) and quartz grains (25%) along with agglomerated fine-grained material consisting of the same constituent minerals identified by PhIVolcS. It is likely that the plagioclase fraction was formed during the crystallisation of the hot magma as a result of hot pyroclastic flows being cooled by rainfall and lake breaches.

2.2 Grading

The laboratory testing showed a well-graded coarse sand to silt-sized material, classified as a gravelly sand, with typically more than 85% of the material passing the 2.36mm sieve size. This grading suggested that the material would be suitable for bituminous mixes made with a 'gap-graded' aggregate structure such as HRA, or as part of the fine aggregate component of an AC mix.

2.3 Properties of the soil fines

The plasticity characteristics of the soil fines, i.e. material less than 0.425 mm sieve, was measured by performing standard Atterberg limit tests. The quantity of fine material was measured by wet sieve analysis. In hot mix asphalt the presence of plastic fines can prevent proper adhesion between the aggregates and bitumen and will lower the quality of the film surrounding the particles. Consequently plastic fines in all hot mixes should be avoided.

With the exception of the Pasig-Potrero II sample, the ash is non-plastic. The Pasig Potrero II sample is representative of the material from the old eruption, which displays some plasticity although its grading characteristics are relatively unchanged. This difference in the plasticity of the new pyroclastic material and material from previous eruptions could suggest that the ash is weathering and breaking down into plastic fines. There is some evidence to support this as local landowners note that during the first few years following the eruption the lahar remained bare. However, it is noticeable that the lahar fields are now covered with tall grass and farmers have commented that whilst the ash was initially deficient in minerals it is now possible to grow some crops.

2.4 Specific Gravity

The compositional design of a hot mix surfacing is an essential prerequisite to ensuring that it gives good long-term performance. The balance between the Voids in the Mineral Aggregate (VMA), the bitumen content and the Voids in the Mix (VIM), must be optimised to obtain a strong and long lasting material.

The specific gravity (SG) of the component materials is critical to the proper volumetric design of a hot mix. VMA can be calculated on the basis of the bulk specific gravity of the combined aggregates in the mix. However, because lahar is porous it is important to take into account the amount of bitumen which will be absorbed into the aggregate particles since this will reduce the effective bitumen content of the mix. To determine VIM, therefore, it is essential to measure the maximum SG (G_{mm}) of the mixed materials (ASTM D2041) which allows for the apparent change in SG associated with the absorbed bitumen. Values of Bulk SG and water absorption for the lahar sampled are given in Table 2.1.

Table 2.1 Results of laboratory testing of lahar at BRS

Sample No.	3	4a	4b	5a	5b	6
Sample Name	Bambam	Pasig Potrero I	Pasig Potrero II	Santo Tomas I	Santo Tomas II	Santo Tomas D8
Grading: Max. particle size (mm) % passing 2.36 mm sieve	19.0 86	37.5 64	25.0 85	37.5 76	19.0 85	25.0 84
Atterberg limits	Non-plastic	Non-plastic	LL=24.0-24.5 PI = 6-7	Non-plastic	Non-plastic	Non-plastic
Bulk Specific Gravity	2.29	2.50-2.55	2.55-2.60	2.02-2.05	2.27	2.27
% Absorption	4.60	2.46	3.30-4.17	8.22-8.69	4.60	5.04

3 PRELIMINARY LABORATORY STUDY

3.1 Bituminous road surfacings

Flexible pavements in the Philippines are almost entirely surfaced with asphalt concrete (AC). Asphalt concrete is a dense mix consisting of continuously graded aggregate and gains its strength from aggregate interlock. Asphalt concrete has a low voids content and consequently low permeability but because of this is very sensitive to errors in proportioning.

A more tolerant mix can be developed by using a gap-graded particle distribution that has a higher air voids content than AC but is just as capable of resisting climatic and traffic related damage. One mix of this type is hot rolled asphalt.

The composition of HRA is less dense than AC but is capable of forming an impermeable mix up to an air voids content (or Voids In Mix (VIM)) of approximately 8 percent. This occurs because the voids tend to remain discontinuous even though the VIM content is higher. Consequently, the mix tolerances for HRA are normally wider than for AC and it is less sensitive to variations in the bitumen content.

HRA was developed in the UK and makes use of sand which is readily available from abundant resources found in sand and gravel pits.

Potentially, up to 50 percent of the aggregates in the mix can be sourced from sand-sized deposits. In the Philippines the recent eruption of Mount Pinatubo has provided an abundant supply of sand-sized material (lahar). Therefore, if laboratory and field trials can prove that the lahar is suitable for use as fine aggregate in an HRA mix, it may offer a cheap, more tolerant alternative surfacing to AC.

The main difference in the grading requirements of an HRA mix as opposed to an AC mix is the introduction of a gap in the grading between the 2.36mm and 9.5mm sieve sizes. The material below the 2.36mm sieve size would be mainly lahar.

Coarse aggregate and filler are added to produce a particle-size distribution parallel to the boundaries of the grading envelope. HRA gains its strength from the bitumen, filler and fine aggregate mortar. The coarse aggregate particles in HRA act as an extender but are insufficient to give stone to stone contact. At high proportions, the coarse aggregate provides adequate surface texture, the preferred target for coarse aggregate being about 50 percent.

The specification for HRA indicates a preference for using 40-50 penetration grade bitumen but, in many countries, bitumen with this viscosity can be difficult to obtain. Alternatively, it is possible to use a 60-70 penetration grade bitumen as long as the filler to binder ratio is increased to a value close to 1.0 to increase the stiffness of the mortar. This will contribute to high cohesion in the mix, which provides the internal tensile strength and mix toughness to resist shearing forces.

An AC grading curve should try to avoid the restricted zone, as defined in the Strategic Highway Research Programme (SHRP) Superpave method of mix design. The Superpave restricted zone was originally introduced to limit the amount of natural sand that was typically incorporated into mixes in the USA. This sand was usually pit sand and tended to be rounded. Whilst it is not always the case that an aggregate grading that passes through the restricted zone will be unsatisfactory, by avoiding this area the mix is likely to be more suitable for heavy traffic. The grading curve can pass above or below the restricted zone, but a curve below the zone is less sensitive to fluctuations in bitumen content than a curve passing above the zone.

[Note that at the time of this study, the ideas emanating from the SHRP in the USA were expected to become the worldwide standard for designing bituminous mixes. Thus use was made of Superpave methods in this preliminary laboratory study. However, for a variety of reasons these methods have not proved as universally acceptable as originally expected and, in practice, the Marshall method of mix design has remained the method of choice. Thus the Marshall method was subsequently used for the full scale trials described].

3.2 Preparation of laboratory bituminous mixes

The materials used in the laboratory study comprised lahar from a single source on the Abacan river near to Mt. Pinatubo and coarse aggregate and bitumen from the UK. The coarse aggregate was a crushed granite. The fine aggregate was lahar, all passing a 6.3mm sieve and UK crushed rock fines. A limestone filler was used and the binder was a 60/70 penetration grade bitumen.

The AC wearing course grading conformed to the Asphalt Institute (Asphalt Institute: MS2, 1997) requirements for a mix with a 12.5mm nominal maximum size aggregate. The HRA wearing course grading conforms to Mix WC5 given in Table 8.8 in Overseas Road Note 31 (TRL, 1993). The aggregate particle size distributions for both mixes are shown in Table 3.1.

The aggregate grading for the AC was designed such that it went above the 'restricted zone' developed during the Strategic Highway Research Program (SHRP) and is shown in Figure 3.1. This helps ensure that the mix has adequate VMA and is therefore more likely to resist plastic deformation under traffic. The aggregate grading for the HRA is shown in Figure 3.2. The optimum binder content for both mixes was based on the relationship between VIM and the level of compaction obtained using samples compacted in a gyratory compactor.

Table 3.1 Aggregate mix proportions

Source of material or sieve size on which aggregate is retained	Amount in mix (%)	
	HRA	AC
14mm	5	5
10mm	41	30
6.3mm	0	6
3.35mm	0	10
Crushed rock fines	0	22
Lahar	50	27
Filler	4	0
Total	100	100

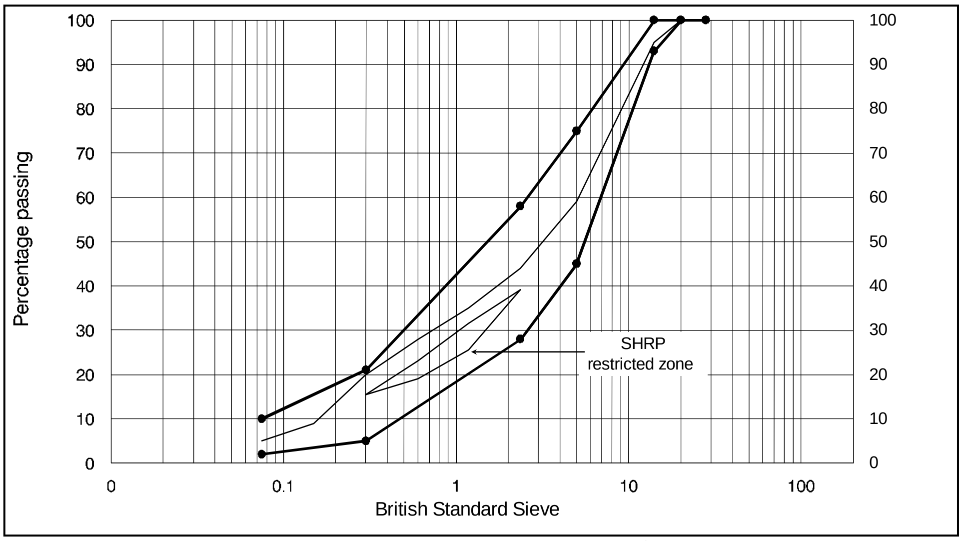

Figure 3.1 Particle size distribution for AC mix

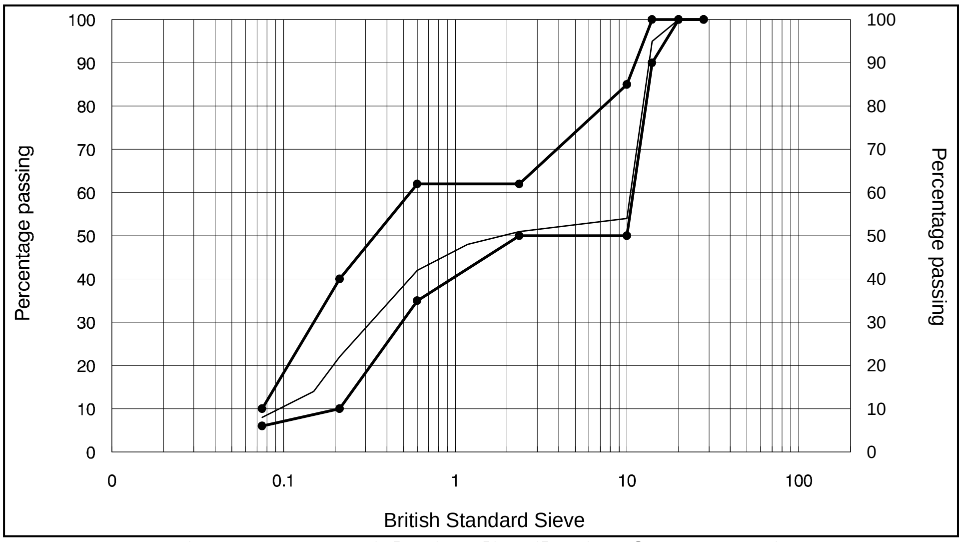

Figure 3.2 Particle size distribution for HRA mix

3.3 Determination of design bitumen content for the AC mix

Two sets of samples covering a range of bitumen contents were compacted to refusal density. In this study this was assumed to be after 600 revolutions in a gyratory compactor. The compacted cores were then tested to determine the bulk specific gravity and maximum specific gravity to enable the relationships between the number of gyrations and VIM to be established. These results are shown in Figure 3.3.

