DETERMINATION OF NOTABLE TOLERENCE LIMITS FOR BITUMEN AND AGGREGATE FOR ASPHALT CONCRETE MIXTURES IN SRI LANKA

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

Determination of notable tolerance limits for bitumen and aggregate for asphalt concrete mixtures in Sri Lanka

The development of corrugation along longitudinal profile is one of the most common failures in asphalt pavement. The corrugation distresses are usually more severe in road sections with high longitudinal slope than sections with mild slope. This is because the slope decreases average speed of vehicles running upward and leads to increase in the total loading time drastically. On the other hand, vehicles tend to apply brakes when running downward.

The research aims at finding out how asphalt material (Bitumen & aggregates) properties have an impact on corrugation distress in sloped pavements. For this purpose a recently constructed and heavily trafficked road (Ambepussa Kurunegala Dambula A006) is considered.

The standard specification for construction and maintenance of roads and bridges (ICTAD) has specified requirement for bitumen content and combined aggregate grading for mix design of asphalt with tolerances. The gradation pattern of the aggregates can have an impact on permanent distress in asphalt concrete pavements. The gradients of roads are usually not considered when selecting the combined grading type for mix design of asphalt.

The specification may be adapted to suit different conditions considering various criteria. For above road project combined grading Type 1 and the bitumen content tolerance percentage by weight of total mixture was adapted as +0.3 % where standard specification states ±0.3 %. This leads the asphalt plant production crew to maintain bitumen content at higher than the design (maintain at 4.9 % in the plant though design bitumen content is 4.8 %).

More than 2000 samples (each 1500 kg batch) of different Asphalt plant bitumen batching details were analyzed to conclude the predefined tolerance limits of bitumen content and combined gradation of aggregates.

It has been concluded that standard values provided in ICTAD specification for bitumen content tolerance can be modified as ±0.2 % and bitumen content tolerance limit should also extend over ± values. Further the combined gradation tolerance of aggregates need no modification based on the sample analyzed in this study.

Key Words: Bitumen content, Combined aggregate gradation, tolerances

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LIST OF ABBREVIATIONS

Abbreviation	Description
AASHTO	American Association of State Highway and Transportation Officials
BS	British Standards
FI	Flakiness Index
AIV	Aggregate Impact Value
MDD	Maximum Dry Density
LAAV	Los Angeles Abrasion Value
SSCM	Standard Specifications for Construction and Maintenance of Roads and Bridges
UK	United Kingdom
USA	United States of America

1 INTRODUCTION

1.1 Background

The development of corrugation along longitudinal profile is one of the most common failures in asphalt concrete pavement. Corrugation in bituminous material in steep slopes is a severe problem. Mixtures with high bitumen content and high fine content of the aggregate will aggravate the problem.

The research aims at finding out how asphalt bitumen content and fine content of the aggregate have an impact on corrugation distress in sloped pavements and identify the changes to be done for the asphalt mix design specifications. For this purpose, a particular road stretch from recently constructed and heavily trafficked road (Ambepussa Kurunegala Trincomalee A006) is considered.

1.2 Problem Statement

The above road has bitumen bleeding and corrugation issues within short period after construction in some sloped pavement sections. The traffic counts during the construction period showed that heavily loaded vehicles travel in the affected sections between 10.00 a.m. to 3.00 p.m. The pavement temperature was above 45^{o}C during the above period.

For above road project, combined grading Type 1 and the bitumen content tolerance was adapted as +0.3% where standard specification states ± 0.3 %. This leads the asphalt plant production operators to maintain bitumen content at higher than the design value (maintain at 4.8% in the plant though design bitumen content was 4.7%).

The actual bitumen content of plant mixtures were in between 4.7 % and 5.0 % by total weight of mixture.

1.3 Objectives

The objective of the research are as follows,

- ✓ Analyse the existing bitumen content and aggregate gradation tolerance limits provided in ICTAD specification.
- ✓ Determining a selection criteria for Type 1 & 3 gradation for asphalt mixtures.

2 LITERATURE REVIEW

Number of researches have been conducted on mixture properties such as aggregate gradation, stability, flow, air voids, specific gravity, bitumen content etc. However research on tolerance limits for bitumen content, aggregate gradation and other mixture properties tolerance limits are rarely carried out. However reviewing the tolerance limits is a must to adopt improved construction procedures at site with modern facilities.

2.1 Effects of Aggregate Gradation Patterns on Performance of Asphalt Pavements

The study carried out by Amir Golalipour et al, 2012, shows that the gradation pattern has an impact on performance of asphalt concrete. The study shows that the optimum bitumen content reduces when the combined gradation curve moves towards courser limits. Further the study also revealed that stability, creep, permanent deformation etc. depend on the gradation pattern of the curve. The relevant bitumen and aggregates properties for the above study are given in Table 2.1 and Table 2.2. The relevant tests were carried out based on the guidelines given in ASTM standards.

Table 2.1 Properties of bitumen

Tests	**Value**
Penetration Grade at 25 C, 1/10 mm	64
Softening point (°C)	61
Kinematic Viscosity (Centi Stokes) 60°C	422
Specific Gravity	1.013

The sieve analysis of aggregate gradation for wearing course with the bands divided into three ranges such as upper, middle and lower limits, is shown in Figure 2.1. In order to compare each variation, the passing percentage of different gradation bands were obtained as shown in Table 2.3.

Table 2.2 Properties of aggregates

Type of Aggregates	**Water Absorption (%)**	**Apparent specific gravity (gr/cm3)**	**Specific gravity (gr/cm3)**	**Remarks**
Coarse aggregates	0.58	2.70	2.65	Retained on No.8 sieve
Fine aggregates	0.63	2.72	2.67	Passing on No.8 sieve and retained on No.200 sieve
Aggregate mixture		specific gravity - 2.68		

Table 2.3 Passing percentage of different gradation ranges

Sieve Size	**lower limit band**	**Middle limit band**	**upper limit band**
25 mm (1 in.)	100	100	100
19 mm (0.75 in.)	91.7	95	98.3
9 mm (0.375 in.)	60	68	76
4.75 mm (# 4)	40	50	60
2.36 mm (# 8)	27.3	36	44.7
0.3 mm (# 50)	7.3	12	16.7
0.075 mm (# 200)	3	5	7
Under sieves	0	0	0

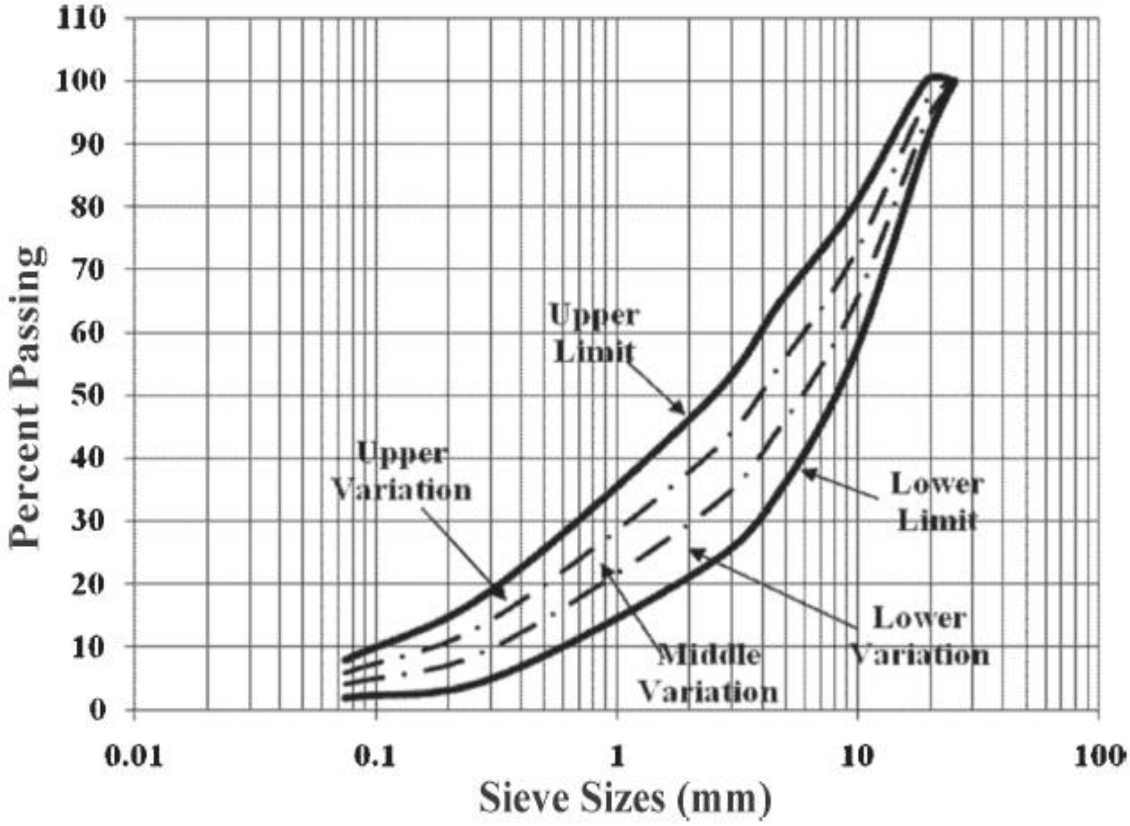

Figure 2.1 Gradation limits for 19 mm nominal maximum aggregate size

The summary of Marshall test results is shown in Table 2.4. It can be observed that the parameters such as Marshall stability, specific gravity and air voids defines optimum bitumen content and parameters such as Marshall flow and voids in mineral aggregates controls optimum bitumen content in asphalt mixture design. Accordingly for Sri Lankan context, if the design (optimum) bitumen content by total weight of wearing course mixture is 4.7% for a particular gradation, the design bitumen content should reduce when the gradation pattern moves towards the upper (Courser) limits.

