TECHNICAL REPORT STANDARD

1. Report No. 315	2. Government Accession No.	3. Recipient's Catalog

4. Title and Subtitle Evaluation of Louisiana's statistically based quality control and acceptance specifications for asphaltic concrete	5. Report Date September 1998 6. Performing Organization Code 127-15-4116
7. Author(s) Metcalf J.B., Ray T.G., Shah S.C.	8. Performing Organization Report No.
9. Performing Organization Name and Address Institute for Recyclable Materials, Department of Civil and Environmental Engineering Louisiana State University Baton Rouge LA 70803	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Louisiana Transportation Research Center, 4101 Gourrier Lane, Baton Rouge, LA 70808	13. Type of Report and Period Covered Final report, April 95 to June 1997 14. Sponsoring Agency Code 95-2B

15. Supplementary Notes

16. Abstract

In 1971, the Louisiana Department of Transportation and Development initiated a statistically based specification systen for asphaltic concrete using historically generated data. A Materials Test Data (MATT) reporting system was also starte archive all materials and construction data. This data was used to validate the specifications in 1975 and 1979 and to adj the specification requirements for asphaltic concrete. Since 1987, major specification changes have been made and the have been improvements in equipment and operational control. This study was therefore conducted to review asphalt quality in terms of the current specifications, to evaluate the effectiveness of the current requirements and to propose future directions for specification compliance judgement and acceptance procedures. A particular aspect was to be an evaluation of the 'unknown sigma' approach.

The study examines data for asphaltic concrete from the MATT system for the period 1987 to 1995. Quality was describe terms of the mean and standard deviation of the specification parameters affecting the payment for product. The propor defective product to specification criteria was also estimated. This data is tabulated and graphed for Marshall stabi gradation, antistrip, density and profile.

The study also developed operating characteristic curves for each of these five parameters and revealed the complexit some. On the basis of the current quality capabilities a selection of simpler but equally rigorous new specification complia criteria were formulated.

17. Key Words asphalt, quality control, acceptance, specification, Marshall stability, antistrip, gradation, density, profile, statistics, operating characteristics	18. Distribution Statement Unrestricted. This document is available through the National Technical Information Service, Springfield, V 21161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		133	

EVALUATION OF LOUISIANA'S STATISTICALLY BASED QUALITY CONTROL AND ACCEPTANCE SPECIFICATIONS FOR ASPHALTIC CONCRETE

FINAL REPORT

by

J.B. Metcalf, Freeport McMoran Professor, LSU
T.G. Ray, Associate Professor, LSU
S.C. Shah, Consultant, Baton Rouge
Institute for Recyclable Materials
Department of Civil and Environmental Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

in cooperation with

U.S. Department of Transportation
Federal Highway Administration

November 1996

ABSTRACT

In 1971, the Louisiana Department of Transportation and Development initiated a statistically based specification system for asphaltic concrete using historically generated data. A Materials Test Data (MATT) reporting system was also started to archive all materials and construction data. This data was used to validate the specifications in 1975 and 1979 and to adjust the specification requirements for asphaltic concrete. Since 1987, major specification changes have been made and there have been improvements in equipment and operational control. This study was therefore conducted to review asphalt quality in terms of the current specifications, to evaluate the effectiveness of the current requirements and to propose future directions for specification compliance judgement and acceptance procedures. A particular aspect was to be an evaluation of the "unknown sigma" approach.

The study examines data for asphaltic concrete from the MATT system for the period 1987 to 1995. Quality was described in terms of the mean and standard deviation of the specification parameters affecting the payment for product. The proportion defective product to specification criteria was also estimated. This data is tabulated and graphed for Marshall stability, gradation, antistrip, density, and profile.

The study also developed operating characteristic curves for each of these five parameters and revealed the complexity of some. On the basis of the current quality capabilities a selection of simpler but equally rigorous new specification compliance criteria were formulated.

ACKNOWLEDGMENTS

The direction and support of the project committee, K. Clement, S. Cooper, G. Doyle, W.E. Drake, N. West, R. Holm, B. Moore, C. Abadie, and C. Fletcher, made this project possible. The active participation of H.R. Paul is gratefully recognized. DOTD Materials Division staff, especially Laura Chapman and Beth Landry, and Lisa Holmes of the Computer Division gave invaluable help in extracting the MATT data files on which the research is based. Our students, Adi Andrei, D. Russell, Kim Taesung, and Li Yongqi helped with the analysis.

IMPLEMENTATION STATEMENT

If the conclusions and recommendations of this report are accepted, changes to the current variability specification can be implemented immediately. Appropriate tables, charts, and a training manual can be developed, and a training program initiated for implementation. It is believed that a change in specification as proposed will result in less uncertainty for supervisory and contractor staff. It will also provide incentives to reduce variability and thus improve overall quality.

The implementation phase will:

- prepare an application manual
- prepare specification clauses, sampling charts and compliance judgement tables
- develop and present a training package.

This follow-up stage of the project will be developed in cooperation with the LTRC Technology Transfer and Training Section. The course will be conducted in at least three regional centers for district and contractor's staff. A separate proposal for the implementation package will be presented and will include a trial validation program before full introduction of the revised specification.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In 1971 the Louisiana Department of Transportation and Development (DOTD) initiated a statistically based specification system for asphaltic concrete using historically generated data. This same system is in use today. The system was validated in additional studies undertaken in 1975 and 1979. The specifications are predicated on contractor quality control and DOTD acceptance testing using "variability known" concepts. A Materials Test Data Reporting System (MATT) was initiated at that time to archive all materials and construction data. The database has been used to adjust specifications but no further major validation has occurred. Since 1987 major changes have been incorporated into the standard specifications, and there have been advances in equipment and operational control devices that can further reduce construction and test variability. Thus now is an appropriate time for an overall review and potential revision of the system.