The SHRP recommendations for a design traffic loading of between 3 and 10 million equivalent standard axles (mesa) and the relationships shown in Figure 3.3, suggested that a combination of 120 revolutions of the gyratory compactor and a Design Bitumen Content (DBC) of approximately 5.5 percent would produce an acceptable AC mix with a VIM of 4 percent.

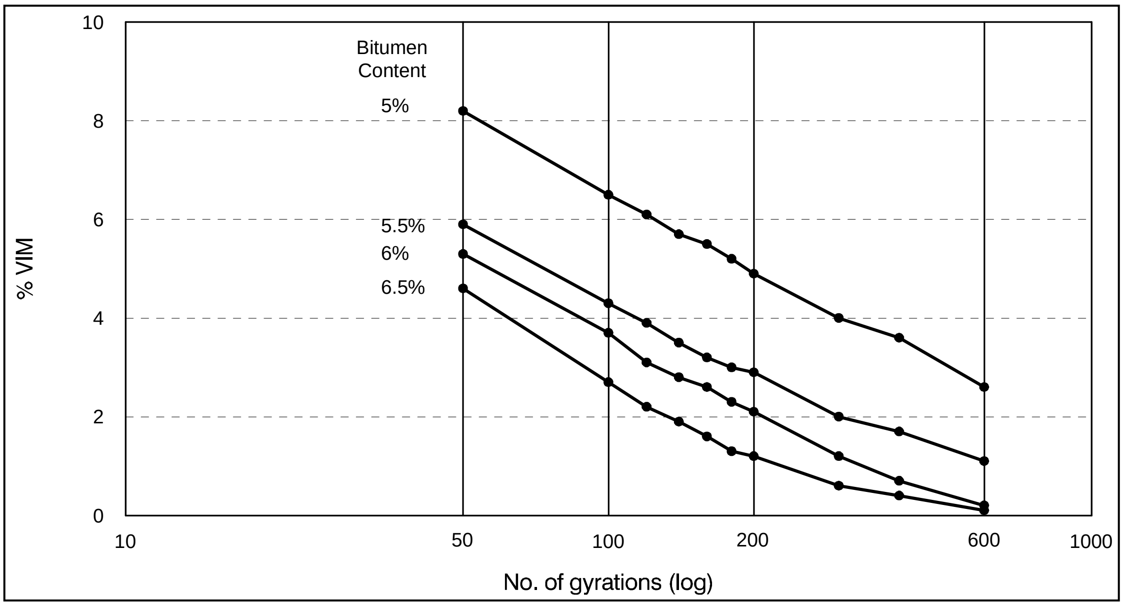

Figure 3.3 VIM versus Number of Gyrations for AC mix

3.4 Determination of design bitumen content for the HRA mix

An important difference between AC and HRA mixes is the level of VIM at which the two mixes become impermeable. For example, the porosity of AC mixes tends to increase rapidly once VIM values exceed 5 percent, whereas HRA mixes can remain impermeable with VIM values as high as 8 percent. A durable HRA could therefore have a VIM of 6 percent. The DBC for the test HRA was selected from the relationships shown in Figure 3.4 to give a mix which would retain 6 percent VIM at 120 revolutions in the gyratory compactor i.e. suitable for a design traffic loading of between 3 and 10 mesa. Inspection of Figure 3.4 shows that the DBC for these conditions is 5.8 percent.

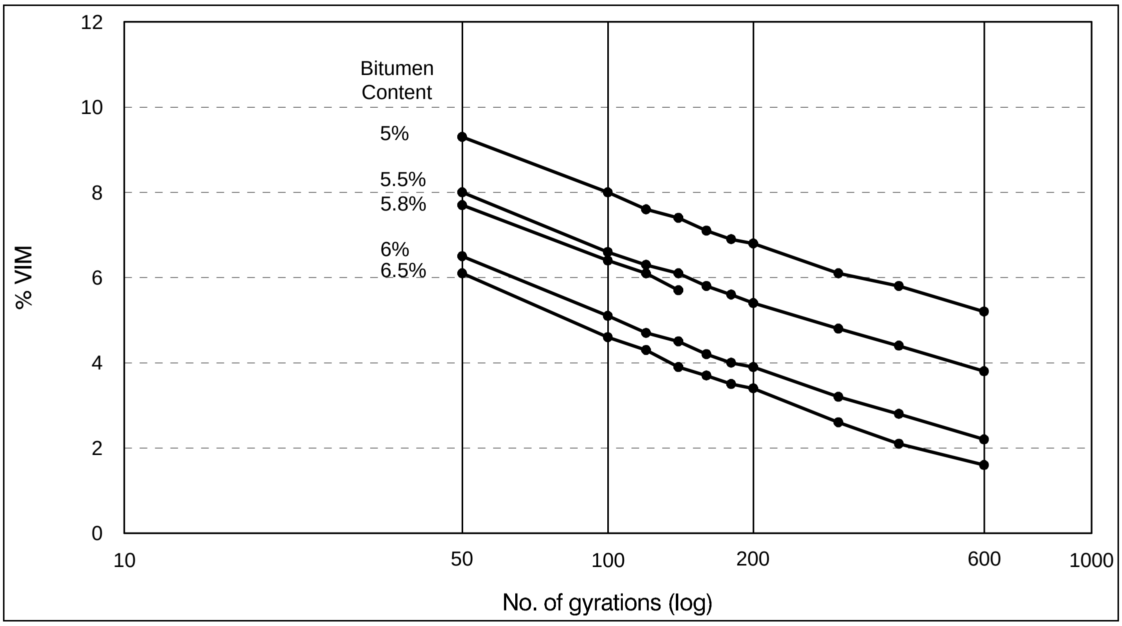

Figure 3.4 VIM v Number of gyrations for HRA mix

3.5 Mix performance

Having established the design grading and DBC for the AC and HRA mixes, their performance characteristics were evaluated using the wheel-tracking test. This test method is used in the UK to determine the susceptibility of, principally, HRA bituminous wearing course materials to deformation under traffic. The test is carried out at 45°C for sites subject to moderately heavy traffic stresses or 60°C for very heavily stressed sites. A test temperature of 60°C is considered appropriate for road surfacing materials to be used in tropical climates and this temperature was therefore used in the study.

Mix densification will occur under moderately heavy traffic but it is usually very difficult to predict the rate and degree of secondary compaction that will actually occur. Thus, to evaluate the performance of the two mixes, duplicate core samples at three levels of VIM for each mix at the design bitumen content were made in the gyratory compactor.

The composition of the cores used for wheel-tracking tests and the results of the wheel-tracking tests are shown in Table 3.2. Figure 3.5 shows the relationship between the mean VIM and mean wheel tracking rates for each mix.

Table 3.2 Details of cores for wheel-tracking tests

Mix Type	Fine Aggregate	DBC (%)	Core No.	VIM (%)	Tracking rate (mm/hr)	
					Result	Specification (See note 1)
HRA	Lahar	5.8	1	7.9	0.3	5.0
			2	7.7	0.5	
			3	6.1	0.2	
			4	6.1	0.5	
			5	4.9	0.1	
			6	4.9	0.0	
AC	Lahar/ Crushed rock	5.5	7	7.4	0.6	
			8	7.6	0.6	
			9	5.9	0.3	
			10	5.9	0.7	
			11	4.7	0.4	
			12	4.3	0.0	

Note 1: UK specification for very heavily stressed site.

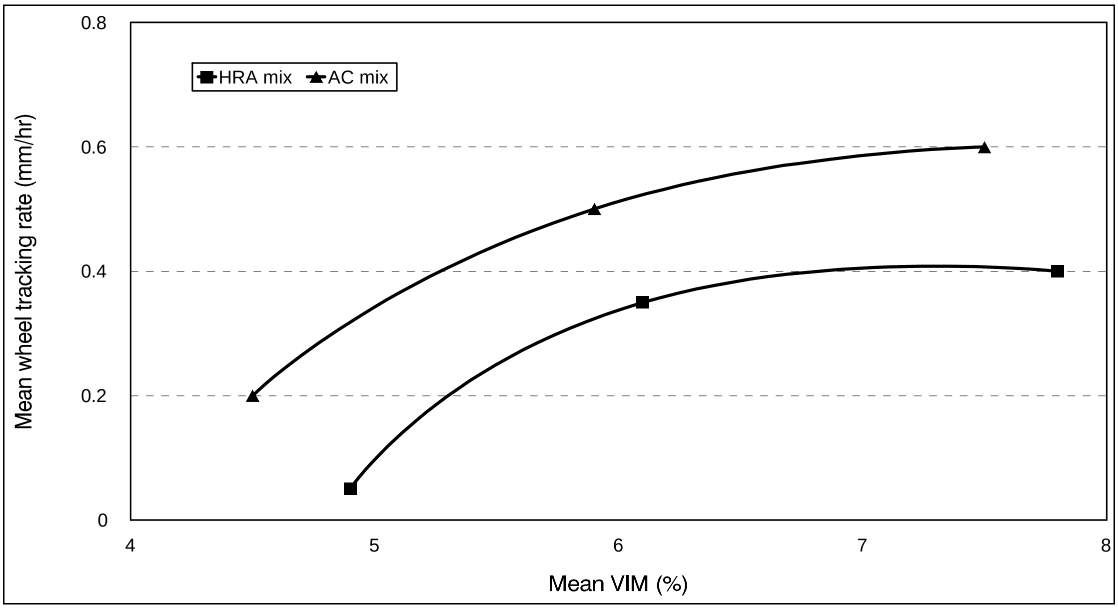

Figure 3.5 Relationship between mean VIM and mean wheel tracking rates

3.6 Conclusions from preliminary laboratory study

The results of the study showed that the wheel-tracking rates for both the AC and HRA mixes are similar and compare very favourably with the maximum rate specified for very heavily stressed sites in the UK. Although both of the mixes are viable, there are considerable advantages in using HRA mixes because of the high proportion of selected lahar that they could contain and their generally favourable performance, as shown through studies in neighbouring Indonesia and elsewhere for the reasons given above.

The results of the study were encouraging and suggested that the use of lahar in HRA and AC bituminous mixes was viable. By incorporating as much as fifty per cent lahar in HRA mixes a very economical surfacing material could be produced. In particular, it was shown that up to fifty per cent of lahar could be incorporated into HRA mixes and that these mixes would be suitable for heavily trafficked roads.

4 FULL SCALE TRIAL

A full-scale trial was constructed to investigate the performance of volcanic ash (lahar) with respect to its technical suitability and cost in comparison with a conventional asphalt concrete wearing course. The trial was constructed between March and April 2002 on the Nasugbu- Palico- Batangas City road in the Philippines.

The trial site was located on a length of PCCP pavement which was in good condition. Prior to overlay, any severe cracks were stitched and joints and other cracks sealed with a joint sealant.

The pilot trial investigates the performance of three types of bituminous surfacing material. These are

- Item 310: Bituminous Surfacing Course, Grading B (Control Section)
- Item SPL-1: Hot Rolled Asphalt with lahar as fine aggregate
- Item 310 (A): Bituminous Surfacing Course, Grading B with lahar as fine aggregate

4.1 Location and design of trial sections

The details of the different trial designs are shown in Table 4.1. The Table gives the start and end stations of the as-built trials and the treatments given to each section. The transitions between sections are also shown.