If an Asphalt batch with combined gradation band with extreme higher (Course) limit and bitumen content with 5% (design bitumen content 4.7%), the batch will be a bitumen rich mixture since the design bitumen content would be less than 4.7% and maximum allowable bitumen content would be less than 5%.

However the mixture still satisfies the specification limits but not complying with theory at an instance according to the research.

2.2 Impact on Aggregate Gradation Limits on Performance Properties and Mix Design characteristics of Hot Mix Asphalt

The study conducted by Ebrahim Sangsefifi et al, 2015, shows that variation in optimum bitumen content affects the mixture behaviour. Further it was concluded that courser gradation mixtures have higher resistance to permanent distresses. The author further recommends a free design for aggregate selection. The relevant material properties and test results are shown in Table 2.5 to Table 2.7. The relevant tests were conducted adhering both ASTM and AASHTO guidelines.

Table 2.4 Marshall mix design characteristics for the lower, middle and upper limits gradation

	Lower limit gradation band	**Middle limit gradation band**	**Upper limit gradation band**
Optimum bitumen content (%)	4.3	4.35	4.4
Marshall stability (kgf)	1150	1380	1400
Specific gravity (gr / cm3)	2.384	2.415	2.399
Air voids (%)	4.5	3.5	4
Marshall flow (mm)	2.94	3.56	3.88
Voids in mineral aggregates (%)	14.7	13.45	14.2

The effect of various bitumen content variation of Marshall test is shown in Table 2.8. Accordingly the upper gradation is more sensitive and withstand permanent deformation better than other gradation.

2.3 Asphalt Mixture Properties for Road Construction in SRI LANKA

2.3.1 Aggregate

The aggregate used for surfacing shall consists of clean, hard, sound, durable particles of angular shape and rough surface texture.

They should satisfy following requirements as specified in Table 2.9

Table 2.5 Properties of aggregate

Aggregate size	**Apparent specific gravity (gr/cm3)**	**Bulk specific gravity (gr/cm3)**	**Water absorption**
Retained in # 8 sieve	2.709	2.645	0.8
Passing # 8 sieve	2.719	2.617	1.4

Table 2.6 Properties of aggregate gradation

Physical feature	**Upper gradation limits**	**Middle gradation limits**	**Lower gradation limits**
D max (mm)	16.26	16.57	16.55
Shape factor (n)	0.39	0.46	0.53
Uniformity coefficient (Cu)	102.5	49.16	26.77
Type of gradation	sand	sand	gravel
Gradation condition	well-graded	well-graded	well-graded

Table 2.7 Physical properties of 60/70 penetration grade paving bitumen

Test	Results	Specification limits
Penetration (25 º C; 0.1 mm)	62	60-70
Softening point (º C)	49	49-56
Specific gravity	1.011	1.01-1.06

2.3.2 Bitumen

The penetration grade bitumen used for road construction is derived by refining petroleum crude and shall conform to the requirements as specified in Table 2.10

2.3.3 Asphalt Concrete

The asphalt concrete consists of binder and wearing course. The grading requirement for the combined aggregate, bitumen content and thickness requirement are given in Table 2.11.

2.3.4 Mixture characteristics

The mixture characteristics for Marshall mixture design procedure are given in Table 2.12 and Table 2.13 for binder and wearing respectively.

2.3.5 Job mixture formula

The job mixture formula is usually based on trial mixture carried out in accordance with “Mixture design methods for Asphalt concrete (MS – 2)” published by American Asphalt Institute which gives following details as shown in Table 2.14.

Table 2.8 Impact of bitumen content variation on Marshall test results

Mix design parameter	Gradation L			Gradation M			Gradation U		
Bitumen content	5.4%	5.1%	4.8%	5.6%	5.3%	5%	6.1%	5.8%	5.5
Air void	3.37%	4%	4.96%	3.37%	4%	4.62%	3.3%	4%	4.8%
Amount of change	16.57%	-	19.66%	13.84%	-	18.17%	17.71%	-	19.55%
unit weight (g/cm^3)	2.398	2.39	2.381	2.377	2.372	2.363	2.353	2.354	2.352
Amount of change	0.22%	-	0.5%	0.21%	-	0.36%	0.04%	-	0.1%
VMA	13.99%	13.94%	14.13%	14.88%	14.82%	14.88%	16.01%	15.74%	15.59%
Amount of change	0.37%	-	1.37%	0.44%	-	0.42%	1.7%	-	0.97%
VFA	77%	71%	64%	77%	73%	68%	80%	75%	71%
Amount of change	8.53%	-	9.65	4.97%	-	6.04%	5.84%	-	5.88%
Marshall stability (KN)	8.67	8.9	8.86	8.46	8.92	9.06	7.39	8.05	8.24
Amount of change	2.56%	-	0.46%	5.17%	-	1.51%	8.17%	-	2.43%
flow (mm)	3.27	3.14	3.03	3.64	3.44	3.27	3.82	3.57	3.37
Amount of change	4.21%	-	3.38%	5.93%	-	5.1%	7.1%	-	5.65%
Marshall quotient (KN/mm)	2.67	2.84	2.91	2.35	2.62	2.8	1.99	2.29	2.44
Amount of change	5.85%	-	2.33%	10.03%	-	5.87%	13.11%	-	6.49%

Table 2.9 Requirement of course aggregate

Property	Requirement	Test method
LAAV	< 40 %	AASHTO T – 96
Flakiness Index	< 25 % for 20 & 14 mm	BS – 812
	< 30 % for 10 & 6 mm	
Soundness (5 Cycles)	< 12 %	AASHTO T – 104
Coated area	> 95 %	AASHTO T - 182
Dust content (passing 75 mm sieve)	< 10 %	

Table 2.10 Requirements of Penetration grade bitumen

Type	60/70	80/100
Property	**Requirements**	
Penetration 25° C 100 gm 5 s. 1/100 mm	60/70	80/100
Softening point	48 - 56	47 - 55
Loss on heating for 5 hrs at 163°C, loss in weight percent	< 1 %	< 0.5 %
Loss on heating for 5 hrs at 163°C, loss in penetration	>75 %	>80 %
Flash point ° C	>232	>232

2.3.6 Particular specification

The above ICTAD specification was adapted as particular specification for the project as follows, The permissible variation from job mixture formula for binder content was adapted as +0.3 % by weight of total mix and selected binder content mixture should be in the range of 4.5 to 6.0 percent by total weight.

Table 2.11 Aggregate grading, binder content and thickness requirement (ICTAD, 2009)

Mixture classification	**Binder course**	**Wearing course Type 1**	**Wearing course Type 2**	**Wearing course Type 3**	**Wearing course Type 4**
Compacted thickness mm – max min	75 35	75 35	75 35	75 40	75 40
Sieve Size mm µm					
28	100	100	-	100	100
20	90 - 100	85 - 100	100	93 - 100	95 – 100
14	-	-	82 - 92	-	-
10	56 - 82	66 - 94	61 - 81	59 - 94	58 – 84
5	36 - 58	46 - 74	41 - 66	38 - 69	36 – 66
2.36	21 - 38	35 - 58	27 - 48	25 - 48	23 – 49
1.18	15 - 32	26 - 48	20 - 40	20 - 40	-
600	10 - 26	18 - 38	15 – 35	15 - 32	-
300	6 - 20	11 - 28	10 - 25	10 - 23	5 – 19
150	3 - 13	7 - 20	7 - 17	4 - 15	-
75	1 - 7	3 - 12	5 - 9	3 - 12	2 – 8
Percentage binder content by total weight of mixture	3.5 – 5.5	4.0 – 6.5	4.0 – 6.0	4.0 – 6.5	4.0 – 6.0

Table 2.12 Binder course (ICTAD, 2009)

Description	Low Traffic CNSA < 104	Medium Traffic CNSA 104 & 106	High Traffic CNSA > 106
Marshall stability / kN	>3.3	>5.34	>8
Marshall flow (0.25 mm)	8 - 20	8 - 18	8 – 16
Air voids in mixture percent (VIM)	3 - 7	3- 7	3 – 7
Voids in mineral aggregate VMA (%)			
for design VIM of 4 %	>13	>13	>13
for design VIM of 5 %	>14	>14	>14

Table 2.13 Wearing course (ICTAD, 2009)

Description	Low Traffic CNSA < 104	Medium Traffic CNSA 104 & 106	High Traffic CNSA > 106
Marshall stability / kN	>3.3	>5.34	>8
Marshall flow (0.25 mm)	8 - 20	8 - 18	8 – 16
Air voids in mixture percent (VIM)	3 - 5	3- 5	3 – 5
Voids in mineral aggregate VMA (%) for design VIM of 4 %	>13	>13	>13

Table 2.14 Permissible variation from job mixture formula (ICTAD, 2009)

Description	**Permissible Variation**
Aggregate passing 14 mm and larger	± 8 %
Aggregate passing 10 mm and 5 mm sieves	± 7 %
Aggregate passing 2.36 mm and 1.18 mm sieves	± 6 %
Aggregate passing 600 μm and 300 μm sieves	± 5 %
Aggregate passing 150 μm sieves	± 4 %
Aggregate passing 75 μm sieves	± 1.5 %
Binder content percent by weight of total mixture	± 0.3 %
Temperature of mixture when emptied from mixtureer	± 10 %
Temperature of mixture when delivered on road	± 10 %

3 METHODOLOGY

3.1 Investigation of Asphal mixture failure at Ambepussa- Galewala (A006) Road

3.1.1 Identified distresses

During the construction stage, a visual field inspection was carried from Ambepussa (0+000 km) to Galewela (75+000 km) for Asphalt wearing surface. It was noticed that bleeding and corrugation of wearing course were in few sloped pavement sections and observed in two to five months after laying asphalt wearing course. Figures 3.1 to Figure 3.3 show some of the corrugated pavement sections, gradient and the k values of the vertical curves.