Variability known compliance judgement specifications, which are based on mean values, were chosen because of the ease of application. The disadvantage of this concept is that there is little incentive for a contractor to reduce variability. The variability unknown specification, however, uses both the mean and standard deviation values to determine a percent within limits. In such a specification, as the standard deviation decreases, the lot mean can shift toward the specification limit and still be acceptable. This provides an incentive for the contractor to reduce variability and thus provide the state with a more uniform product. The variability unknown specification is more difficult to apply but with the use of personal computers or charts this difficulty can be overcome.

Many changes have been incorporated into the current DOTD specifications since the last validation. The Federal Highway Administration (FHWA) has questioned the appropriateness of some of these changes. Industry has questioned many of the specification changes with respect to uncertainty and subjectivity. Spot checks of criteria variability indicate some change since the initiation of Quality Control/Quality Assurance (QC/QA) specifications in 1971, because of improvements to equipment and control systems. It is possible that the QC/QA system does not provide sufficient incentive for the contractor to reduce product variability. Through the use of a variability unknown specification, both reduced costs and improved uniformity of pavements can be achieved.

DOTD therefore supported this research project to establish current quality, to evaluate current specifications and, to develop proposals for specification revisions to improve quality by reducing variability.

OBJECTIVES

This study will evaluate DOTD's current (1992) statistically based specifications and potential directions for improvements. Three specific aims include:

A. Evaluate the current system for quality control and acceptance criteria, develop updated operating characteristic curves, and propose improvements to this system.

B. Evaluate the potential of a variability unknown specification using "percent within limits" concept, using the existing database to include recommendations for appropriate tests and revised adjustment tables.

C. Present findings of research in a one-day workshop for DOTD and contractor personnel to be held in conjunction with the FHWA Demo 89 two-day workshop entitled *Materials Control and Acceptance--Quality Management*.

SCOPE

The study examines asphaltic concrete data filed in the MATT system from 1987 to 1995. The data selected was that applied to acceptance compliance judgement under the requirements in the 1992 specification.

Should major changes in quality be detected during the period for which data was extracted, then previous versions of the specification will be reviewed for their influence on those quality changes.

METHODOLOGY

Background on Louisiana's Specification

Conventional specifications. Prior to 1960, DOTD used traditional method-type specifications (also called recipe-type specifications). With this type of specification, the methods that are generally used in production of materials and construction of pavements are defined specifically by the highway agency. In essence, the highway agency controls the entire process. If the contractor adheres to the defined recipe, he gets 100 percent pay upon verification by the inspector. Statistical concepts are rarely applied in such method-type specifications.

Development of statistical specifications. In the 1960's, there was considerable momentum from the FHWA to develop and implement construction specifications on asphaltic concrete, which are based on statistical quality control concepts *[1]*. Louisiana was one of the first states to study the variability in asphaltic concrete and develop statistically based specifications based on the results of the study *[2]*. These specifications were then simulated before final adoption in 1971 *[3], [4]*. The newly adopted specifications reflected a major shift in the sampling, control, acceptance and disposition of materials and construction. In essence, the specifications reflected a shift in three basic criteria:

- Process control by the contractor
- Use of variability known statistical sampling plan for acceptance testing
- Price adjustment for non-conforming materials and construction

The following philosophy governed the above shifts from the conventional specifications:

1. As in the industry, the process control should be the responsibility of the contractor and not the state highway department, as was the case with the method-type conventional specifications.
2. The sampling plan for acceptance should be based on what is achievable within the constraints of the system that is used to deliver the product. The current specifications were developed using the mean and variability parameters of the

asphaltic concrete population (1960's data). Specifications based on such population parameters are known as "variability known" specifications. Such specifications are easy to use without going through the computation required for variability unknown type specifications.

3. Although variability known type specifications are easy to apply, there is also some disadvantage since there is no incentive for the contractor to pay particular attention to the variability of the product on lot-by-lot basis. On the other hand, the variability unknown type specifications use both the mean and standard deviation of each lot to determine acceptance. In such specifications, as the variability decreases, the probability of acceptance of lot mean may still remain high even though the mean may shift close to the specification limit. This is generally not the case with the variability known type specifications.

4. The contractor payment should be adjusted in relation to the quality of the product delivered. The philosophy here is that any deficiency from defined quality may result in loss in pavement life or performance hence increasing maintenance cost.

Post Specification Studies: 1971-1979. Since the adoption of the statistically based specifications, there have been two separate studies to determine their impact on the price adjustment criterion and on the overall variability of the product. The first evaluation was on the data generated by the new specifications between 1971 and 1975 *[5]*. The second evaluation was for data from 1975 to 1977 *[6]*.

In the initial specifications of 1971, the acceptance criterion for the production phase of asphaltic concrete was defined by Marshall stability. Acceptance for the lay down, compaction, and final finishing (roadway phase) was based on compaction and surface profile criteria.

The primary thrust of the two evaluations was to determine the effect of the specifications on the price adjustments and on the variability of the product. Almost half the number of projects evaluated during the first four years since adoption had some reduction in pay. However, from 1975-1977, this portion decreased to 18 percent, indicating the industry adjustment to the new concept in specifications and improvement in average quality, table 1 *[6]*.