Table 4.1 Construction details for lahar trials

Section	Trial description	Length	Stations, Km		Pre-treatment	Construction	
		m	from	to		Date in 2002	Lane
T1	Ramp	13	97.018	97.005		April 26,	both
1	50mm Item 310 (A) Grading B with lahar as fine aggregate	115	97.005	96.890	Stitch severity 4 cracks. Seal joints and cracks	April 26,	left
						April 26,	right
2	50mm SPL-1 Hot Rolled Asphalt with lahar as fine aggregate	112	96.890	96.778	Stitch severity 4 cracks. Seal joints and cracks	April 25,	left
						April 23,	right
3	50mm Item 310 Grading B	104	96.778	96.674	Stitch severity 4 cracks. Seal joints and cracks	April 12,	left
						April 13,	right
T2	Compaction trial – SPL-1	29	96.674	96.645		April 17,	left
	Compaction trial – Item 310(A)					April 22,	right

The right lane is the lane away from Manila (i.e. in the direction of increasing chainage). The left lane is the lane towards Manila.

4.2 Aggregate for hot mixed asphalt

Aggregates were available from suppliers in single sizes of 3/4 and 3/8 inches, and as manufactured, crushed sand (S1). A natural sand was supplied from a local mountain source and bagged agricultural lime was used for the mineral filler. The lahar was obtained from Baluyot Quarry, Bambam, Tarlac Province which was a material site approved by the Department of the Environment and Natural Resources (DENR). Details of the suppliers of the materials are given below. The materials were used in the production of Item 310 (Grading B), Item 310 (A) and SPL-1.

- Concrete Aggregates Corporation (CAC) — crushed 3/4 inch
- Robust, Mariveles, Bataan — crushed 3/8 inch
- CAC — Crushed S1 Sand
- Double B Aggregates Supply, Agoncillo — Forest Mountain Sand
- Baluyot Quarry, Bambam, Tarlac — Lahar Sand
- Oria Agrotech — Lime Filler

The compliance testing for these materials is summarised in Table 4.2.

4.3 Mix Design

The mix composition for each of the materials used in the trials was determined by the Marshall laboratory method of mix design. The laboratory results and volumetric calculations are shown in Appendix A. The design bitumen content for the control, AC and HRA Lahar mixes were found to be

5.5%, 4.9% and 5.8% respectively. The aggregate proportions required to meet the grading specifications for each material are shown in Table 4.3.

Table 4.2 Compliance testing for processed and natural materials

GRADING RESULTS		CAC	Robust	CAC	Agoncillo	Lahar	Lime
Cumulative Passing sieve:		3/4 ins	3/8 ins	S1	Sand	Sand	Filler
Inches.	mm						
2.0	50.8						
1.5	38.1	38.1					
1	25.4	100.0					
¾	19.0	95.1					
½	12.7	55.6	100			100	
3/8	9.5	28.8	96.3	100	100	98.1	
¼	6.3						
No 4	4.75	4.26	28.4	94.8	90.2	96.5	
No 8	2.36	2.34	12.0	60.1	82.4	94.2	
No 10	2.0		7.8			88.2	100
No 16	1.18	1.89		33.2	68.2	75.3	
No 30	0.6	1.25		19.3	54.3	59.6	
No. 40	0.42		6.1		37.6	40.3	100
No. 50	0.3	0.91		8.8	24.8	32.2	100
No. 100	0.15		5.9		20.4	19.3	100
No.200	0.075	0.54	2.3	2.6	16.1	9.7	97.3
Unit Weight Kg/m^3	Loose	1694	1600	1604	1384		NA
	Rodded	1857	1713	1869	1642		NA
Specific Gravity		2.775	2.724	2.702	2.496	2.534	2.467
Absorption		0.86	0.92	1.46	2.67	0.70	NA
Liquid Limit		NP	NP	NP	NP	NP	NP
Plasticity Index		NP	NP	NP	NP	NP	NP
Abrasion Loss		19.04	23.1	NA	NA	NA	NA
Soundness Loss		1.22	1.31	5.36	8.18		NA
Sand Equivalent Value		NA	NA	96	79	80	NA
Fractured Face %		100	100	NA	NA	NA	NA
Flakiness Index		21	27	NA	NA	NA	NA
Elongation Index		18	16	NA	NA	NA	NA

Table 4.3 Aggregate proportions

Mix design	CAC crushed 3/4 inch	Robust crushed 3/8 inch	CAC Crushed S1 sand	Agoncillo sand	Lahar sand	Lime
AC Control	19	31	28	20	-	2
AC Lahar	40	23	-	17.5	17.5	2
HRA Lahar	43	-	-	-	53	4

4.4 Compaction trials

It is important to determine the rolling pattern and frequency that is needed to achieve the required final level of compaction of the mixed material after laying. The AC control mix compaction procedure had already been established by the contractor and this was 8-10 passes of an 8-tonne steel-wheeled roller (SWR) followed by 15-20 passes of a pneumatic tyred roller (PTR).

For an AC surfacing layer, the Asphalt Institute (AI MS-2) recommend that the air void (VIM) content of the mix after lay-down should be approximately 8%.

Unlike an AC mix, there is no compaction criteria for a high stone content HRA. The UK Specification for Highway Works (1998) states that rolling shall continue until all roller marks have been removed from the surface. Clearly this is a visual judgement which will also depend upon the temperature at which the material is compacted. Thus although it would therefore seem unnecessary to carry out a compaction trial, it was considered worthwhile for two reasons. Firstly, it enabled some indication of how many passes would be required to free the surface from roller marks and, secondly, since the HRA mix was new to the paving gang, it was an ideal opportunity to gain some experience in laying and rolling this material.

4.4.1 Compaction trial site layout

A 25m section of the site next to the control mix was allocated for the compaction trials. The right lane was used for the AC mix and the left lane for the HRA mix. A schematic diagram of the compaction trial sections is shown in Figure 4.1.

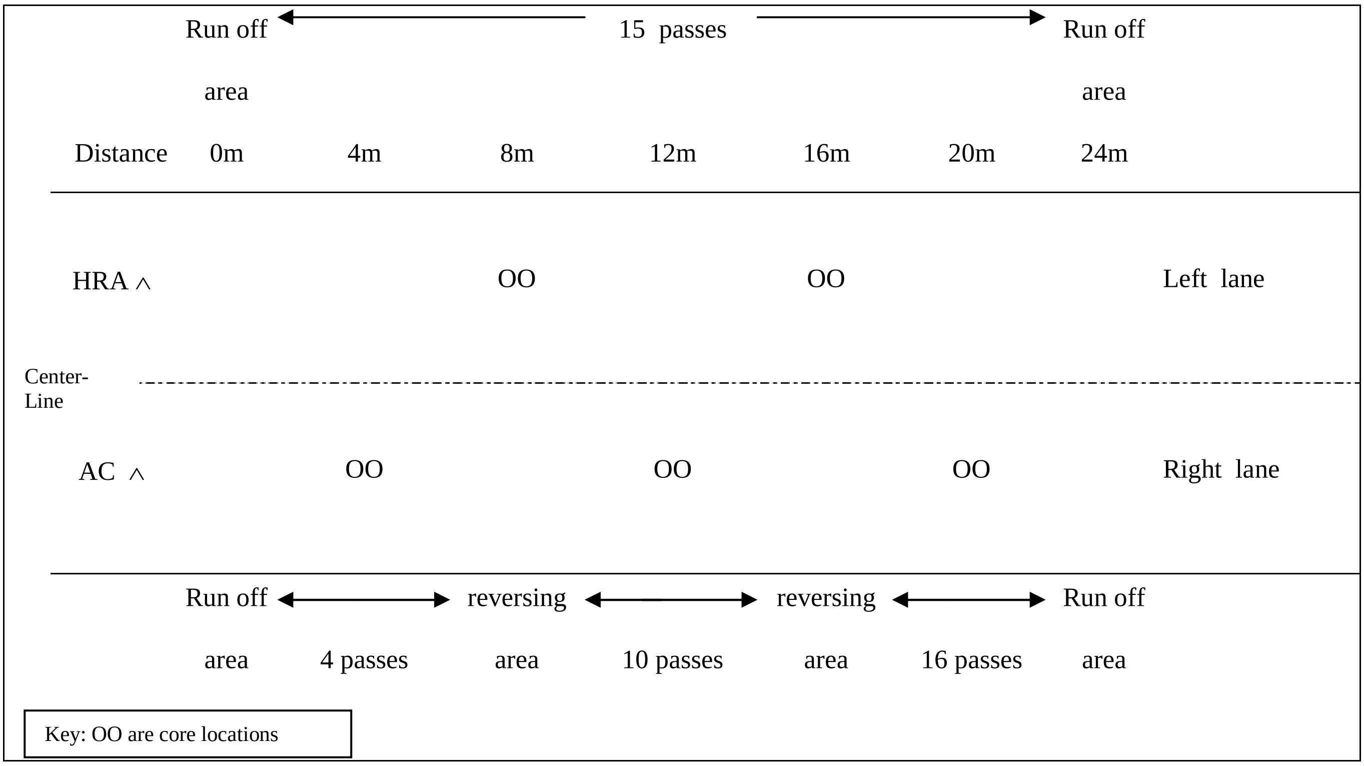

Figure 4.1 Compaction trial layout using SWR

Plate 1 Compaction trial: hot rolled asphalt

4.4.2 AC Lahar mix

Prior to laying, the road surface was tack coated with a slow setting bitumen emulsion applied at 0.4 l/m^2. Twelve tonnes of AC Lahar material were mixed at 150-160°C at the asphalt batching plant and transported in one truck to the laying site. This material was laid along the 25m section using a conventional asphalt paver. This section was then divided into three 8m subsections on which three levels of compaction were carried out namely 4, 10 and 16 passes using the SWR. Finally the whole 25m section was finished off with 15 passes of the PTR. The rolling temperatures measured were between 100 and 120°C.

Two 100mm diameter cores from each 8m section were extracted the following day to determine the thickness, density and VIM content, these results are shown below in Table 4.4.

Table 4.4 Core results of AC lahar compaction trial

Number of passes	Core number	Thickness (mm)	Bulk SG (Mg/m^3)	Maximum SG (Mg/m^3)	VIM (%)
4 SWR 15 PTR	1	64	2.232	2.439	8.5
	2	63	2.206	2.439	9.6
10 SWR 15 PTR	3	53	2.251	2.437	7.6
	4	51	2.264	2.437	7.1
16 SWR 15 PTR	5	49	2.253	2.419	6.9
	6	50	2.253	2.419	6.9

For the compaction levels of 4, 10 and 16 passes, the mean VIM content of the cores was found to be 9.1%, 7.4% and 7% respectively. Thus it was decided that a rolling pattern of 8 passes of the SWR followed by 15 passes of the PTR would be needed to achieve the 8% VIM as specified by the Asphalt Institute.

4.4.3 HRA Lahar mix

The road surface was prepared as for the AC mix using a bitumen emulsion. Twelve tonnes of HRA Lahar material were mixed at 150-160°C at the asphalt batching plant and transported in one truck to the laying site. This material was laid along the 25m section using a conventional paver. No problems were encountered in laying the material and it was found that 15 passes of the SWR were sufficient to free the surface of roller marks. Finally the whole 25m section was finished off with 20 passes of the PTR. The rolling temperatures measured during the trial were between 105 and 109°C.

Four 100mm cores at intervals of 8m were extracted the following day to determine the density and VIM content, the results are shown in Table 4.5. In the absence of a compaction specification, this information may prove useful for future specification guidelines.

Table 4.5 Core results from HRA lahar compaction trial

Number of Passes	Core Number	Thickness (mm)	Bulk SG (Mg/m^3)	Maximum SG (Mg/m^3)	VIM (%)
15 SWR 20 PTR	1	63	2.294	2.438	5.9
	2	60	2.278	2.438	6.6
	3	60	2.330	2.438	4.5
	4	58	2.299	2.438	5.7

4.5 Construction of main trial.

The full scale trial was constructed as described in detail in the construction report. Details of the mix design are shown in Appendix A of this report.