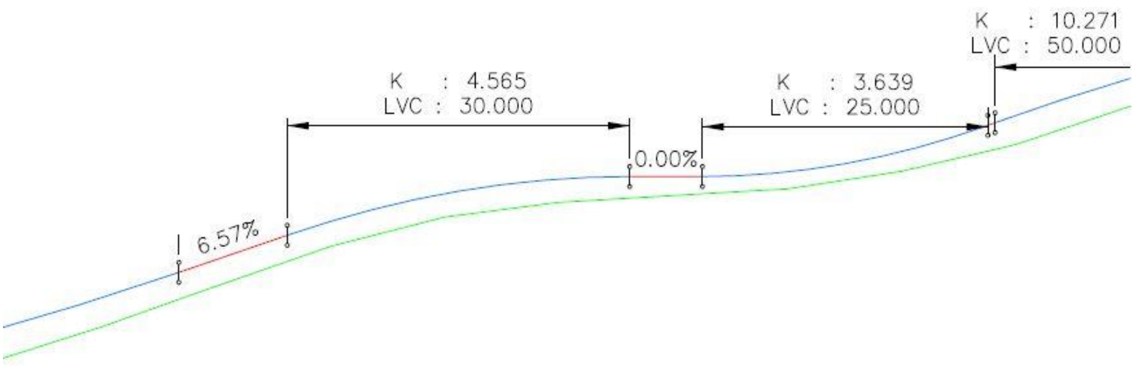

Figure 3.1 Vertical profile of corrugated pavement section (45+250 km)

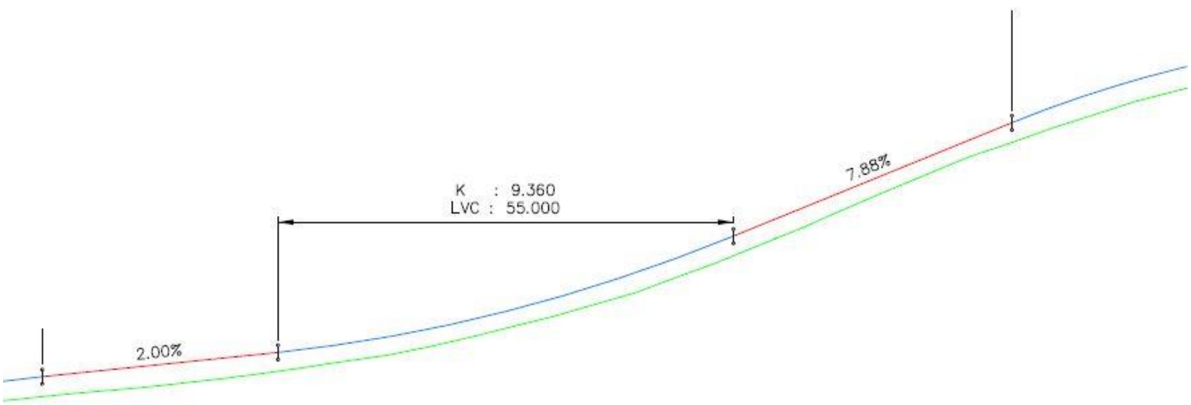

Figure 3.2 Vertical profile of corrugated pavement section (45+500 km)

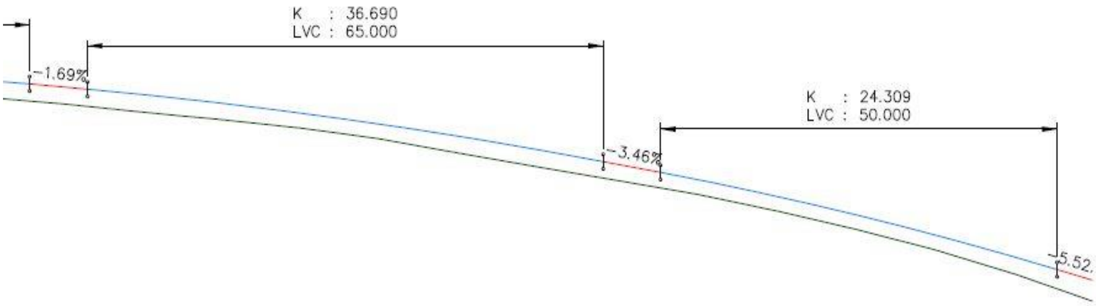

Figure 3.3 Vertical profile of corrugated pavement section (36+300 km)

However, one of the steep slope sections which also consists of climbing lane, has good quality surface and it has also been observed that the particular stretch is covered by big trees with windy climate. Both upward and downward view of above stretch is shown in Figure 3.4 and Figure 3.5. The gradient and curve values of non-corrugated sections are shown in Figure 3.6 and Figure 3.7.

Figure 3.4 Downward view of non-corrugated pavement section (67+200 km)

Figure 3.5 Upward view of non-corrugated pavement section (67+700 km)

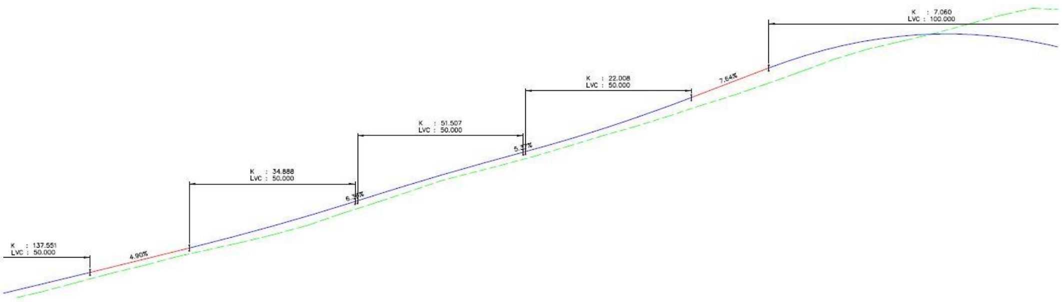

Figure 3.6 Vertical profile of non-corrugated pavement section (67+700 km)

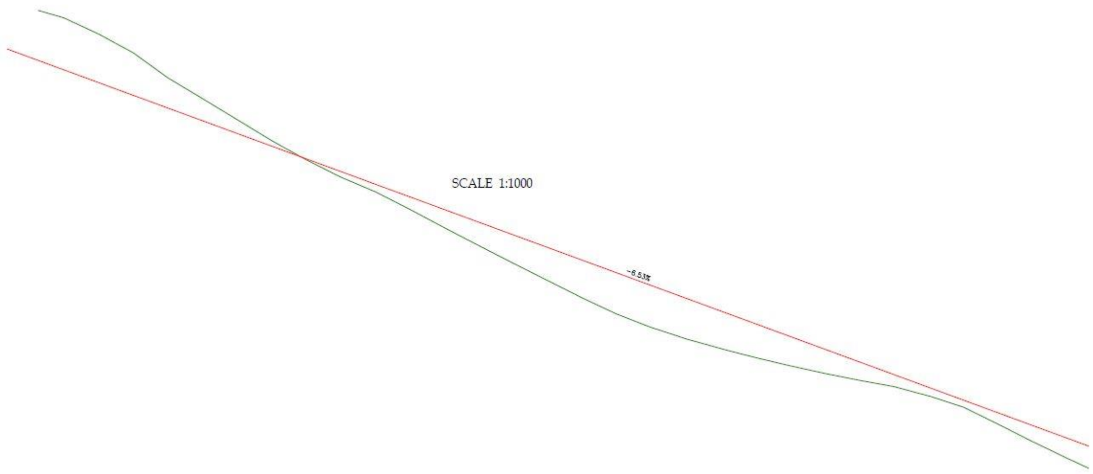

Figure 3.7 Vertical profile of non-corrugated pavement section (68+400 km)

Figure 3.8 Survey for longitudinal surface regularity in corrugated section (40+200 km)

Figure 3.9 Survey for longitudinal surface regularity variations in non-corrugated section (60+400 km)

Further undulation survey along and across the corrugated and non-corrugated sections were carried out as shown in Figure 3.8 and Figure 3.9. However there is no any significant correlation was observed among failure sections, gradient and curvature of the failure stretch, k values etc.

3.1.2 Properties of asphalt mixture

Survey were carried out to check the undulation pattern in affected sections. However there is no any significant correlation among undulation, gradient, bleeding, corrugation etc.

The asphalt sample were taken for each 300 ton after laying by paver for laboratory testing. The results showed that mixture properties are within the specification limits. However, the actual bitumen content varied from 4.8 % to 5 % where the design bitumen content was 4.7 %. The gradation pattern deviated either side of the job mixture formula satisfying the tolerance limits. Bitumen content, gradation and other properties of the tested samples are given in Annex D and Annex E.