Table 1

Variability comparison--conventional and new specifications (after Shah)

Criteria	**Standard Deviation**		
**************	**1960**	**1971-75**	**1975-77**
Stability, lb.	220	280	290
Compaction, percent	1.8	1.7	1.8
Percent Passing #4	3.3	5	5.1
Percent Passing #10	3.1	4.7	4.7
Percent Passing #40	2.4	3.5	3.6
Percent Passing #80	1.6	2.3	2.4
Percent Passing #200	1	1.3	1.5
Percent Asphalt Content	0.25	0.35	0.4

This, however, was not the case for the variability measurement of the 1971-75 and 1975-77 data. The jump in variability shown in the 1971 data compared to the 1960 data was not surprising since it was derived from products produced under a methods specification which generally show greater compliance with specification requirements. The minor increase in variability between 1971-75 and 1975-77 can be attributed to variability known specifications.

Such specifications generally provide little incentive for the producer to reduce variability. As a result of this negative trend in uniformity, a major change was made in the specification requirements. After the first full-scale evaluation of 1971-1975 data, gradation of extracted aggregate was introduced as an additional acceptance requirement *[5]*.

MATerial Test Data Reporting System: MATT System. During the period of evaluation of the statistical specifications, the DOTD developed and implemented a computerized system of archiving all materials and construction data generated by construction and maintenance projects in the state *[7]*. One of the primary reasons for implementing such a system was to provide a mechanism for validation of specifications at periodic intervals. The system was able to generate a variety of reports to validate specifications in terms of compliance (or noncompliance), contractor performance, process and construction variability, etc. Unfortunately, the system has not been used to full advantage since the above two evaluations. Although there have been major changes in the specifications since 1987, there has been no major evaluation of the data from the MATT system other than that which was necessary support for minor modifications to specifications.

Current Specifications. Since the adoption of the statistical specifications in 1971 there has been one major revision. In 1977 a requirement for gradation was added to the acceptance criteria. A second change was implemented when a requirement for anti-strip additive was added. Since then, there have been continuing minor changes in the requirements for design, control and acceptance for stability, gradation, antistrip, density and, profile. Another addition was the requirement for Tensile Strength Ratio. It is clear that the specifications are constantly under development and the application of the specifications in practice is also subject to interpretation. Table 2 defines the various requirements for the design, control and acceptance of asphaltic concrete.

Current quality

MATT data extracted. Data relevant to the quality of asphaltic concrete was extracted from the MATT database with the assistance of DOTD staff and written to ASCII files. To keep the data set a manageable size, and to ensure a relationship between the data and the specification, the period 1987-1995 was selected for the primary sample. Records were assembled covering all mix types, for all 55 plants operating in Louisiana during that period. Determining the appropriate processing technique(s) and attending to problems of interpretation and data integrity took longer than anticipated. The impact of these problems on the analysis is described in those instances where it was significant in the interpretation of the results. The final sample (table 3) consisted of 16,356 records assembled by mix type, of which 8,295 had purpose code "3"; that is, they were used for acceptance compliance judgement. Of these, 411 were accepted at less than 100 percent pay.

The pattern of production is revealed by MATT data and elegantly displayed by figure 1. Clearly the use of asphalt by DOTD is intermittent. Figure 2 shows that the occurrence of unacceptable quality is very small, and figure 3 shows that in many instances data is subject to errors, in processing or because a particular requirement is irrelevant to a particular record. Thus spurious zero values are found.

Table 2

Overview of the current requirements for the design, control, and acceptance of asphaltic concrete – 1992 specification *[7]*

Quality Control Testing by the Contractor	Sampling Plan	Comments:
Job Mix Formula (JMF)	minimum of 1/project/mix type	New JMF when changes in equipment occur.
Materials and their assembly, mix production, plant and roadway equipment, hauling, and lay down	daily check	Certified technician required.
Control charts for aggregate gradation	2/lot	Correct if within 1 percent of JMF limits, 0.5 percent for #200.
Surface profile	each lot	Correct if outside of tolerance.
Quality Assurance (Acceptance) Testing by the DOTD:	**Sampling Plan**	**Comments:**
Gradation, percent crushed, AC content	3/lot*	Test 1; if it passes, no adjustment in pay; if 1st test fails, test other 2; average 3 for #4, #40, #200 only for pay.
Marshall stability	4/lot	Must meet average and individual test requirement.
Pavement density	5/lot	
Surface profile	day's length	
Anti-strip	2/lot	percent pay to be adjusted for each sublot, then averaged to determine adjustment for the lot.

* a lot is 1000 tons of consecutive production of the mix from the same JMF. Adjustment to lot size may be made by the engineer based on certain conditions defined in subsection 501.12 of the standard specifications.

Table 3
Database records accessed

Mix code	Description	Number of records	Number of valid records (1)	Number of defectives (2)
1	type 1 wearing course	4,384	2,306	129
9	type 5A base course	2,815	1,434	59
10	type 5B base course	121	66	1
15	shoulder wearing course (3)	3,542	1,798	49
17	asphalt treated drainage blanket (4)	64	32	0
18	type 7 wearing course (4)	45	18	0
20	type 8 wearing course	2,450	1,158	71
21	type 8 binder course	2,599	1,303	86
22	type 8 friction wearing course	259	119	11
23	type 9 wearing course for shoulders	122	61	5

(1) records with purpose 3 code, i.e. those used to judge specification compliance
(2) records with a percent pay less than 100
(3) not analyzed in this report
(4) not analyzed because of the small number of records