4.5.1 Sampling and testing of material from the trial.

Samples of the hot mixed material were taken from augers of the paving machine for laboratory testing. The tests included grading, bitumen content analysis and wheel-tracking to evaluate deformation. In addition, 100mm cores were extracted from the road surface to measure the bulk density and thickness of the compacted material.

4.5.2 Grading and bitumen content

The samples of the mixed material were tested in the Contractors testing laboratory. The results and the Job Mix Formula (JMF) specification are tabulated in Table 4.6 and shown graphically in Figure 4.2

4.5.3 Core results

A pair of 100mm cores was taken in the oil lane (the area between the wheel-paths) of each carriageway at approximately 25m, 50m and 75m along each section of the laid material. The cores were used to measure thickness of the layer and the bulk specific gravity (BSG). The mean of each pair of results is shown in Table 4.7. The VIM contents are calculated using the maximum specific gravity value at the mix design optimum bitumen content.

Table 4.6 Grading and bitumen content of the mix samples

Passing sieve (mm)	AC CONTROL MIX			AC LAHAR			HRA LAHAR		
	JMF Spec	Left lane	Right lane	JMF Spec	Left lane	Right lane	JMF Spec	Left lane	Right lane
19	95-100	100	98.2	95-100	98.6	99.0	95-100	97.2	96.1
12.5	71-85	84.0	82.6	70-84	72.3	74.3	71-85	79.5	80.0
9.5	63-77	71.1	73.5	58-72	60.7	62.0	59-73	69.8	71.0
4.75	42-56	51.0	55.5	37-51	41	43.3	47-61	50.2	61.0
2.36	35-43	40.7	36.5	32-40	34.4	36.0	47-55	47.2	57.3
1.18	23-31	28.6	23.9	28-36	29.4	30.1	41-49	42.1	49.4
0.600	13-21	17.9	16.0	20-28	22.9	23.3	30-38	33.1	36.4
0.300	7-15	11.0	10.6	10-18	15.4	14.9	16-24	20.3	22.4
0.075	2-6	4.3	6.2	3-7	4.8	4.4	5-9	7.4	7.5
% bitumen	5.1-5.9	5.6	5.7	4.5-5.3	5.1	4.9	5.4-6.2	5.8	6.0

Table 4.7 Core location and densities

Material	Location	Chainage (km)	Thickness (mm)	BSG (Mg/m^3)	Maximum specific Gravity (Mg/m^3)	% VIM
AC Control Mix	Left lane	96+724	44.5	2.342	2.481	5.7
		96+749	59.5	2.344	2.481	5.5
		96+774	65	2.346	2.481	5.5
	Right lane	96+724	62.5	2.344	2.481	5.6
		96+749	61	2.333	2.481	6.0
		96+774	64	2.349	2.481	5.3
AC Lahar	Left lane	96+909	58.5	2.291	2.459	6.9
		96+949	49.5	2.266	2.459	7.9
		96+989	53	2.286	2.459	7.1
	Right lane	96+909	55	2.295	2.459	6.7
		96+949	56	2.288	2.459	7.0
		96+989	48	2.282	2.459	7.2
HRA Lahar	Left lane	96+802	63.9	2.296	2.437	5.8
		96+827	48.2	2.295	2.437	5.8
		96+852	54.4	2.271	2.437	6.8
	Right lane	96+802	58.5	2.296	2.437	5.8
		96+827	60	2.296	2.437	5.8
		96+852	54	2.280	2.437	6.4

4.5.4 Marshall Tests

In addition to bitumen content, aggregate grading and coring, Marshall tests were also carried out during construction. The results of the bituminous material tested during construction are summarised below in Table 4.8.

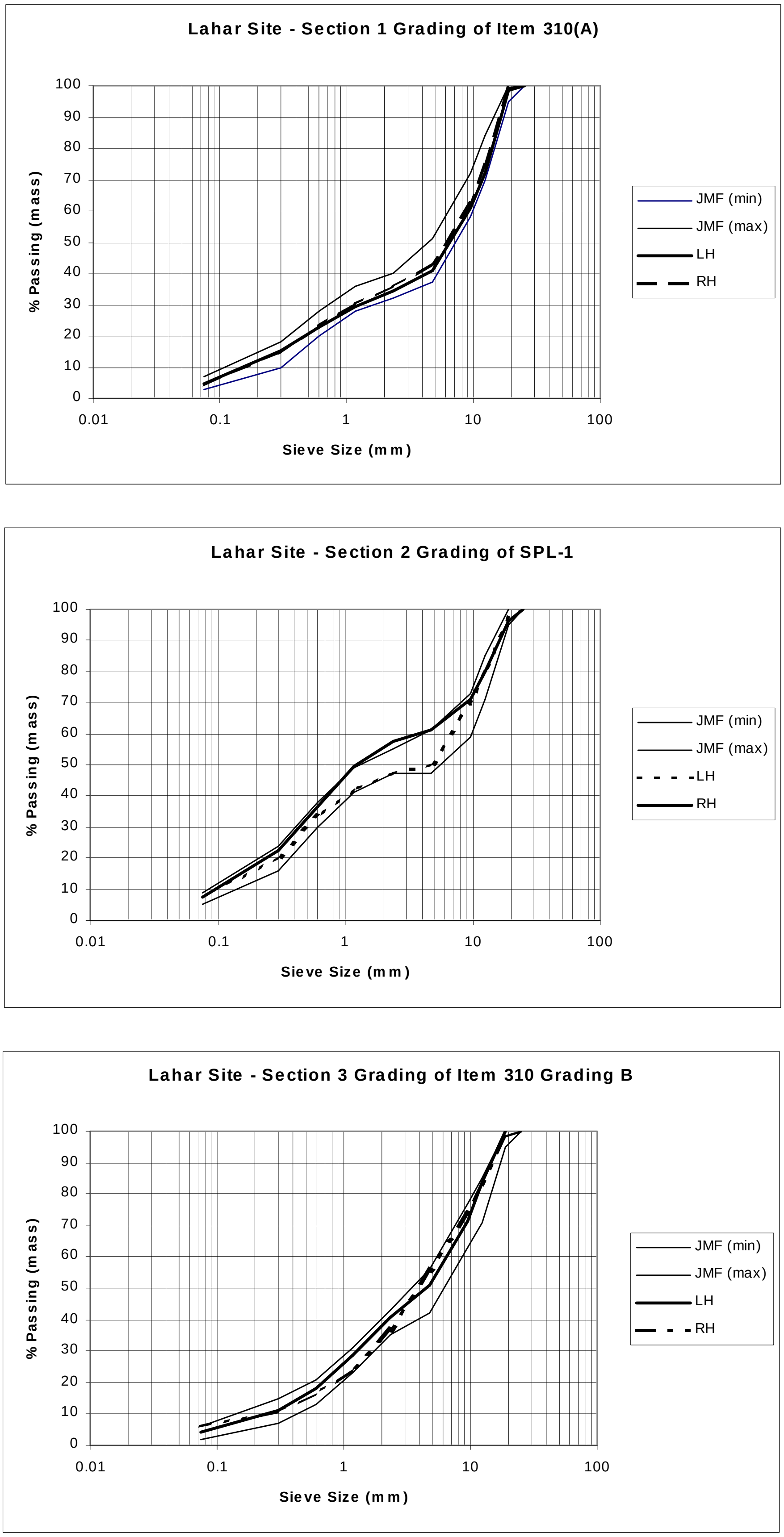

Figure 4.2 Results from the Job Mix Formula

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Table 4.8 Summary of Marshall test results - 75 blow Marshall compaction

Date sampled	Specification	04/12/02	Specification	04/12/02	04/26/02	Specification	04/17/02	04/23/02	04/25/02
Lab No	Item 310	MS-310B-004	Item 310 (a)	MS-AC lahar - 007	MS-AC lahar - 010	SLP-1	MS HRA 005	MS-HRA 008	MS-HRA 009
Section No/Lane	-	3	-	Compaction	1		Compaction	2 / Right	2 / Left
Bitumen Content (%)	5.1 - 5.9	5.5	4.5 – 5.3	5.1	5.1	5.4 – 6.2	5.7	5.96	5.78
Marshall Properties									
Stability **kg**	544 minimum	1715	> 815	927	950	435 – 815	1066	959	987
Flow (mm)	2 - 4	3.05	2 – 3.5	2.33	2.20	<5	2.27	2.27	2.43
Air Voids (VIM)	3 to 6	3.2	3 – 5	4.5	4.5	-	4.4	3.4	3.6
Voids in the mineral aggregate (VMA)	> 13	14.1	> 13	16.3	16.2	-	16.6	16.6	16.7
Voids filled with asphalt cement (VFAC)	70-80	85.9	65 – 75	83.7	83.8	-	83.4	83.4	83.3
Soak for 24 hrs at 60°C									
Stability **kg**	-	1446	-	819	834	-	905	855	873
% Loss	20% max	15.6	-	11.7	12.0	-	15.1	10.8	11.6

5 IN SERVICE PERFORMANCE OF TRIAL SURFACINGS

The purpose of this full scale trial is to assess how the bituminous mixes perform under service conditions. If the HRA and AC mixes incorporating lahar are to be successful then they must resist deformation under conditions of heavy traffic and high temperatures and they must not fail for any other unforeseen reasons.

In the preliminary laboratory study (see paragraph 3.6) performance assessment by wheel-tracking tests showed that the two mixes *should* be able to withstand very heavy traffic without excessive deformation. However the relationship between wheel-tracking rate and long term performance is very sensitive to climatic conditions and therefore, for this reason alone, it is prudent to monitor the trials for somewhat longer than has been possible so far.

Furthermore, with untried materials, other forms of unexpected deterioration may occur, so once again the only way to be sure that new materials will perform satisfactorily for long periods of normal service is to monitor their performance until they do eventually deteriorate to an unsatisfactory level. Only then can there be full confidence in the materials and be able to design for a predictable life. Therefore the trial surfacings we will need to be monitored for some time to come.

Appendix C describes the traffic and axle load analysis for the site. The cumulative traffic to date in one direction is 1.5 million equivalent standard axles (in two years).

5.1 Additional wheel-tracking tests.

There are, however, some measurements that can be taken during the life of the materials to give greater confidence at an early stage. Thus in November 2003, 18 months after the construction of the trial sections, core samples were taken from the road to re-assess their likely future performance after this initial trafficking period. Six cores were taken from each of the two bituminous mixes, HRA and AC sections incorporating lahar, and also six from the control asphalt concrete section. The performance of the materials was carried out by subjecting the cores to wheel-tracking testing in the UK. The results of the testing are given in Table 5.1.

The results are comparable to those obtained from the initial study and give greater confidence that the bituminous mixes are viable and able to withstand the conditions of heavily stressed sites.

5.2 Surface condition measurements

Various measurements of surface condition were carried out in the early life of the surfacings and the results are summarised in Tables 5.2 and 5.3 below. To carry out these measurements, each traffic lane is sub divided into 5 linear metre blocks by paint marking and information is recorded for each block as necessary.

The low values of texture depth are as expected for HRA since no chippings were rolled into the surface for these trials. It can be concluded that there is nothing in the data so far that gives cause for concern.