3.1.3 Heavy vehicle distribution and temperature of pavement

The sand transporting trucks were the major overloaded vehicles which travelled on the rehabilitated road. Moreover, due to the restrictions imposed on overloaded vehicles along Kandy – Mahiyangana (A026 – 18 hair pin bends) road, more sand tippers were diverted to A006 road from sand mining areas such as Girandurukotte, Hasalaka and Bakamuna. As such the volume of sand trucks along the road had increased in large numbers. Hence a traffic survey was carried out to monitor the travelling pattern and cumulative axle load calculation. The traffic survey was carried out at 42+500 km in Ambepussa Kurunegala Dambula A006 road and traffic counts of different vehicle categories are provided in Appendix A.

During the traffic survey, the pavement temperature was monitored. A hole was made by nailing the wearing course up to 20 mm to 30 mm depth and filled with glycerin to have a better contact of the pavement material and thermometer. Traffic survey data showed that heavily loaded vehicles travel in the affected sections between 10.00 a.m. to 3.00 p.m. and the pavement temperature was in the range between 45^{o}C and 55^{o}C during the period. The summary of traffic survey and pavement temperature are shown in Table 3.1. The road surface temperature which was monitored during traffic count survey is provided in Appendix B.

3.2 Marshall Mixture Design

Asphalt concrete are composed of course aggregate, fine aggregate, mineral filler, binder and air voids that fill the space in the mixture. The Marshall Mixture design was carried out to check the conformity of the previous findings to the local context and compare the mixture properties of type 1 and type 3.The relevant mixture design for type 1 and 3 are provided in Appendix D and Appendix E.

The following parameters of the asphalt mixture were analyzed

- ✓ Stability
- ✓ Flow
- ✓ Air voids
- ✓ Voids in mineral aggregates
- ✓ Bitumen content
- ✓ Voids in total mixture

Table 3.1 Traffic Survy Samples and Pavement Temperature

Time	Avg T (°C)	LARGE BUS	MEDIUM TRUCK (WITHOUT SAND TRUCK)	HEAVY TRUCK (3 AXEL)	HEAVY TRUCK (4 OR MORE AXEL)	NO. OF LOADED SAND TRUCK
00:00 - 01:00		372	1240	108	78	10
01:00 - 02:00		271	983	107	67	18
02:00 - 03:00		291	855	104	68	6
03:00 - 04:00		206	824	85	71	7
04:00 - 05:00		194	1010	117	60	11
05:00 - 06:00		331	1055	90	65	22
06:00 - 07:00		762	1338	129	50	38
07:00 - 08:00		843	1062	107	47	47
08:00 - 09:00		863	1053	127	47	480
09:00 - 10:00		719	965	122	28	998
10:00 - 11:00	45	739	884	128	34	1251
11:00 - 12:00	50	730	1005	128	43	1363
12:00 - 13:00	55	752	1165	138	52	1174
13:00 - 14:00	59	755	1057	129	48	1189
14:00 - 15:00	57	904	1184	174	55	1092
15:00 - 16:00	55	766	1242	142	59	689
16:00 - 17:00		703	1444	244	54	453
17:00 - 18:00		709	1527	250	51	204
18:00 - 19:00		605	1485	156	54	132
19:00 - 20:00		470	1343	187	68	159
20:00 - 21:00		347	1257	158	66	166
21:00 - 22:00		262	1277	209	64	205
22:00 - 23:00		239	1313	153	54	54
23:00 - 00:00		295	1193	169	51	12

3.3 Analysis of Asphalt Batching Plant Samples

The Marshall mixture design at laboratory is carried out in ideal conditions. However the asphalt batching process in plant is not carried out in same conditions. Hence tolerance limits have been adopted for aggregate gradation and bitumen content.

More than 2000 batch samples from different plants in the country have been analysed. The study of actual parameters of aggregate gradation and bitumen content showed that significant modification can be made in bitumen content tolerance.

A sample of plant batch is provided in Appendix C.

4 TEST RESULTS AND DISCUSSION

4.1 Mixture Design

Asphalt mixture design for type 1 and type 3 were carried out to compare the Marshall properties. Aggregates for this study were obtained from same source and the Table 4.1 shows the results of both type 1 and type 3 mixture design.

Table 4.1 Marshall Test Results for Type 1 and Type 3 Gradations

Mixture property	**Unit**	**Actual value of mixture**		**Specification requirements**	**Remarks**
		Type 1	**Type 3**		
Binder content by weight of mixture	%	4.8	4.7	4.0 - 6.5	Complies
Voids in total mixture (VIM)	%	3.7	4.0	3 - 5	Complies
Voids in Mineral aggregate (VMA)	%	14.3	14.7	Not less than 13	Complies
Marshall Stability	kN	12.4	14.1	Not less than 8	Complies
Marshall flow	0.25mm	9.5	10.2	8-16	Complies

The above comparison for Sri Lankan context further justified the literature studies that optimum bitumen content reduces when the gradation curve moves towards the courser limits.

Further both Marshall Stability and voids in mineral aggregates values are higher for courser gradations.

The comparison of test results for type 1 and type 3 mixture design are shown in Figure 4.1 to Figure 4.4.

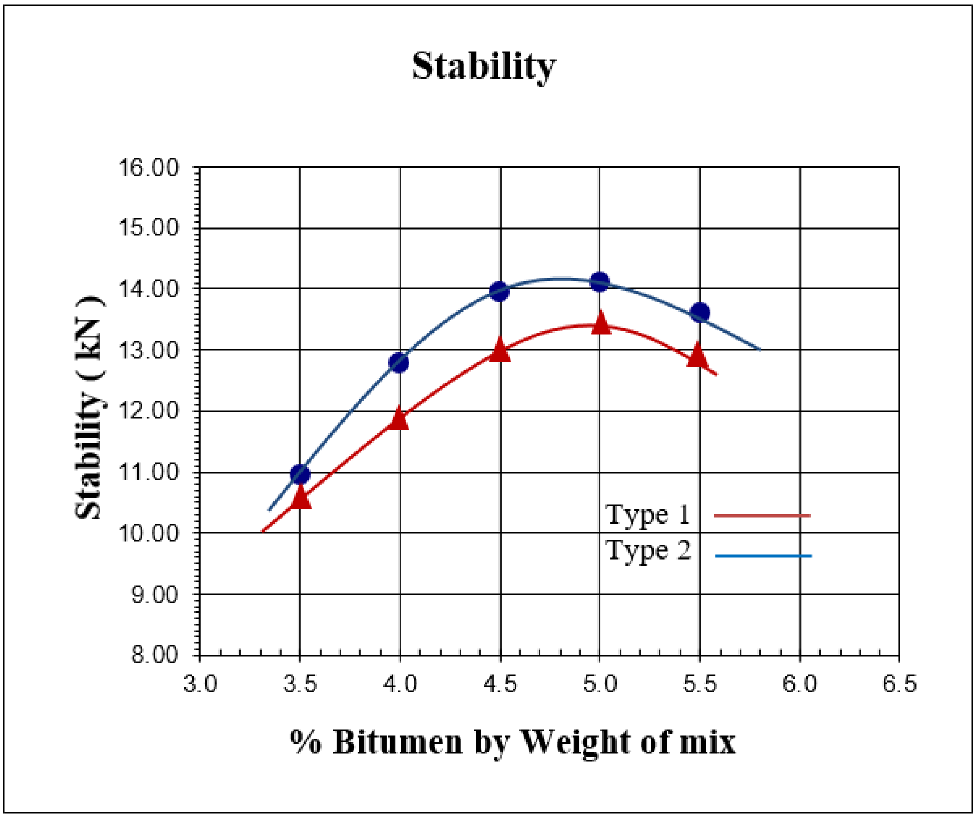

Figure 4.1 Stability comparison for asphalt mixtures

Figure 4.1 explains that Marshall Stability values are higher for courser gradations (Type 3) than the finer gradations (Type 1). The air voids are higher in coarser gradation (Type 3) than that in the finer gradation (Type 1). The difference are illustrated in figure 4.3. The mixture with upper gradation band has higher VMA values than the lower gradation band mixtures.

The past researches findings of asphalt mixtures have revealed that mixtures with higher VMA and air voids values which are within the limits, show better performance against rutting and permanent deformation.

Hence for heavily trafficked roads, it's recommended to adopt Type 3 gradation for asphalt concrete for better performance of the pavement.