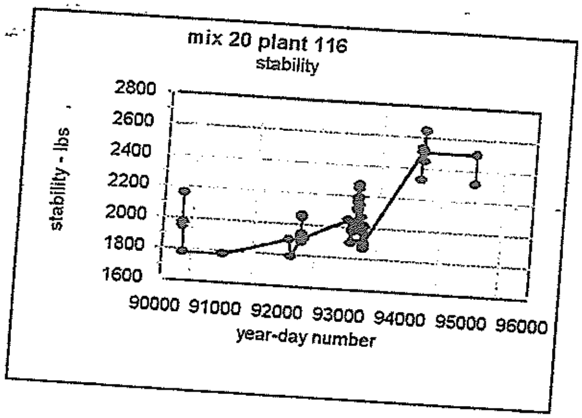


Figure 1
Time pattern of production stability data

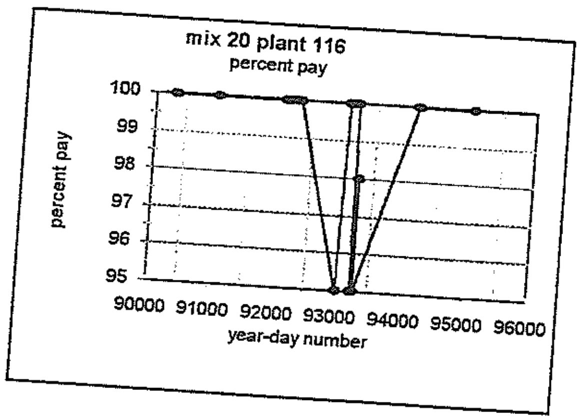


Figure 2
Time pattern of occurrence of pay penalty

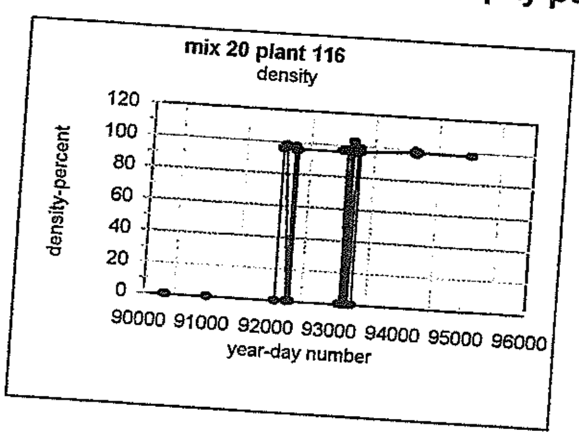


Figure 3
Time pattern of occurrence of data errors

Acceptance compliance quality. Attention was concentrated on determining the quality parameters best defining acceptable quality and the converse, rejectable (defective) quality. The usual statistical quality control terminology is adopted here *[8]*. The term “rejected” does not mean physical rejection of a product, but rather non-compliance with the specification requirements for payment at 100 percent of the contract price. The term “proportion (percent) defective” similarly means that portion of the product estimated to fall outside the specification limits. It does not imply any physical defect, and is used as a quality descriptor. The reasons for this will become evident as the data are presented below. The overall quality is excellent in terms of current specification requirements and therefore the sample of reject product is very small.

The philosophical approach to the analysis of the specifications and proposal of improvements to enhance quality is based on the premise that it is possible to derive a description of currently acceptable quality in terms of the statistical interpretation of the specification compliance acceptance clauses and to relate this to the variability of the product. The variability of most parameters is normally distributed for all practical purposes. The normal distribution also permits the description of quality by a single parameter; the proportion defective to the specification limit(s). Changes to the specifications which will serve to improve quality, must recognize what current asphalt production and construction technologies can achieve and focus attention on the quality level which the statistical descriptions of properties indicate can be achieved *[9], [10], [11], [12]*. A legitimate approach to a quality compliance judgement is to set the requirements such that 80 percent of the current product would pass, and to apply a penalty to that product in the lower 20 percent of production. This is done to encourage producers to improve their quality control and construction supervision and to reduce variability to within a reasonable industry standard.

The penalty ideally should be related to the significance of the particular property in long-term pavement performance. This is not possible at present, and an informed judgement is necessary to set these criteria. Proposals to validate the effect of any particular requirement form part of this report.

Population characteristics. The data has been analyzed with specific attention to those parameters currently subject to specification acceptance clause penalty for non-compliance. These are:

1. Plant process criteria, for which mix type is the primary classifier (table 3)
   a. Marshall stability
   b. gradation
   c. antistrip agent content
2. Lay down process criteria, for which mix use is the primary classifier (table 4)
   a. density
   b. profile

Note that analysis of profile data strictly requires segregation of the data by pavement code (e.g. segregation of the data by the use for new construction - multi lift (rdwy) etc.). However, as the data sets are relatively small a more general evaluation has been used at this stage.

In the analyses reported here mix types 01, 09, 10, 20, 21, 22 and 23 with mix use codes 01 and 09 (density 96 percent, wearing and binder courses) and uses 05, 10, 11, and 12 (density 95 percent, base courses and shoulder placement) were grouped. The other types and uses are not analyzed.

General data processing/file clean up. The primary pavement data files assembled contain 92 items in four categories: identification codes, descriptor codes, test data, and derived data (table 5). The data processing began with separation of the data by mix type. The 1992 DOTD Specification defines eight mixes in five mix types. However, the database contains ten mix type codes (table 3) and 14 mix uses (table 4).

Table 4

Mix use codes and related density requirement

Code	Description	Density specified percent (1992)
01	roadway wearing course	96
02	patching - roadway	-
03	leveling	-
04	widening	-
05	shoulder wearing course	95
06	turnouts	-
07	airport	-
08	miscellaneous	-
09	roadway binder course	96
10	roadway base course	95
11	shoulder binder course	95
12	shoulder base course	95
13	patching - shoulder	95
14	joint repair	-

The data were written to a series of spreadsheet files, one for each mix type, for ease of analysis. Then data for any one mix type were first examined to remove unwanted data items (for example: the item "filler1", which contained no records), and to separate each quality parameter (stability, gradation, antistrip, density, profile) onto a separate page of the spreadsheet. The spreadsheet pages then contain blocks of data with common features for analysis. In this process it was necessary to more closely define the data, as far as practicable, into unique populations. The steps taken were:

1. Sort by purpose.

   Select only data taken for acceptance compliance judgement, i.e. purpose code 3. Note that where verification samples are taken and listed in the data, the number of samples is usually less than that required for a formal compliance judgement.