Table 5.1 Results of wheel-tracking testing carried out in the UK

Material	Specimen Identity No.	Specimen Density Mg/m^3	Maximum Rut Depth (mm)	Wheel tracking Rate (mm/hr)	Wheel tracking Rate UK specification, very heavily stressed site (mm/hr)
AC Lahar	1	2.276	0.5	0.1	5.0
	2	2.292	0.6	0.1	
	3	2.273	0.5	0.2	
	4	2.264	0.4	0.2	
	5	2.301	0.5	0.2	
	6	2.284	0.5	<0.1	
Mean		**2.282**	**0.5**	**0.2**	
HRA Lahar	7	2.306	0.4	0.3	
	8	2.319	0.8	0.2	
	9	2.293	0.7	0.2	
	10	2.233	1.0	0.3	
	11	2.300	0.3	<0.1	
	12	2.291	0.6	0.1	
Mean		**2.290**	**0.6**	**0.2**	
AC Control	13	2.381	0.5	0.3	
	14	2.373	0.6	0.2	
	15	2.367	0.9	0.2	
	16	2.394	0.5	0.3	
	17	2.375	0.7	0.3	
	18	2.417	0.4	<0.1	
Mean		**2.385**	**0.6**	**0.3**	

Table 5.2 Cracking as of July 2004

Section	Direction	No of blocks	No of cracked blocks	Length of cracking per 100 lane metres (m)
AC Lahar	To Manila	23	1	1.3
AC Lahar	To Nasugbu	23	3	10.4
HRA Lahar	To Manila	23	0	0
HRA Lahar	To Nasugbu	23	0	0
AC Item 310	To Manila	21	1	3.0
AC Item 310	To Nasugbu	23	1	0.8

Table 5.3 Skid resistance and texture depth as of November 2003

Section	Skid Resistance				Texture Depth			
	LL		RL		LL		RL	
	OWP	IWP	IWP	OWP	OWP	IWP	IWP	OWP
AC Lahar	43.3	59.4	57.6	55.7	0.44	0.51	0.42	0.47
HRA Lahar	63.7	64.7	61.7	64.4	0.33	0.33	0.30	0.31
AC Item 310	60.9	57.2	62.7	60.8	0.25	0.28	0.32	0.35

6 INDICATIVE COST BENEFITS

The saving from the use of lahar in either asphalt concrete or hot rolled asphalt have been considered in terms of the unit cost of asphalt concrete, Item 310 of the DPWH standard specifications. An average value of approximately Pesos 3500 for the unit cost per metric tonne was obtained from a list of the ADB Sixth Road Project civil works contracts. Using the standard 15% for indirect costs, the direct cost of Item 310 is Pesos 3043. This (direct cost) is apportioned between the costs of labour (1.5%), equipment (11.5%) and with the cost of materials accounting for the remaining 87%. Allowing for the cost of lime in the mix of Pesos 70, the remainder is usually split equally between the cost of bitumen and the cost of aggregates. A typical asphalt cement content of 5.5% has been assumed. The actual split will be determined by the relative haul distances to the batching plant for mixing. The cost of aggregates is therefore Pesos 1250, approximately.

Average pick-up prices in Pesos for aggregates canvassed from 4 suppliers for the sizes in use were: P326 for 3/4 inch; P194 for 3/8 inch; and P143 for S1. Haulage rates for bitumen and aggregates obtained were given as either per 200kg drum, or by volume. The equivalent costs are Pesos 7.29/t/km for asphalt cement and 2.35/t/km for aggregates.

The proportional usage of aggregates and lahar in the pilot trials are given in Table 4.3. Using this basis, the savings from the use of lahar are 18% and 33% of the cost of aggregates in asphalt concrete and hot rolled asphalt, respectively. These values give savings in the unit costs of 7.5% and 13.5% in AC or HRA, respectively. They equate to savings of P390,000 per kilometer for a surfacing with a thickness of 50mm and a width of 7.0m.

The costs of lahar from a material site approved by the DENR and operated by a contractor were approximately Pesos 720 for $20m^3$ loaded. Approximately 50% of this cost is paid back to the DENR, giving further benefits in the use of the lahar.

Further savings can be made by reducing the proportion of 3/4 inch aggregate in the mix because the cost of this size is 90% higher than the average cost (pick-up prices) of the other crushed aggregates (3/8 and S1) in the mix. The specification for HRA permits a reduced proportion of 3/4 to be used and finer gradings can be chosen for the asphalt concrete mix. In addition, it may be possible to remove or reduce the quantity of any other natural sands in the mix.

By examining the lahar available from a number of DENR approved sources together with the manufactured aggregates that are also available, it should be possible to prepare quality hot mixed asphalt surfacings at considerably lower cost than conventional surfacings.

7 CONCLUSIONS AND INTERIM RECOMMENDATION

Conclusions

1. The design of both the HRA mix and the AC mix using lahar followed standard Marshall methods and the design criteria could be achieved. For the HRA, the method was consistent with the recipe method.
2. In the case of the HRA, all of the sand-sized material was lahar and this provided 50% of the total aggregates. For the AC mix, 17.5% of sand-sized material was lahar sand and the other 17.5% was natural sand.
3. The full-scale trials have been trafficked for 2 years and show no signs of deterioration after exposure to the environment and after carrying a traffic loading of 1.5mesa. The average annual daily traffic is 10,500 vehicles. All the sections are performing similarly.
4. Wheel track testing in the laboratory indicates that the mixes will perform under trafficking of up to 10mesa.
5. The cost savings amount to 7.5% (AC Lahar) and 13.5% (HRA Lahar) of the unit cost of asphalt concrete. These savings are considerable. For example, if it were possible to use HRA with lahar as fine aggregates for the whole of the structural overlay component of the Sixth Road Project alone, the savings would exceed Pesos 840M ($9M).
6. Further savings are possible by reducing the use of one of the standard aggregates (3/4 inch) which is considerably more expensive than the others. This is permitted within existing specifications.

Interim recommendation

The project has shown that lahar is a suitable low cost alternative to conventional aggregates for both AC and HRA surfacings. Far greater cost savings may be achieved with the use of HRA. As an interim recommendation, lahar can be used as the fine aggregate in bituminous HRA or AC for surfacings designed to carry up to 2mesa.

8 FURTHER WORK

Performance monitoring of the trials should continue to ensure that no unforeseen deterioration occurs and to enable the interim recommendations to be upgraded to considerably higher traffic levels and therefore achieve a far greater application.

When sufficient performance data is available, the potential for whole life benefits should be examined because the current satisfactory performance is sustained these benefits will be in addition to those obtained from unit construction costs.

Studies should be expanded to include other regions in the Philippines with these materials. The lahar available from: other DENR approved sources near Mount Pinatubo and those in the vicinity of other volcanoes in the Philippines should be examined, together with the manufactured aggregates that are also available. It should then be possible to prepare quality hot mixed asphalt surfacings at considerably lower cost than conventional surfacings over a much greater geographical area.

9 ACKNOWLEDGEMENTS

This Report was produced in the Infrastructure Division of TRL Limited (Director Mr M Head) on behalf of the Department for International Development. The research was carried out in the Research and Development Division of the Bureau of Research and Standards (Director Mr A V Molano) in the Philippines and their valuable co-operation has been essential to the success of this project.

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APPENDIX A

MARSHALL MIX DESIGNS

A.1 Particle size distribution

Aggregate samples were taken from the plant hot bins for the determination of particle size distribution. The proportions of aggregates were then calculated to give a blend which conformed to the material specification. The resultant aggregate blend and specifications for the control mix (Item 310), AC (Item 310(A)) and HRA lahar (Item SPL-1) mix designs are shown in Figures A1 to A3.

	Percentage passing		
Sieve size	Mix	Specification	
(mm)	blend	Min	Max
25	100	100	100
19	96	95	100
12.5	78	68	86
9.5	70	56	78
4.75	49	38	60
2.36	39	28	47
1.18	27	18	37
0.600	17	11	28
0.300	11	6	20
0.075	4	0	8

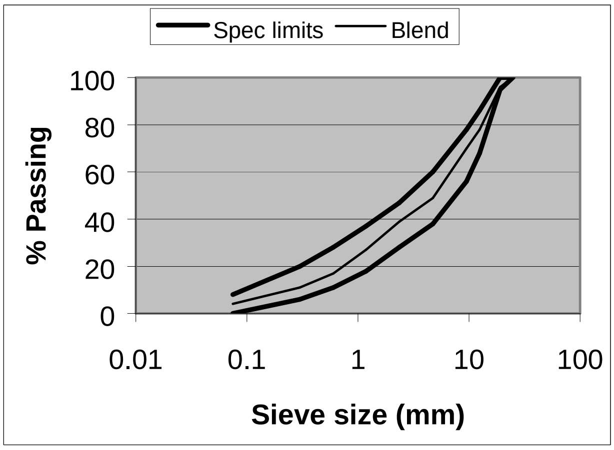

Figure A1 AC control mix grading

	Percentage passing		
Sieve size	Mix	Specification	
(mm)	blend	Min	Max
25	100	100	100
19	100	90	100
9.5	65	56	80
4.75	44	35	65
2.36	36	23	49
0.300	14	5	19
0.075	5	2	8

Figure A2 AC lahar mix grading

	Percentage passing		
Sieve size (mm)	Mix blend	Specification	
		Min	Max
20	100	100	100
14	83	90	100
10	69	50	85
2.36	51	50	62
0.600	34	20	40
0.212	17	10	25
0.075	7	6	10

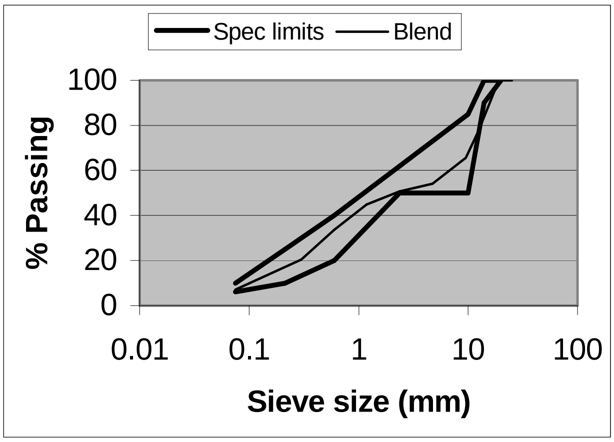

Figure A3 HRA lahar mix grading

A.2 Marshall testing

The Marshall data and the calculated volumetrics of the three mix designs used for the surfacing trials are shown in Tables A1 to A3.

Table A1 AC control mix Marshall data

Bitumen %	Specific gravity (Mg/m^3)		Voids			Marshall stability (kN)	Flow (mm)
	Specimen Bulk SG	Maximum SG Loose material	VIM %	VMA %	VFB %		
5.0 A	2.348					14.9	3.5
5.0 B	2.369					15.1	3.7
5.0 C	2.347					14.1	3.8
Mean	2.355	2.497	5.7	15.7	63.8	14.7	3.7
5.25 A	2.368					16.0	3.3
5.25 B	2.364					16.8	3.1
5.25 C	2.374					15.5	3.4
Mean	2.369	2.490	4.9	15.4	68.6	16.1	3.3
5.5 A	2.399					17.8	3.2
5.5 B	2.411					15.9	3.2
5.5 C	2.401					17.5	3.2
Mean	2.404	2.479	3.0	14.4	78.9	17.1	3.2
5.75 A	2.394					18.1	2.9
5.75 B	2.398					17.3	3.2
5.75 C	2.393					17.0	3.3
Mean	2.395	2.473	3.2	15.0	78.8	17.5	3.1
6.0 A	2.382					16.5	3.2
6.0 B	2.388					16.7	3.1
6.0 C	2.382					15.2	3.4
Mean	2.384	2.467	3.4	15.6	78.4	16.1	3.2