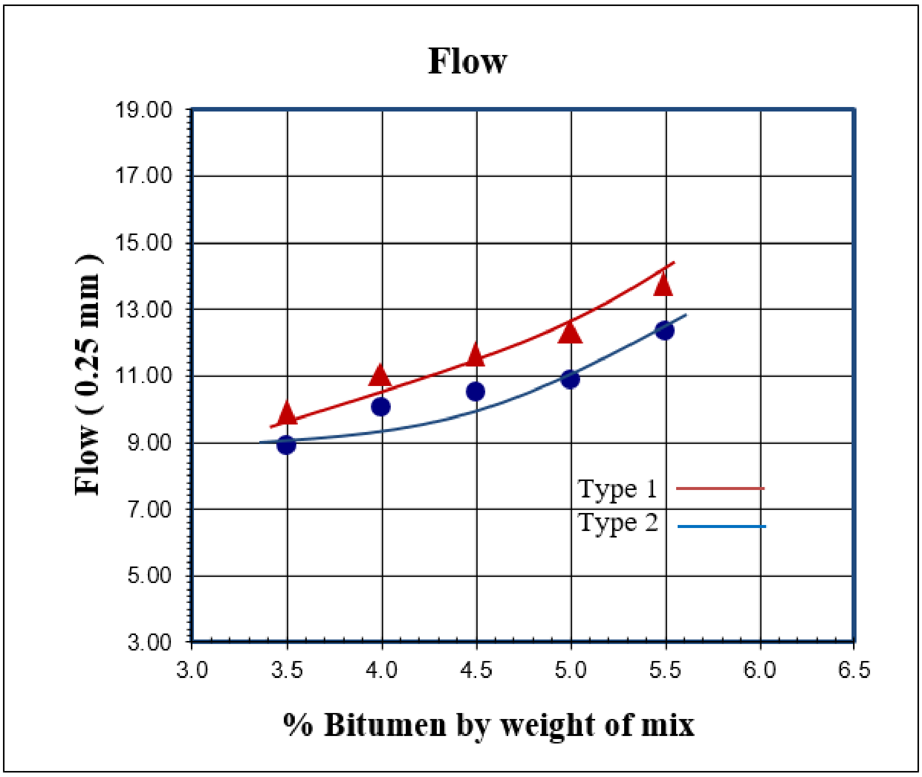

Figure 4.2 Flow comparison for asphalt mixtures

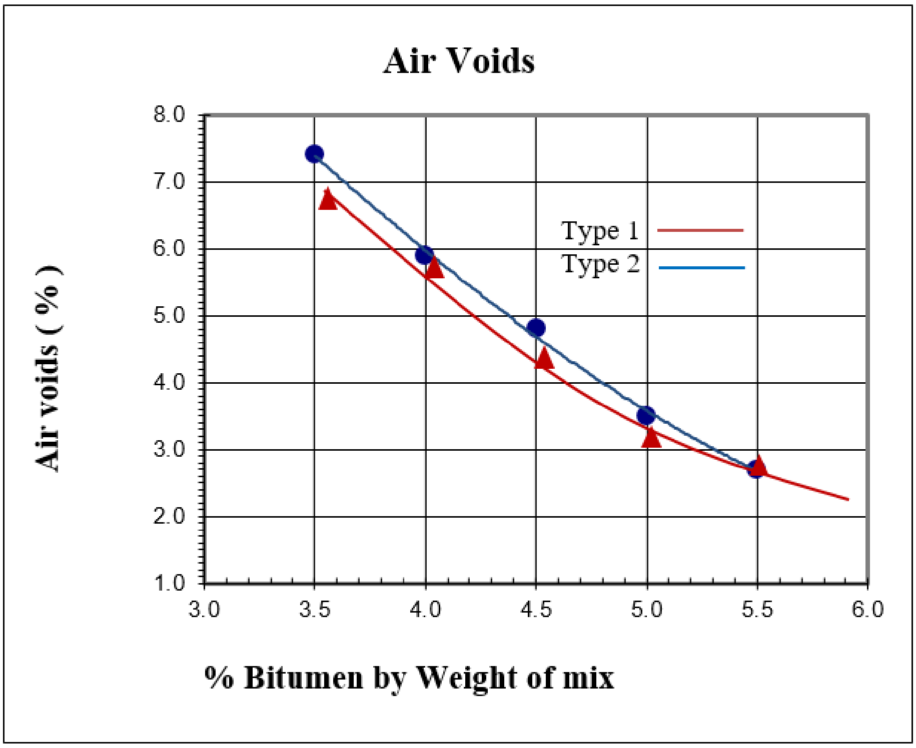

Figure 4.3 Air voids comparison for Asphalt mixtures

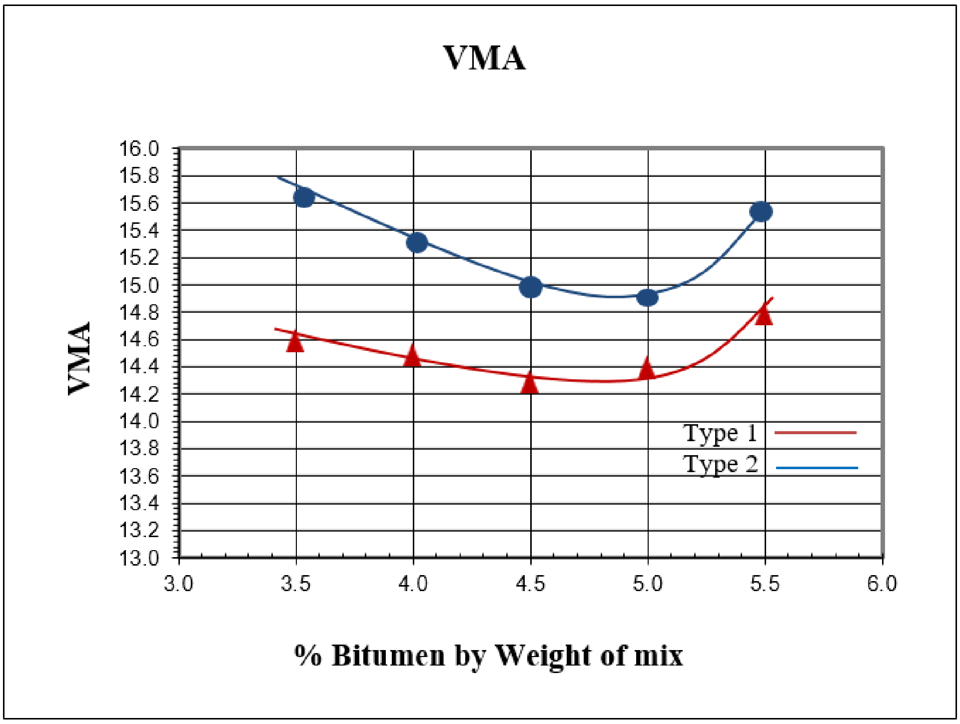

Figure 4.4 VMA percentage comparison for asphalt mixtures

4.2 Plant Batch Samples Analsis for Bitumen Content

The actual bitumen content of samples from various plants were analsed to study the present tolerence limits for optimum bitumen content. The analsys of nearly 2000 samples showed that bitumen content values deviate by ± 0.2 percentage from optimum bitumen content. The samples analysis from four different plants in various part of the country are shown in Figure 4.5 to Figure 4.8. The results of all the plants are shown in Figure 4.9.

The plant A batch had 1500 kg by weight of total mixture with 72 kg bitumen weight. The actual bitumen content deviation from optimum value (72 kg) were analyzed and the results are shown in figure 4.5.

The 95th percentile values of plant A are -0.17 and 0.19 as shown in table 4.2. The results shows that bitumen tolerance deviation can be modified from ±3 provided in the ICTAD specifications.

Further the analysis also showed that nearly 59 % of the samples in plant A fall less than the optimum bitumen content value and 41 % of the samples fall more than the optimum bitumen content value as shown in Table 4.3.

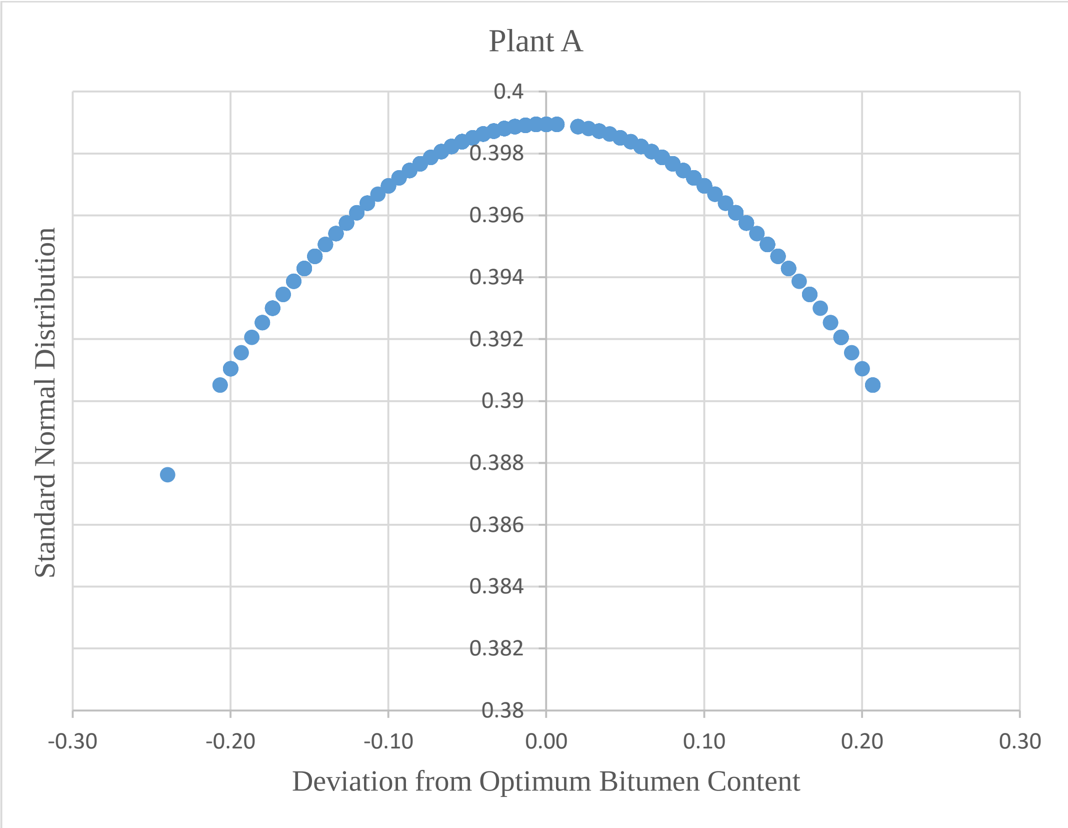

Figure 4.5 Actual bitumen content variation for plant A asphalt mixture

The plant B batch had 1000 kg by weight of total mixture with 48 kg bitumen weight. The actual bitumen content deviation from optimum value (48 kg) were analysed and the results are shown in figure 4.6.