2. Sort by a population parameter.

   For example, identifier or descriptor file codes (JMF or mix use), to create blocks of common origin.

3. Sort by data value.

   Delete or replace evidently spurious data, for example, where the percent pay was recorded as "0," replace as "100"; where the percent passing was recorded as "0" or "100" for one sieve size and a smaller size also showed either "0" or "100," delete the first record.

4. Sort by data set.

   Select complete sets. For example: where the specification calls for four stability and five density results for a compliance judgment, select only sets with the required number of records.

5. Sort by other data items.

   With clearly spurious values; which were either amended or the data discarded. For example: where the asphalt content was recorded as 55, this was amended to 5.5.

Where less than 30 records remained in a category, this data usually was also discarded. All analyses are available on disk.

Table 5

Data file codes

Identifier	Descriptor	Test	Derived
Code	**purpose**	filler1	**paycalc**
Project	**mixuse**	Specgrav1-4	Voids1-4
Mattid	date_enter	**Stab1-4** (4)	Vma1-4
Specseries	time_enter	Thickness1-5	Vfa1-4
Mixcode	termid	**Density1-5** (5)	Ftoutside
lot_num	date_delete_dist	Meterscale1-2	Pctoutside
Plant	date_delete_fill	**Antistrip1-2** (2)	Weight
Process_date	plantorveri	Twohalfavg	Theoryyield
Security_code	Mixas	Twohalfdev	Actualyield
Item	Jmf	Twoavg	Portoflot
Remarks	speccd	Twodev	**Pctacavg**
Lastbyte	Ngrad	Onehalfavg	**Pctacdev**
	Lotsize	Onehalfdev	Pctacms
	Start_date	Oneandforthavg	**Prctpaystab**
	End_date	Oneandforthdev	**Prctpayden**
	Stations	**oneavg**	**Prctpaytol**
	Accepttol	Onedev	**Prctpaygrad**
	Controltol	**Threeforthsavg**	**Prctpayanti**
	Linearft	Threeforthsdev	Avgspecgrav
	Sqyards	**Halfavg**	Avgstab
	Pctacjmf	Halfdev	Avgvfa
		Threeeightsavg	Avgthick
		Threeeighsdev	Avgdensity
		Nofouravg	**Avganti**
		Nofourdev	**Avgprofind**
		Notenavg	
		Notendev	
		Nofortyavg	
		Nofortydev	
		Noeightyavg	
		Noeightydev	
		Notwohundavg	
		Notwohunddev	
		Crushavg	

Note:
***Numbers** after item refer to the number of results which should be present for a complete record*
*Items in **bold** retained for analysis*

Preprocessing the data in this manner resulted in the selection of coherent data sets for analysis but greatly reduced the number of results. Most of the sample sizes examined in this part of the study were large, thus these precautionary filters applied to the complete data sets are not likely to have created major or systematic bias. However, missing and/or suspect data in some fields, (e.g. antistrip content and profile, has hampered analysis.

Compliance quality parameters

Stability. The Marshall stability of specimens compacted from fresh mix sampled from the delivery stage is an acceptance compliance parameter subject to penalty for non-compliance. Details of the operating characteristics of the various specification clauses are given beginning page 35 of this report.

The compliance clause requires four specimens to be tested for each lot (of 2000 t), so only data where four specimen test results were reported were analyzed. The distribution of mean stability for each mix type was calculated, together with the standard deviation of each set of four tests. The proportion defective to the 100 percent pay criteria of the 1992 specification for that set of results was also estimated. A count of the number of lots penalized (i.e. recorded as defective) is also reported in table 6.

A typical distribution of the stability quality parameters, mean, standard deviation, and proportion defective to the 100 percent pay criterion is given in figures 4-6 for mix type 09 (type 5A base course mix). The distributions for mix types 01, 10, 20,21,22, and 23 are given in appendix A.

Table 6

Stability parameters for mix types

Code	total records	valid records	penalties recorded	mean - lbs	standard deviation	percent defective
01	4,384	1,654	0	1,719	99	0.12
09	2,815	2,813	4	1,673	120	3.00
10	121	66	0	2,307	123	0.01
20 (1987)	2,450	652	0	2,076	108	0.16
20 (1992)	2,450	1,052	5	2,086	111	0.54
21	2,599	1,137	12	2,100	110	0.19
22	259	96	0	2,307	123	0.01

The data suggest an average standard deviation of stability of about 100 lbs, showing a reduction since the 1970's. The proportion defective to specification is also very low.

Gradation. Gradation data cannot be simply described by one mean, standard deviation and proportion defective because there are up to ten particle size categories. Each size category has an upper and lower specification limit for design purposes. A design gradation, the Job Mix Formula (JMF), is established within these specification limits for each particle size. A set of upper and lower compliance limits is developed from the JMF for sizes numbered 4, 40, and 200. This JMF is provided in the plant data file, not in the pavement data file set. Thus both files had to be extracted and combined for analysis with the tolerances taken from the specification requirements. Nor is the deviation from the JMF reported in