Table A2 AC lahar mix Marshall data

Bitumen %	Specific gravity (Mg/m^3)		Voids			Marshall stability (kN)	Flow (mm)
	Specimen Bulk SG	Max. SG loose material	% VIM	% VMA	% VFB		
4.5 A	2.331					7.1	2.4
4.5 B	2.314					6.8	2.4
4.5 C	2.341					7.1	2.4
Mean	2.328	2.467	5.6	16.1	64.9	7.0	2.4
4.7 A	2.325					8.8	2.4
4.7 B	2.336					8.9	2.4
4.7 C	2.342					8.2	2.4
Mean	2.334	2.460	5.1	16.0	68.1	8.6	2.4
4.9 A	2.334					8.0	2.2
4.9 B	2.358					8.6	2.2
4.9 C	2.330					11.0	2.5
Mean	2.341	2.452	4.6	16.0	71.5	9.3	2.3
5.1 A	2.353					8.2	2.5
5.1 B	2.349					8.4	2.3
5.1 C	2.348					8.5	2.4
Mean	2.350	2.445	4.4	16.3	72.8	9.5	2.4
5.3 A	2.345					8.8	2.3
5.3 B	2.369					9.3	2.4
5.3 C	2.389					11.1	3.0
Mean	2.368	2.438	2.9	15.3	81.0	9.7	2.6
5.5 A	2.390					10.2	2.7
5.5 B	2.392					11.4	2.9
5.5 C	2.367					10.5	2.3
Mean	2.383	2.431	2.0	15.0	86.7	10.7	2.6
5.7 A	2.361					8.2	2.8
5.7 B	2.393					10.5	3.0
5.7 C	2.403					10.3	2.6
Mean	2.386	2.424	1.6	15.1	89.4	9.7	2.8

Table A3 HRA lahar Marshall data

% Bitumen	Specific gravity (Mg/m^3)			% VIM	Marshall stability (kN)	Flow (mm)
	Bulk SG	Max. SG loose material	Compacted Aggregate			
5.0 A	2.299				8.9	2.1
5.0 B	2.294				11.0	2.2
5.0 C	2.300				8.8	2.0
Mean	2.297	2.465	2.182	6.8	9.6	2.1
5.5 A	2.325				11.4	2.9
5.5 B	2.329				8.4	2.5
5.5 C	2.324				10.5	3.0
Mean	2.326	2.447	2.198	4.9	10.1	2.8
5.75 A	2.331				10.7	2.1
5.75 B	2.333				9.4	2.7
5.75 C	2.338				10.3	2.5
Mean	2.334	2.438	2.200	4.3	10.1	2.4
6.0 A	2.341				10.9	2.4
6.0 B	2.337				9.4	2.4
6.0 C	2.345				7.7	2.2
Mean	2.341	2.429	2.201	3.6	9.3	2.3
6.25 A	2.359				8.1	2.2
6.25 B	2.355				8.8	2.9
6.25 C	2.365				9.9	2.3
Mean	2.360	2.421	2.213	2.5	8.9	2.4
6.5 A	2.340				10.7	3.1
6.5 B	2.347				9.0	3.1
6.5 C	2.339				9.6	3.0
Mean	2.342	2.412	2.190	2.9	9.8	3.1
6.75 A	2.325				8.7	3.0
6.75 B	2.333				8.7	3.2
6.75 C	2.300				8.1	3.0
Mean	2.320	2.403	2.162	3.5	8.5	3.1

A.3 Calculation of the design bitumen content

The calculation of the DBC for each of the three mixes depends upon the Marshall criteria specified for that material. In the case of the AC control mix, which is the Philippine DPWH specification, the DBC is calculated from the mean of the optimum bitumen contents at 4.5% VIM, maximum stability and at maximum bulk specific gravity.

The AC lahar mix is based on the Asphalt Institute Specification and the DBC is determined at 4% VIM. For the HRA the DBC is determined according to British Standard (1990) and is calculated from the mean of the optimum bitumen contents at maximum stability, maximum bulk specific gravity and at the maximum aggregate density.

Graphs plotting the Marshall properties for each of the mixes are shown in Figure A4 for the AC control mix, Figure A5 for the AC lahar mix and Figure A6 for the HRA lahar mix.