The 95th percentile values of plant B are -0.18 and 0.21 as shown in table 4.2. The above plant results also revealed that bitumen tolerance deviation can be modified from ±3 provided in the ICTAD specifications.

The analysis also showed that nearly 47 % of the samples in plant B fall less than the optimum bitumen content value and 53 % of the samples fall more than the optimum bitumen content value as shown in Table 4.3.

The plant C batch also had 1000 kg by weight of total mixture with 48 kg bitumen weight. The actual bitumen content deviation from optimum value (48 kg) were analysed and the results are shown in Figure 4.7.

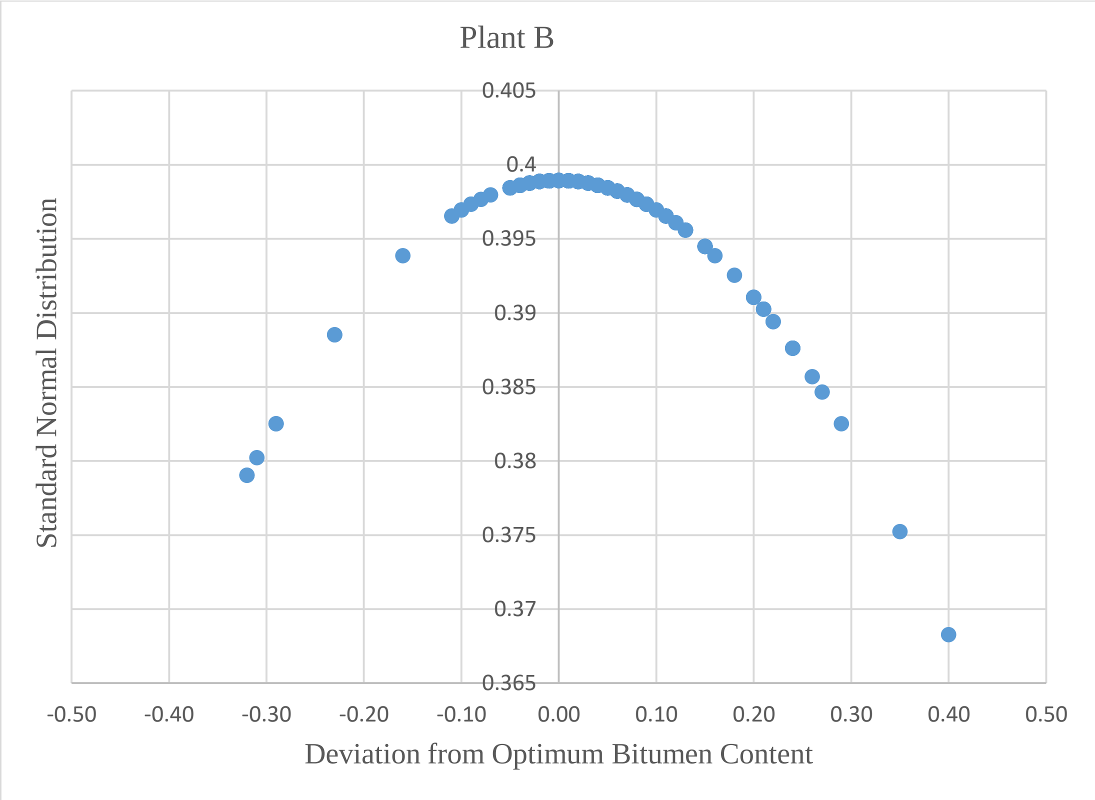

Figure 4.6 Actual bitumen content variation for plant B asphalt mixture

The 95th percentile values of plant C are -0.19 and 0.15 as shown in table 4.2. The above plant results also revealed that bitumen tolerance deviation can be further modified from ±3 provided in the ICTAD specifications.

The analysis also showed that nearly 43 % of the samples in plant C fall less than the optimum bitumen content value and 57 % of the samples fall more than the optimum bitumen content value as shown in Table 4.3.

The plant D batch also had 1000 kg by weight of total mixture with 48 kg bitumen weight. The actual bitumen content deviation from optimum value (48 kg) were analyzed and the results are shown in figure 4.8.

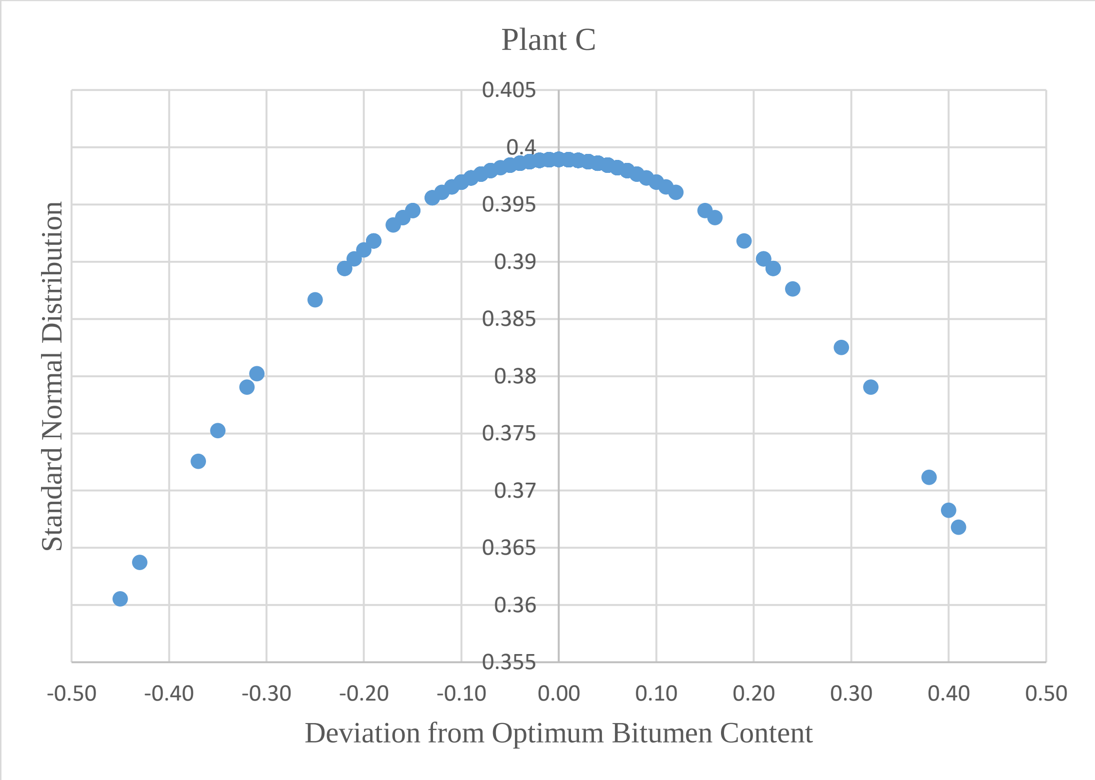

Figure 4.7 Actual bitumen content variation for plant C asphalt mixture

The 95th percentile values of plant D are -0.18 and 0.21 as shown in table 4.2. The above plant results also revealed that bitumen tolerance deviation can be further modified from ±0.3 provided in the ICTAD specifications.

The analysis also showed that nearly 44 % of the samples in plant D fall less than the optimum bitumen content value and 56 % of the samples fall more than the optimum bitumen content value as shown in Table 4.3.

The above analysis show that the allowable deviation from optimum bitumen content values ±0.3 can be modified as ±0.2 since the analyzed results of plant in various part of the country showed that the tolerance limit are within ±0.2. Further it is advisable to always adapt the tolerance limits (both positive and negative) since almost 50 % of actual bitumen content values lies either ± values as shown in Table 4.3.