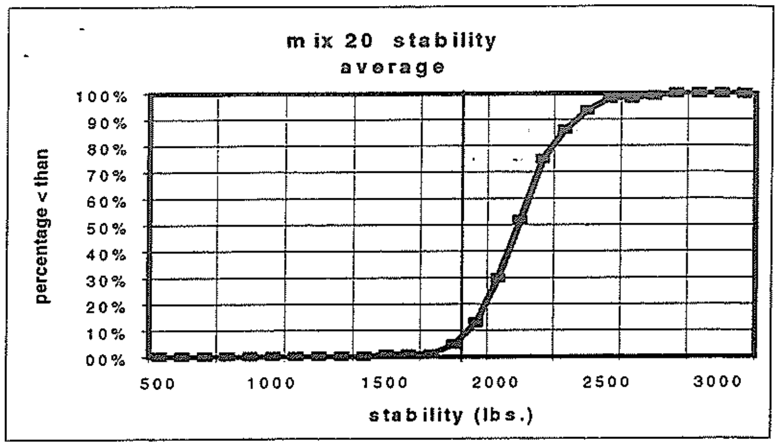


Figure 4
Distribution of mean -- stability, mix 9

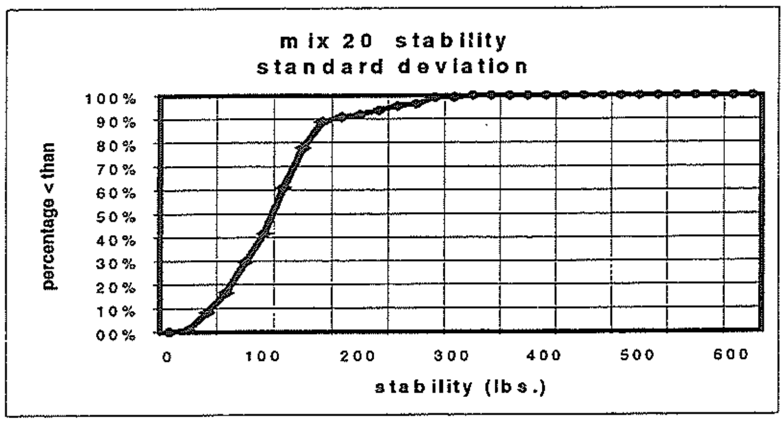


Figure 5
Distribution of standard deviation -- stability, mix 9

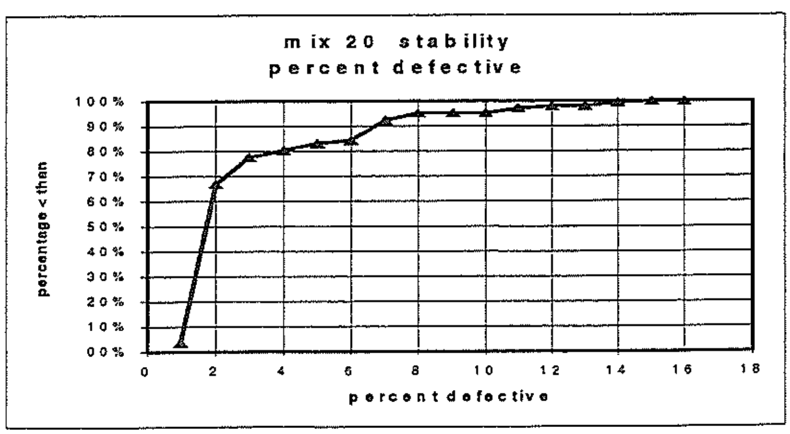


Figure 6
Distribution of proportion defective -- stability, mix 9

most records. A MATT record may indicate that more than one gradation has been tested, but average results only are given. The data has therefore been processed by selecting those pavement records for which gradation results matching the specification limits exist, for the 4, 40 and 200 numbered sieve sizes, and which can be matched to a plant file for the JMF. The mean gradation and standard deviation of all such records for individual lots submitted for a mix type have been calculated. The distributions of the means and standard deviations for the passing #200 sieve sizes are shown in figure 7a and 7b. The maximum and minimum percent passing for each particle size category is plotted (with the nominal specification gradation limits) in figure 7c, for mix type 20. Plots for other mix types are included in appendix A.

The specification acceptance penalty payment criteria are applied only to sieves numbered 4 (4.75 mm), 40 (0.425 mm), and 200 (0.075 mm). Where these penalties have been applied for mix type 20 the results have also been assembled in table 7.

For mix type 20, the non-compliance is found across the three critical sieve sizes. Lots that do not meet the specification (on sieves numbered 4, 40, and 200) have been accepted without penalty, presumably where the engineer has used judgement in interpretation of the significance of the deviation. Similar patterns are evident for all mix types.

Antistrip. Antistrip content is also subject to a penalty payment clause but related to a JMF requirement that is not available in the pavement data file extract. However, by checking the JMF mix file extracts and cross correlating the data by job, sequence and JMF number, the records could be partially matched so that the relation to specification limits could be derived. Table 8 shows the mean and standard deviation of all (matched) lots, for which a standard deviation could be estimated.