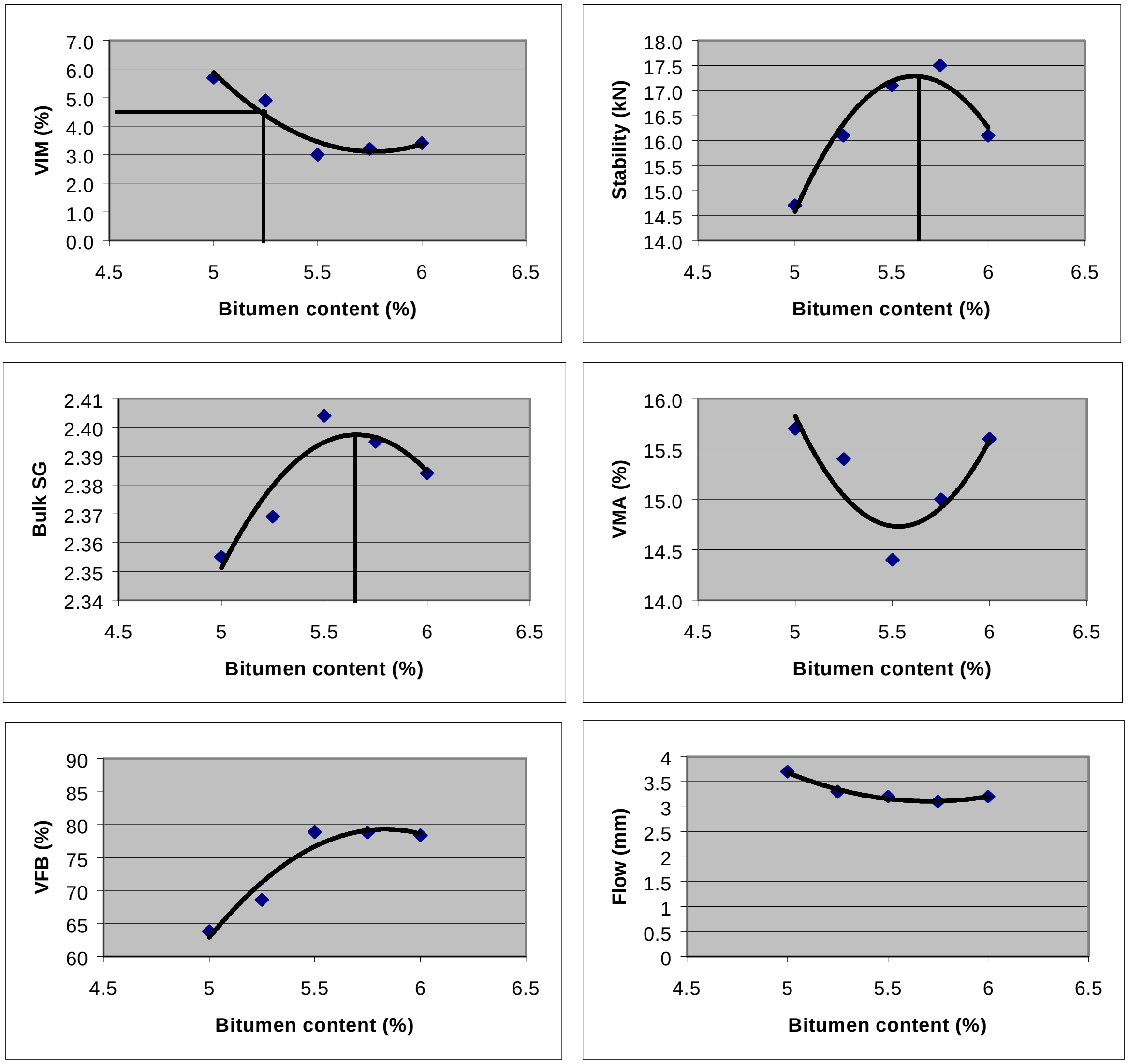

Figure A4 Marshall properties for AC control mix

The DBC for the AC control mix = (5.25+5.6+5.6)/3 = 5.5%

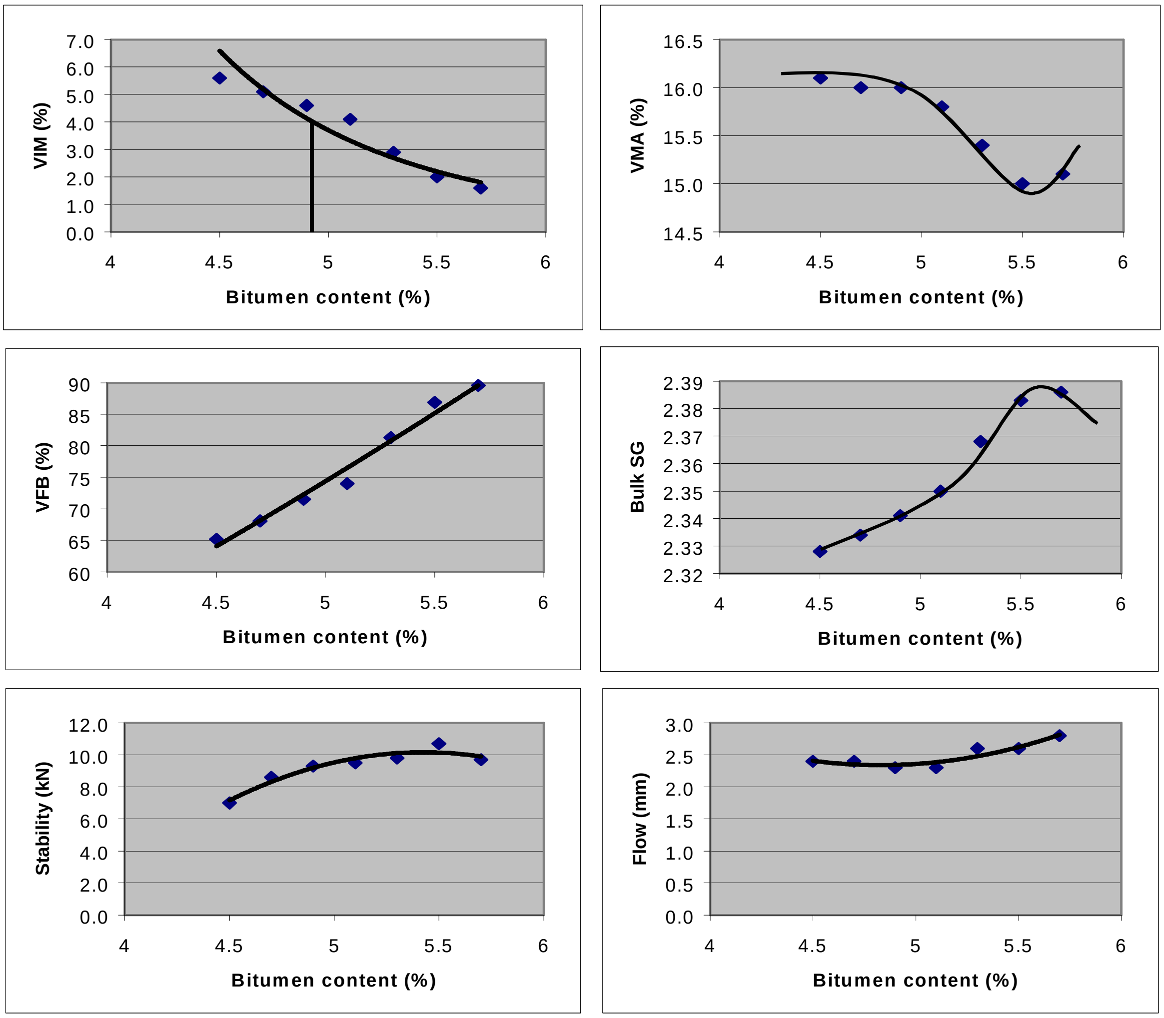

Figure A5 Marshall properties for AC lahar mix

The DBC for the AC lahar mix at 4% VIM = 4.9%

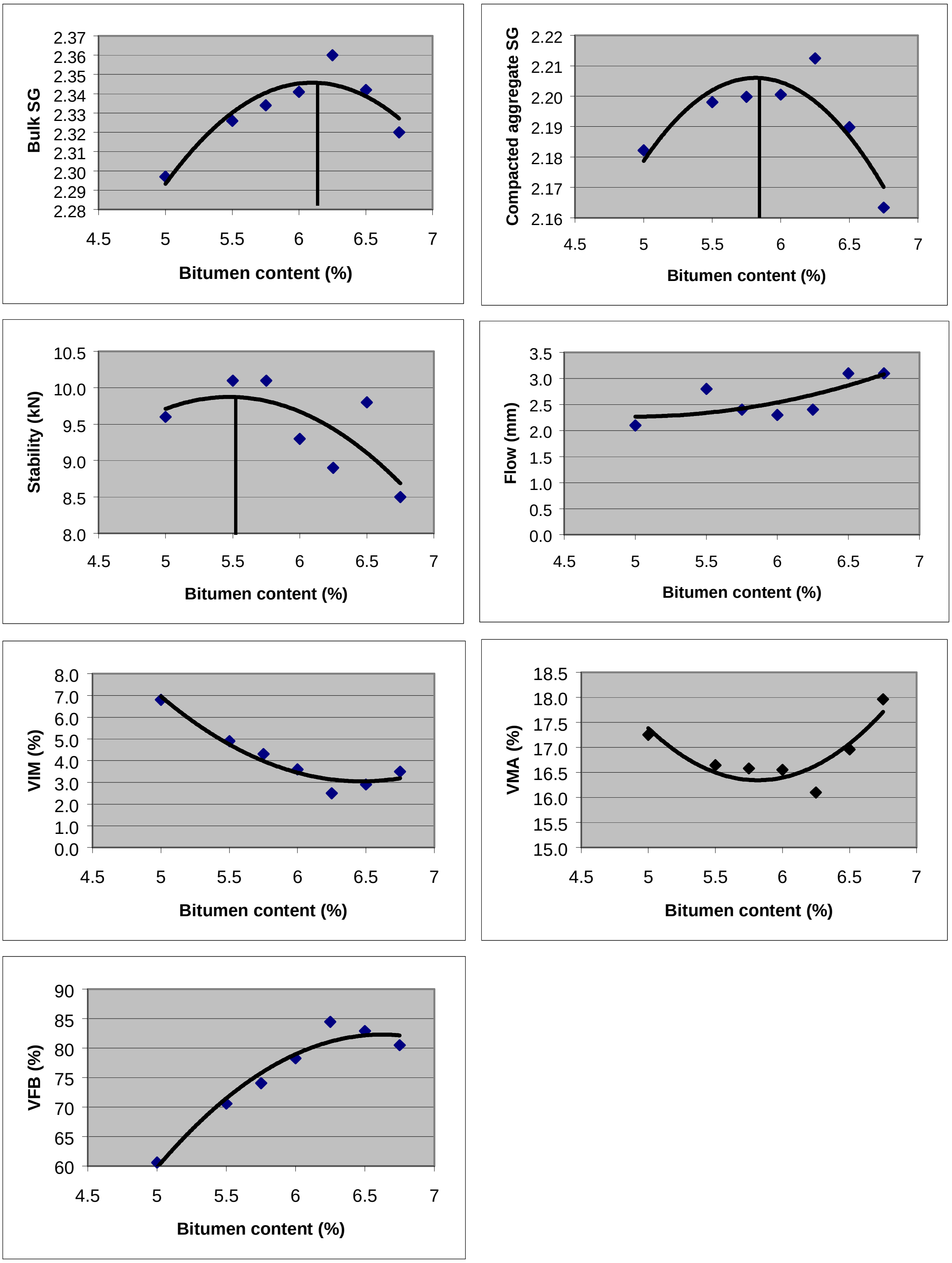

Figure A6 Marshall properties for HRA lahar mix

The DBC for the HRA lahar mix = (6.1+5.8+5.5)/3 = 5.8%

A.4 Marshall mix criteria

By using the graphs in the figures above, other Marshall properties at the DBC can be evaluated. These can then be compared with any Marshall criteria specification. Table A4 shows the Marshall properties at the DBC for each mix and the specification criteria.

Table A4 Marshall criteria

	AC Control Mix		AC Lahar		HRA Lahar	
	Spec[1]	Value at DBC	Spec[2]	Value at DBC	Spec[3]	Value at DBC
VIM (%)	3-6	3.5	3-5	4.0	-	3.9
VMA (%)	14-20	14.8	>13	16.0	-	16.3
VFB (%)	70-80	77.3	65-75	72.0	-	76.3
Stability (kN)	>5.3	17.3	>8.0	9.2	4-8	9.8
Flow (mm)	2-4	3.2	2-3.5	2.3	<5.0	2.4

Notes
1. DPWH Republic of the Philippines
2. Asphalt Institute MS-2
3. BS 594 Part 1

APPENDIX B

BRS WHEEL TRACKING EQUIPMENT DETAILS

B1 WHEEL TRACKING TEST

Purpose

Dry Condition: To measure the Dynamic Stability (DS) which shows the rutting resistance of asphalt mixtures in the hot condition.

Wet Condition: To get the Stripping Ratio (SR) which shows the stripping resistance of asphalt mixtures.

Test Equipment/Apparatus

A. Wheel Tracking Test Machine

- Specimen: 300 x 300 x 50 mm
- Wheel: Solid Tire, Dia. 200 mm x width. 50 mm
- Tracking Speed: 42 ± 1 pass/min.
- Tracking Distance: 230 ±10 mm

B. Apparatus for the Preparation of Specimens

- Frame: for the specimen above
- Roller: Compactor with heater
- Mixer with heater
- Balance: Max. capacity - more than 15 kg. Min. graduation- less than 1.5g

Test Method

A. Sample

1. Number of Sample: Prepare at least three for each combination of aggregates and asphalt content.

2. Preparation of Aggregates: Dry aggregates to constant weight at 105 to 110 °C and separate the aggregates to dry-sieving into the desired size fractions. The following size fractions are recommended. 13.2mm, 4.75mm and 2.36mm.

3. Determination of Mixing and Compaction Temperature: The temperature to which the asphalt cement must be heated to produce a viscosity of 180 ± 20 cSt shall be the mixing temperature. The temperature to which the asphalt cement must be heated to produce a viscosity of 300 ± 30 sSt shall be the compacting temperature.

4. Preparation of Mixtures: Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 300 x 300 x 50 mm = 4,500 cm^3.

Weight of Specimen = 4500 **x** D **x** 1.03

4500: Volume of Specimen (cm^3)
D: Standard Density of the Compacted Mixture (g/cm^3)
1.03: Weight Loss Ratio

Place the pans on the hot plate or in the oven and heat to a temperature not exceeding the mixing temperature, by more than approximately 28*°C*. Transfer the mixtures heated into a mixer and dry mix for about 10 seconds. Weigh the pre-heated required amount of asphalt into the mixture. Care must be exercised to prevent loss of the mix during mixing and subsequent handling. At this point, the temperature of the aggregate and asphalt shall be within the limits of the mixing temperature. Mix the aggregate and asphalt until thoroughly coated.

5. Compaction of Specimens: Thoroughly clean the specimen frame assembly and the face of the compactor of a roller compactor and heat them to a temperature between 100 and 150 °C. Place the entire batch in the frame, spade the mixture vigorously with a heated spatula around the perimeter and heap up the center of the specimen. Compact the mixture using a roller compactor with the compaction loads 900 kg (8.33 kN). Number of compaction shall be established in the calibration for the specimen density to reach to 100 ± 1% of the standard density of the mixture.

6. Curing: After the compaction, write the compaction direction on the surface of the specimen and allow it to stand overnight (12 hours) at room temperature. After the curing, measure the density of the specimen.

B. Tracking Test

1. Number of Tests: The test shall be conducted at least three times for each combination of aggregates and asphalt content.

2. Curing of specimens prior to the tracking test: Settle the specimen into the frame and bring the specimen to the specified temperature (60 ± 2*°C)* in the wheel tracking test machine for more than five hours prior to the tracking test not exceeding 24 hours.

3. Tracking Test: Place the specimen with the frame to the Wheel Tracking Test Machine and place the thermometer on the corner of the specimen. Start the tracking test at the center of the specimen when the surface temperature becomes 60 ± 0.5 *°C*. The load of the wheel shall be 70 ± I.0 kg (686 ± I0N).

4. Measuring: Measure the deformation at every five minutes until 70 minutes. If the deformation exceeds 25mm, within 70 minutes, read the time when the deformation becomes 25 mm.

5. Calculation of the Result: In this test, following values are calculated.

Symbol	Name	Definition
RT (mm/min)	Rate of Tracking	Ratio of the deformation to time, when the deformation reach to 15 mm or at 45 min.
RD (mm/min)	Rate of Deformation	Deformation per one minute between 45 and 60 minutes.
DS (pass/mm)	Dynamic Stability	Number of wheel pass per one millimetre deformation between 45 and 60 minutes.
Do (mm)	Consolidated Deformation	Intersection of vertical axis and the product of the line between 45 and 60 minutes (see figure 1 below)

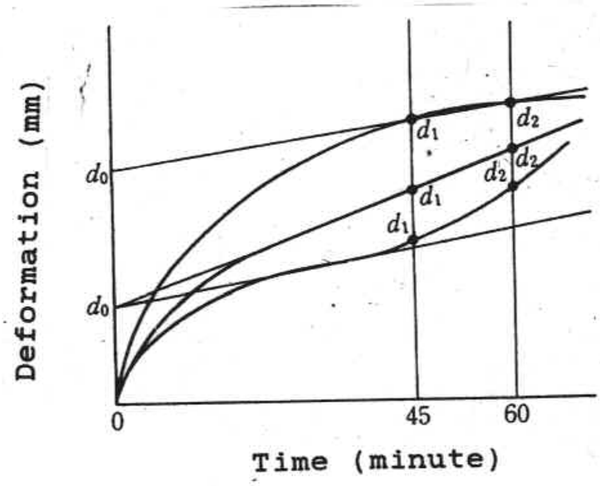

FIGURE 1 DEFORMATION CURVE

$RD = (d_2 - d_1)/15$

$DS = 42 \times (15/(d_2 - d_1))$

where d_1 : deformation at 45 minutes (mm)
d_2 : deformation at 60 minutes (mm)

C. Evaluation of the Result

Dynamic Stability and rutting depth of asphalt pavement have a correlation in the researches in Japan. In Japan, the target value of the DS of asphalt pavement in heavy traffic is 1500 pass/mm, based on the results in the past (Figure 2, 3 and 4 on the next page).

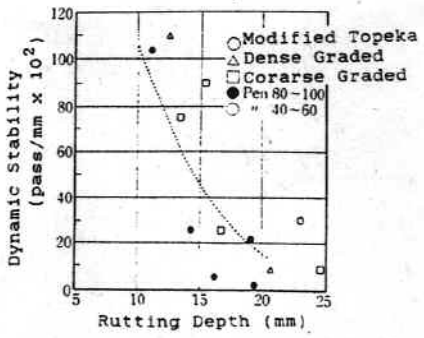

FIGURE 2 RELATION BETWEEN RUTTING AND DS (Cumulative Heavy Vehicle Traffic Volume 15 x 10^6)

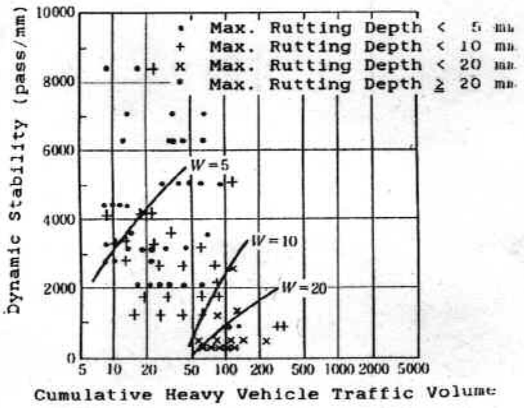

FIGURE 3 RUTTING DEPTH AND DS

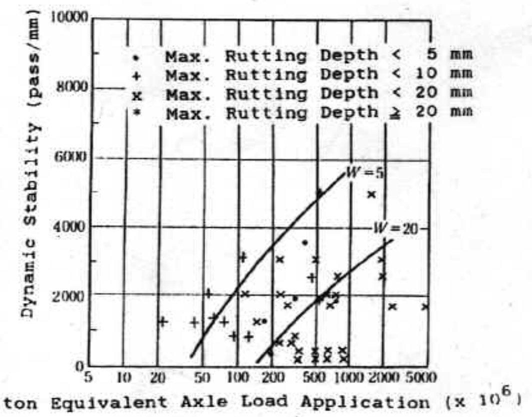

FIGURE 4 RUTTING AND DS (at intersection)

Note: Based on communications with JICA; in Figure 3 on this page the multiplication factor x10^4 should be inserted on the x-axis and on Figure 4 on this page the multiplication factor of the x-axis should be changed from 10^6 to 10^4 .