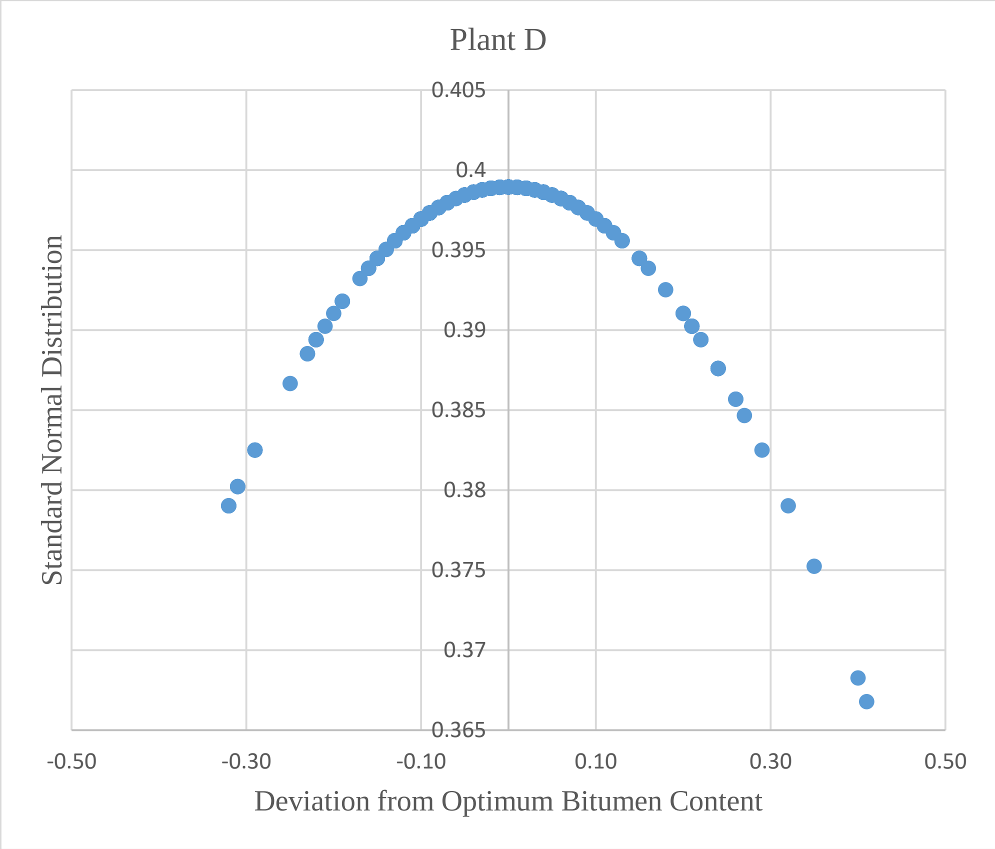

Figure 4.8 Actual bitumen content variation for plant D asphalt mixture

Table 4.2 95th Percentile values of deviation from optimum bitumen content

Plant	95th Percentile Value	
A	-0.17	0.19
B	-0.18	0.21
C	-0.19	0.15
D	-0.17	0.21
Average	-0.18	0.21

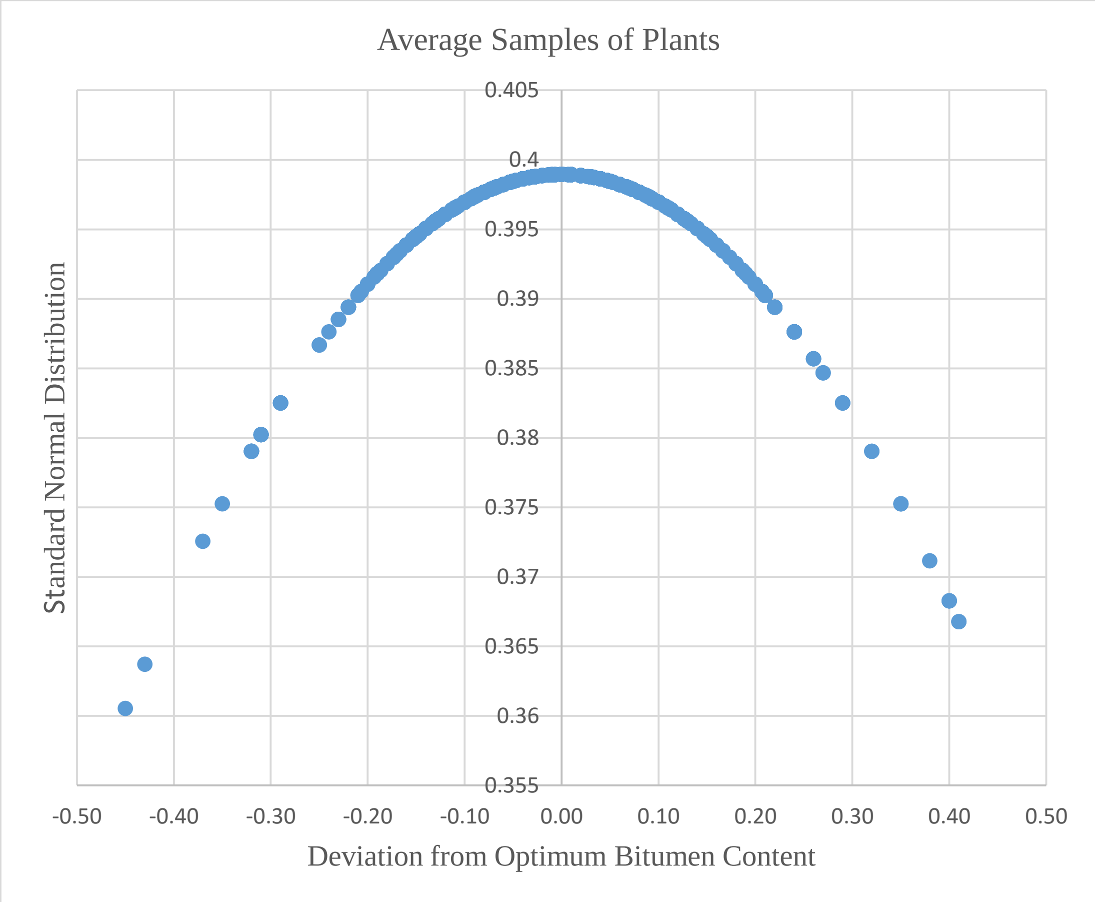

Figure 4.9 Actual bitumen content variation for average plant mixture

Table 4.3 Percentage of Bitumen content deviation from optimum value

Plant	Tolerance / %	
	(-)	(+)
A	59	41
B	47	53
C	43	57
D	44	56
Average	47	53

4.3 Plant Batch Samples Analysis for Combined Gradation

The actual combined gradation pattern were analyzed to modify the present gradation limits provided in the ICTAD standard specifications. Nearly 200 batches from four plants were analyzed for the study of actual gradation pattern.

Each aggregate by weight of total mixture were analyzed to find whether the deviation from optimum value shows any possibilities of further reduction in the tolerance limits. The analysis were also carried out visually by looking at the collected gradation curves whether the actual gradation curve shows any significant relation towards the design gradation curve.

The typical gradation curves of samples from four different plants in various part of the country are shown in Figure 4.10 to Figure 4.13.

Table 4.4 shows ICTAD specification limits for combined gradation and numerical values of design combined gradation for plant 1, 2, 3 and 4 as explained in Figure 4.10 to Figure 4.13.

The gradation pattern of combined gradation of asphalt concrete were analyzed from the samples collected from plant 01. There is no any significant deviation towards the design gradation curve to reduce the tolerance limits.

Further other plants 2, 3 and 4 also show no significant findings to determine a new tolerance limits for combined gradation. It can be observed that combined gradation curves in above four plants falls within the upper and lower limits provided in ICTAD specifications. Further it can be noted that tolerance limits of combined gradation moves towards lower and upper limits in different plants. Hence it can be concluded that the present tolerant limits provided in the ICTAD specification for combined gradation need no any modifications.