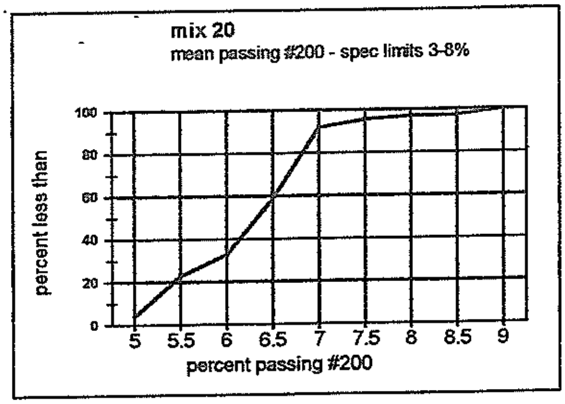


Figure 7a
Distribution of mean percent passing #200 sieve

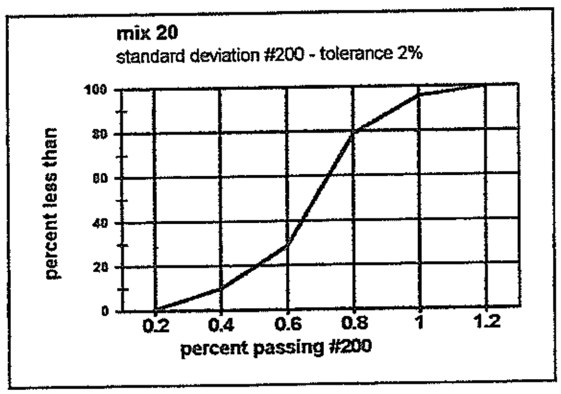


Figure 7b
Distribution of standard deviation of percent passing #200

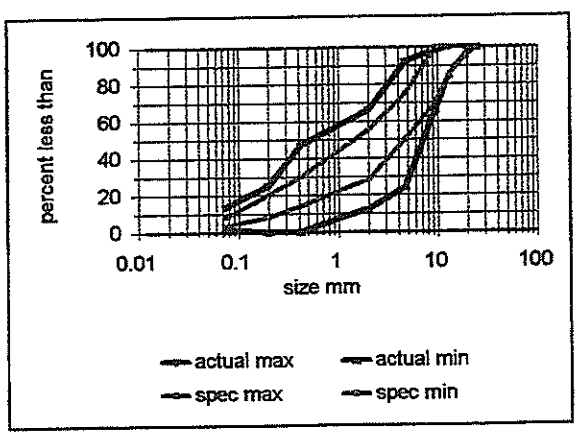


Figure 7c
Distribution of gradations

Table 7

Gradation parameters – percent passing, mix type 20 (type 8 wearing course)

Records	Parameter	No 4	No 40	No 200
Specification	Maximum	75	30	8
	Minimum	50	14	3
Actual	Maximum	92	47	13
	Minimum	31	9	1
Accepted	Mean	62	24	6.7
n = 1,709	Standard Deviation	3.7	2.0	0.90

Percent pay	MATT records		Specification algorithm	
	number	Percent	number	percent
100	1,709	98.2	1,598	91.8
98	25	1.4	85	4.9
95	7	0.4	29	1.7
80			12	0.7
50			17	0.9

Table 8

Antistrip content parameters

mix code	sets of records	number of records	weighted mean percent percent	Weighted mean standard deviation	weighted mean percent defective	penalties
01	103	1,369	0.69			
01	49	821	0.71	0.07	64	0
09	81	1,842	0.70			7
09	66	781		0.07	49	
10	5	25	0.62	0.03	100	0
20	89	884	0.69	0.06	43	
21						
22	8	64	0.79	0.05	32	0
23	3	17	0.60	0.52	64	0

However, the matching process for mix 9, for example, yielded only 81 sets (1,842 records), out of 2,815 records in the pavement file for which the standard deviation could be estimated (fig 8) and only 66 sets (781 records), for which the proportion defective to the JMF specification limit could be calculated (fig 9). Again all the results are given in appendix A. It is evident that there is considerable variability in the recorded antistrip content and a very substantial proportion defective. This may be related to practice which uses the "meterscale" reading, presumably converted to the antistrip values recorded for specification compliance. This aspect should be the subject of an in-depth study to ensure the data recorded is both accurate and pertinent to product quality.