APPENDIX C

TRAFFIC ANALYSIS

C1 Location

The site is located on the road from Palico junction (on the Tagaytay to Batangas City road via Tuy) and is the main route to the towns of Nasubgu and Lian to the west. To the south of the road and with many entrances is the very large Don Pedro Central cane processing facility. Along the road on the north side are many small commercial outlets, schools and residences. The Don Pedro sugar Central dominates the local traffic conditions during the sugar cane hauling season from November to May and numerous short-term truck parks are located along the road and in the vicinity. The Central processes about 1,000,000 tonnes of sugar cane annually and produces about 120,000 tonnes of raw sugar which is then transported to the sugar refinery at Balayan. Trucks haul cane from all directions to the Central and are usually assigned to the parking areas until called to the plant for unloading.

C2 Traffic counts

Traffic volumes and loading for the trial site have been determined by considering two available traffic surveys; the Pavement and Axle Load Study of 1984, PALS84, (DPWH 1985) and the MetroCount (MetroCount, 2000) studies undertaken in this project in 2003 and 2004. Use has also been made of the KAMPSAX study which was undertaken in 1994 (DPWH 1995).

The PALS84 survey was undertaken using the familiar manual classified counting method whereas the MetroCount (MC) study was undertaken by a modern automatic classified counting system supported by a computer based analysis package.

The MC system counts cumulative axle events from vehicle tyres running over (‘hitting’) pneumatic tubes fixed across the road. By using a twinned tube layout on the site, each spaced from the other by 1m, the data can be assessed as numbers of vehicles in a traffic category. The principal method of separating axle ‘hits’ into vehicle categories is by measuring (very accurately) the time between hits on the adjacent tubes which, in turn, provides a measure of the wheelbase between subsequent axles or the arrival of the next vehicle. These data may then be analyzed using algorithms provided with the system. To simplify analysis, a number of categories are given as options for the user. From these the “ARX” system was selected, principally because it isolated motor cycles and motor tricycles from other traffic and yet retained sufficient other sub-divisions of the traffic mix, although further analysis was still required to separate buses and 2-axle trucks in class C4 (Class C4 contains 2-axle vehicles with a wheelbase of >3.2m). The ARX system is shown below.

Using the MC system, automatic traffic counts were collected separately in each direction during November 2003 (before the sugar cane hauling started) and in April/May 2004 during the sugar cane hauling season. Counting continued for a continuous minimum period of at least 7 days and often longer. The estimated number of vehicles counted in one direction was approximately 35,000 for the November survey and 102,000 for the April/May surveys. The traffic flow is approximately equal in each direction.

C3 Classification of traffic

The Average Annual Daily Traffic (AADT) given in the PALS84 Study was 2,600 comprising 2,000 light vehicles, 50 buses and 550 trucks. Growth rates given for the periods 1984 to 1989, 1989 to 1994 and 1994 to 2004 were 1%, 5% and 5% for buses and light vehicles, and 0%, 2% and 2.5% for goods tonnage.

Using these data and applying the growth rates annually at the end of each period, the AADT values were estimated for 2002 (when the trial was constructed) and for 2003 and 2004 when the MetroCount studies were undertaken. These AADT values are shown in Table C1.

Table C1 Traffic volumes

Study	Year	Light	Buses	Trucks	AADT
PALS84	1984	2,000	50	550	2,600
PALS84	2002	3,964	99	758	4,799
PALS84	2003	4,162	104	755	5,021
PALS84	2004	4,370	109	774	5,253
MC03	2003 November	8,729	94	610	9,433*
MC04	2004 April	9,728	115	1,627	11,470*
MC average	2004 average	9,229	105	1,119	10,452

* these are ADT values

Traffic volumes measured in 2003 and 2004 using the MetroCount system gave AADT's of 9,433 and 11,470 in November and April/May, respectively. The increase in April/May is attributed to increased truck traffic during the sugar hauling season and increased light traffic in the summer vacation season. Given that the sugar hauling season is for half the year, the average value for the ADT's has been used to estimate the AADT. From the Table it can be seen that the estimate for the light traffic given by the MC system is more than twice that estimated by the PALS84 survey. It is not known whether the PALS84 study excluded motor cycle and tricycle traffic, so perhaps this could explain the differences. Or maybe this is evidence of much higher growth over the years than those estimated in 1984. The differences in truck traffic are likely to be caused by seasonal sugar cane hauling and this is discussed in detail in the next Section.

C4 Estimate of traffic loading

In the PALS84 study, the percentages of loaded trucks towards Palico junction and towards Nasugbu were 24% and 80%, respectively and the annual Equivalent Standard Axles (ESA) given for the year 1984 were 230,000 and 368,000 for the traffic towards Palico and towards Nasugbu. Present and future projected truck composition by number of axles per vehicle was 69% for 2-axle, 12% for 3-axle, 18% for 4-axle and 1% for 5-axle trucks.

Applying these growth data to the estimated annual loading given in the PALS84 study for the more heavily loaded direction (368,000 ESA) provides a projection for annual values for 2002 (when the trial was constructed) of 502,000 ESA as shown in Table C2. The data for 2003 and 2004 projected in the same way are also shown in Table C2.

The MetroCount traffic data have also been analyzed to provide an estimate of ESAs based on the ADTs measured during this project. To do this it has been necessary to sub-divide the 2-axle vehicle data in category C4 into those which are passenger Jeepneys or into other 2-axle vehicles by selecting an appropriate value for the wheelbase of the Jeepneys. The wheelbase of a sample of Jeepneys was measured and found to be invariably 3.8m. Using the PALS84 study projections for each particular year of counting, the number of large buses has also been separated from the remainder of the 2-axle vehicles.

The value of 80% for the loaded (and 20% for the unloaded) truck traffic used in the PALS84 study has been reviewed. General loaded and unloaded vehicle weight figures were also given by KAMPSAX in their 1994 study. These assumed a lower loaded percentage of 65%. Given the weighting for this road whereby 50% of the sugar trucks are unloaded on their return journey, the value of 65% loaded seems sensible and has been adopted.

Using the same equivalence factors for the vehicles as used in the PALS84 study the projected annual loading for 2002, 2003 and 2004 given by the MetroCount system are shown in Table C2. It can be seen that the values outside the sugar hauling season are about 20% lower and those within the season are twice as large as the PALS84 values. The average for the year is then 50% higher than projected in the PALS84 study. To examine the likely cause of this difference, the tonnage of sugar cane received and the raw sugar produced by the Don Pedro factory has been considered together with the weights given for the sugar cane hauling trucks.

Table C2 Traffic loading

Study	Year	ESA per year (x1000)
PALS84	1984	368
PALS84	2002	502
PALS84	2003	515
PALS84	2004	529
MC	2003	432
MC	2004	1,068
MC average	2004	750

As mentioned in the PALS84 study, the annual tonnage of cane processed at the Don Pedro factory was nearly constant for the previous 20 years at 1,000,000 tonnes. The hauling trucks are 6-wheeler (2-axle) or 10-wheeler (3-axle) trucks, and their average payloads are 12 tonnes and 20 tonnes respectively. The proportion of each is not given and so for this estimate a 50% split has been assumed. Given these values, the total tonnage would require 66,667 loaded journeys. With a hauling season of six months this would contribute an average of 365 loaded vehicles per day and the same number unloaded; totaling 730 per day. By considering the total raw sugar processed by the Balayan sugar refinery and that produced by the four Centrals in the region, the tonnage of raw sugar produced by the Don Pedro central has been estimated to be 120,000 tonnes. The truck types which deliver this is not known and the use of 3-axle trucks with a load capacity of 20 tonnes has been assumed. Delivery of this amount over 6 months of the year adds a further 6000 loaded journeys or 65 loaded and unloaded journeys per day in the season. It can be seen, therefore, that the additional daily truck traffic could account for an increase in ADT of nearly 800 per day. Given that the increased activity at the sugar Central would also lead to increases in associated traffic, the increase of truck traffic of approximately 1000 per day shown in Table C1 is reasonable.

Considering the annual ESAs in the above estimates, carriage of the sugar cane and raw sugar alone would contribute 490,000 ESAs to the annual loading. Therefore the annual average estimate given in Table C2 of 750,000 is also considered reasonable. Thus the trial has carried 1.5million equivalent standard axles in the two years since construction.

C5 ARX Classification Scheme

ARX Classification Scheme

ARX is a modification of AustRoads94. It removes class 12, moves all other classes up by one, and inserts a cycle class as class 1.

Level 1	Level 2		Level 3	ARX Classification			
Length	Axles and Groups		Vehicle Type				
Type	Axles	Groups	Description	Class		Parameters	Dominant Vehicle
	Light Vehicles						
Short up to 5.5m	2	1 or 2	Very Short Bicycle or Motorcycle	MC	1	d(1) < 1.7m and axles = 2	
	2	1 or 2	Short Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc.	SV	2	d(1) >= 1.7m, d(1) <= 3.2m and axles = 2	
Medium 5.5m to 14.5m	3, 4 or 5	3	Short - Towing Trailer, Caravan, Boat, etc.	SVT	3	groups = 3, d(1) >= 2.1m, d(1) <= 3.2m, d(2) >= 2.1m and axles = 3,4,5	
	Heavy Vehicles						
	2	2	Two Axle Truck or Bus	TB2	4	d(1) > 3.2m and axles = 2	
	3	2	Three Axle Truck or Bus	TB3	5	axles = 3 and groups = 2	
	> 3	2	Four Axle Truck	T4	6	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	Three Axle Articulated Three axle articulated vehicle or Rigid vehicle and trailer	ART3	7	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	Four Axle Articulated Four axle articulated vehicle or Rigid vehicle and trailer	ART4	8	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	Five Axle Articulated Five axle articulated vehicle or Rigid vehicle and trailer	ART5	9	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	>= 6	> 2	Six Axle Articulated Six (or more) axle articulated vehicle or Rigid vehicle and trailer	ART6	10	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium and Long Combination Over 17.5m	> 6	4	B Double B Double or Heavy truck and trailer	BD	11	groups = 4 and axles > 6	
	> 6	5 or 6	Double or Triple Road Train Double road train or Heavy truck and two trailers	DRT	12	groups = 5 or 6 and axles > 6	
	Ungrouped Classes						
			Unclassifiable Vehicle		13		
			Unclassifiable Axle Event		0		

Group: Axle group, where adjacent axles are less than 2.1m apart

Groups: Number of axle groups

Axles: Number of axles (maximum axle spacing of 10.0m)

d(1): Distance between first and second axle

d(2): Distance between second and third axle

MetroCount Traffic Executive User Manual

C6 Traffic analysis references

DPWH 1985. Pavement and Axle Load Study Final Report (in 3 volumes). Ministry of Public Works and Highways. Republic of the Philippines. (Renardet S.A. and Associates) Philippines 1985.

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