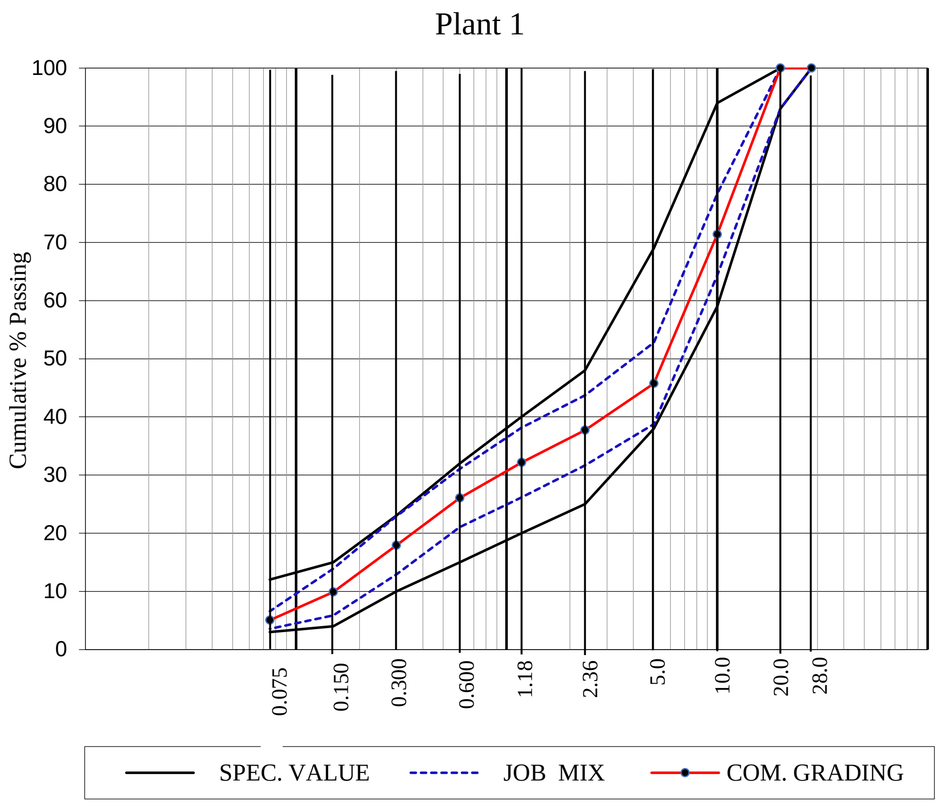

Figure 4.10 Combined gradation of asphalt concrete of plant no 01

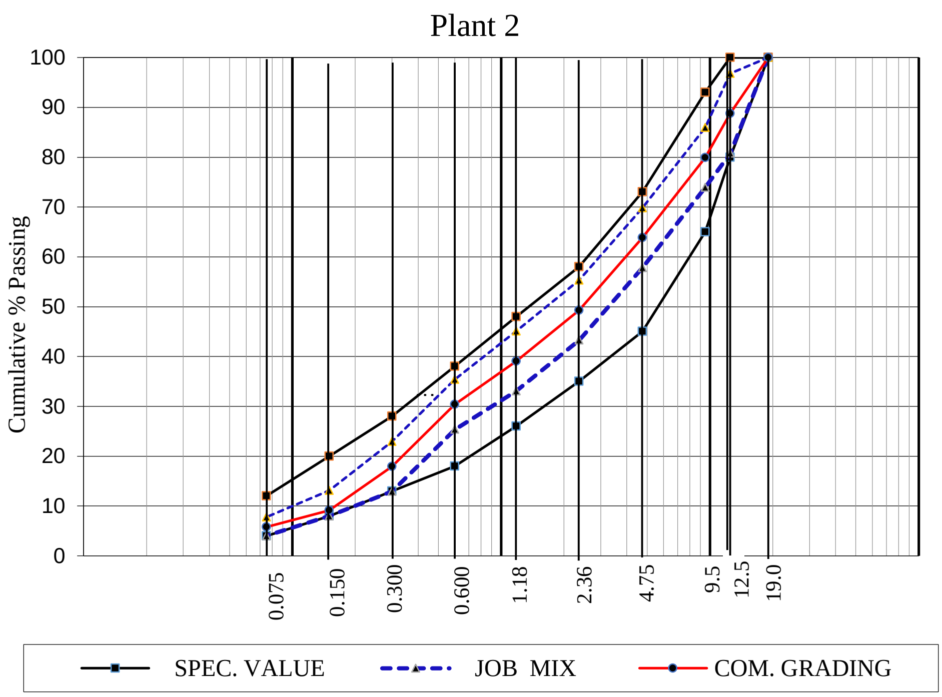

Figure 4.11 Combined gradation of asphalt concrete of plant no 02

Plant 3

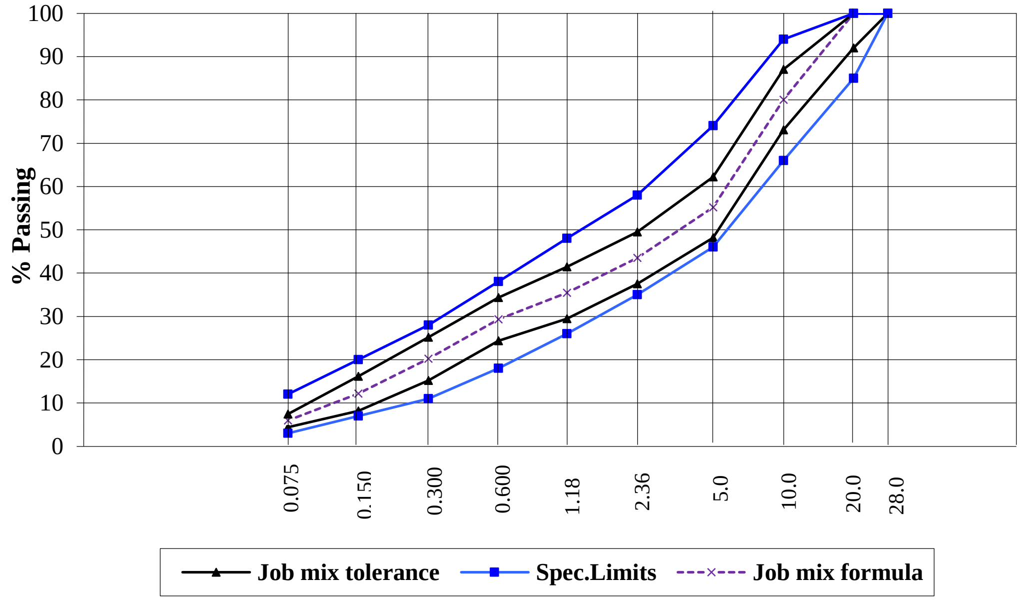

Figure 4.12 Combined gradation of asphalt concrete of plant no 03

Plant 4

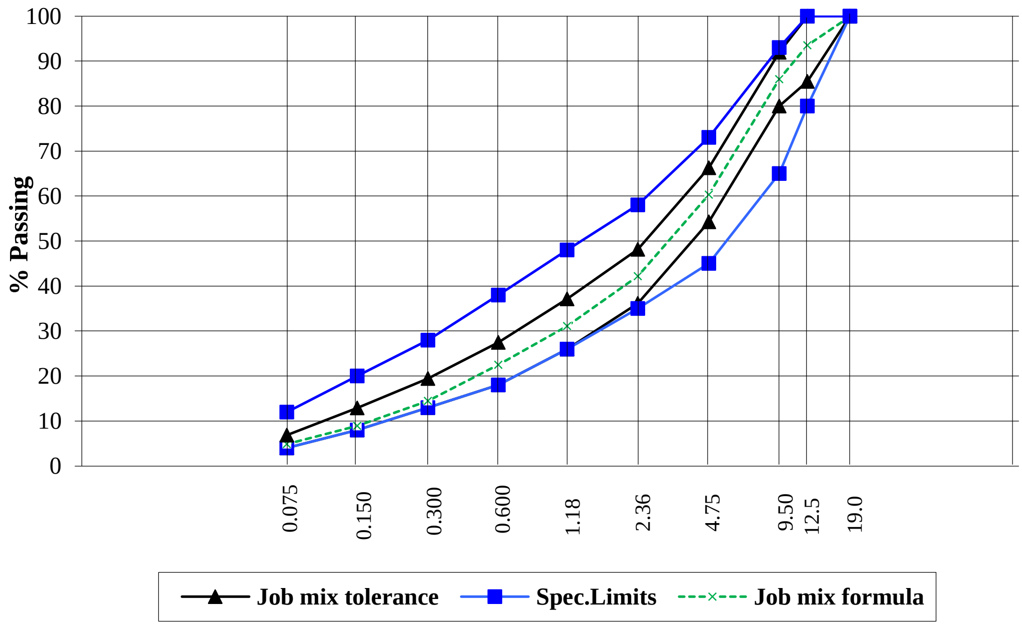

Figure 4.13 Combined gradation of asphalt concrete of plant no 04

Table 4.4 Analysis of combined gradation of asphalt concrete aggregates at plant

Sieve		**28**	**20**	**10**	**5**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
ICTAD Specification limits	min	100	85	66	46	35	26	18	11	7	3
	max	100	100	94	74	58	48	38	28	20	12
Plant 1	**Design**	100	100	81	62	51	42	33	23	13	7
Actual variation	min	100	87	67	45	34	24	17	10	7	4
	max	100	100	93	73	57	46	35	25	18	13
Plant 2	**Design**	100	100	80	55	44	35	29	20	12	6
Actual variation	min	100	86	65	45	33	25	17	11	6	4
	max	100	100	93	75	57	49	36	26	15	11
Plant 3	**Design**	100	100	78	64	49	44	32	25	14	9
Actual variation	min	100	85	64	44	35	27	19	9	6	3
	max	100	100	92	73	57	45	38	24	18	10
Plant 4	**Design**	100	100	81	62	51	42	33	23	13	5
Actual variation	min	100	84	63	46	32	23	19	9	7	3
	max	100	100	93	72	59	43	39	26	21	9

5 CONCLUSIONS AND RECOMMENDATIONS

The study on failure sections in A006 road shows that positive tolerances adopted in bitumen content have significant impact on behavior of asphalt mixtures particularly in sloped pavements. Therefore study was focused on applicable tolerance limits for bitumen and aggregates.

The actual plant bitumen content samples for nearly 2000 batches showed that bitumen content tolerance limits were within ± 0.2. Therefore, it is recommended to change the tolerance limit ± 0.2 from ± 0.3 specified in ICTAD specification. Further it can be noted that almost fifty percent of batches fall in both ± values. Hence it can be concluded that bitumen content tolerance limit should always extend to both ± value range.

However based on the analysis of actual combined gradation curves for aggregates, the results show that the current tolerance limits need no modification.

Previous studies over aggregate gradation pattern shows that gradation bands towards courser limits in asphalt mixture, provide better performance against rutting while upper band gradation were more sensitive compared to lower band gradation. Further Marshall Stability and volume of voids in mineral aggregates can be the factors used to predict the permanent deformation of asphalt mixtures.

Type 3 (Courser) combined grading shows higher values of Marshall Stability and voids in mineral aggregates than that of Type 1 (Finer) in the study. Hence, asphalt mixture design, Type 3 (Courser) should be recommended for heavily trafficked roads. However, it’s recommended to conduct both type 1 and type 3 gradation for mixture design for heavy traffic roads before finalizing the gradation type.

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APPENDIX A: Traffic Count Samples

APPENDIX B:

Asphalt Concrete Pavement Temperature

APPENDIX C:

Asphalt Plant Batch Bitumen Content Sample Samples

APPENDIX D:

Asphalt Concrete Mixture Design for Type 1 Gradation

APPENDIX E:

Asphalt Concrete Mixture Design for Type 3 Gradation