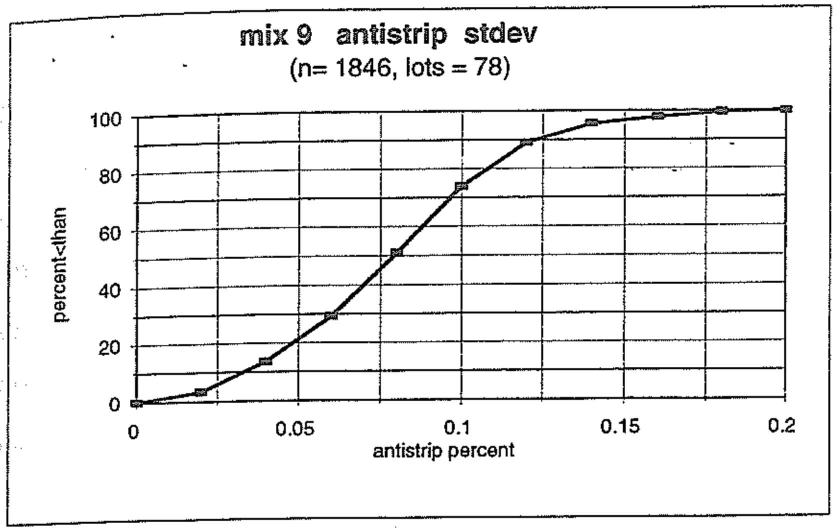


Figure 8

Distribution of deviation--antistrip content, mix 9

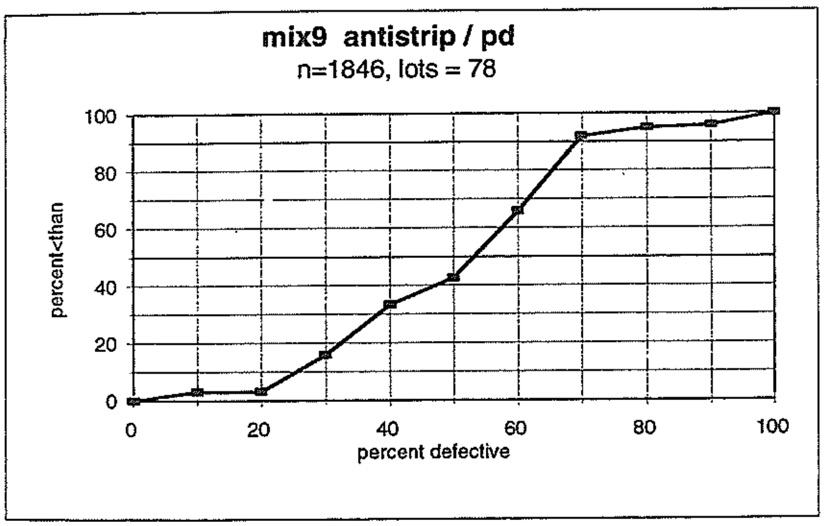


Figure 9

Distribution of proportion defective--antistrip, mix 9

Density. The density measured after lay down is subject to an acceptance compliance clause which incorporates a penalty payment. A penalty applies where the density is less than 96 percent laboratory maximum Marshall density, for wearing and binder course; or 95 percent for base course or mixes placed on shoulders. The compliance clause uses the mean of five results as the criterion. The density data were processed in a similar manner to stability data. Any lot without five density results was discarded, and the mean, standard deviation and proportion defective, to the appropriate limit, were calculated and plotted. Table 9 summarizes the results by mix type and mix use. A typical distribution in given in figures 10-12. All data analyzed are reported in appendix A. The analyses indicate a mean standard deviation of one percent of compacted density with the mean proportion defective varying between five and seventy percent depending on mix type and usage.

Profile. Profile is accepted on the basis of a profile index, reported as inches/mile/lot, and is reported only for wearing and binder course applications. Only one index result is given for a lot therefore only a crude estimate of the average and variability of the data can be estimated by assembling all lots in one job and assuming the data can be amalgamated. This process leads, for example, to a mean profile index of 5.1 in/mile, for mix 20 applications, with a weighted mean standard deviation of 1.5 in/mile. However, the sample size is only 32 and no great confidence can be placed in the results (fig 13). Table 10 shows the very limited profile data recorded and all results are given in appendix A.

The data sample is too small for robust general conclusions. It does suggest, however, that a sampling approach rather than total profile measurement procedure could be better to give an estimate of the mean and variability of profile on any job. New technology for measuring profile may also have potential application.

Table 9

Density parameters

Mix/use code	total records	valid records	spec. min.	mean density percent	standard deviation percent	percent defective	penalties
1/10-11-12	4,384	1,025	95	96.8	0.84	22	0
1/1-9		110	96	96.7	0.98	15	0
9/10-11-12	2,815	611	95	97.5	0.89	4.8	4
10/10-11-12	53	39	95	97.5	1.1	5.7	0
20/1	4,815	1,184	96	95.4	1.2	70	54
20/9		84	96	97.2	1.0	19	4
20/5		103	95	94.2	1.3	71	9
20/10		13	95	96.3	1.0	16	1
22/1-9	260	70	96	97.0	0.93	19	4
22/5		11	95	95.8	0.98	21	0
23	122	36	95	97.3	0.90	8.8	0

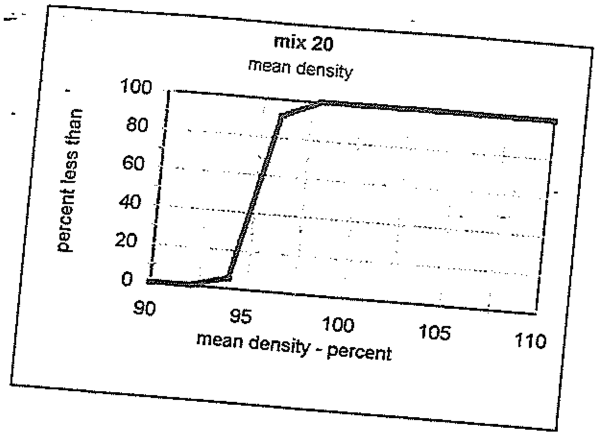


Figure 10
Distribution of mean density

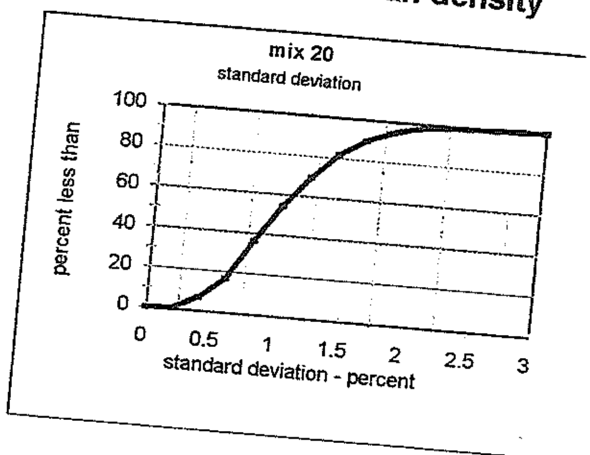


Figure 11
Distribution of standard deviation

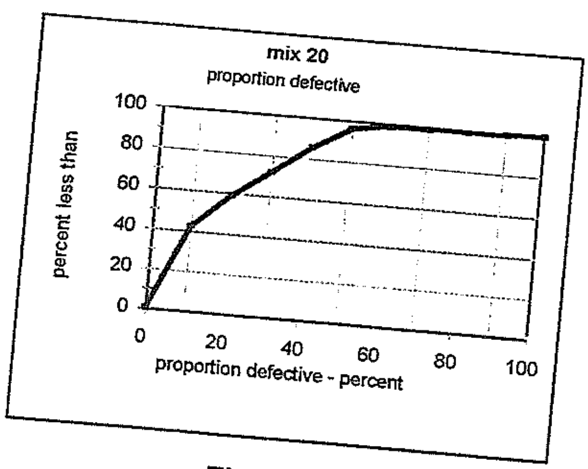


Figure 12
Distribution of proportion defective

Table 10

Profile parameters

mix code	Valid records	mean profile index (in/mile)	standard deviation of index
20	32	5.1	1.5
21	15	5.0	0.5
22	38	1.6	0.8

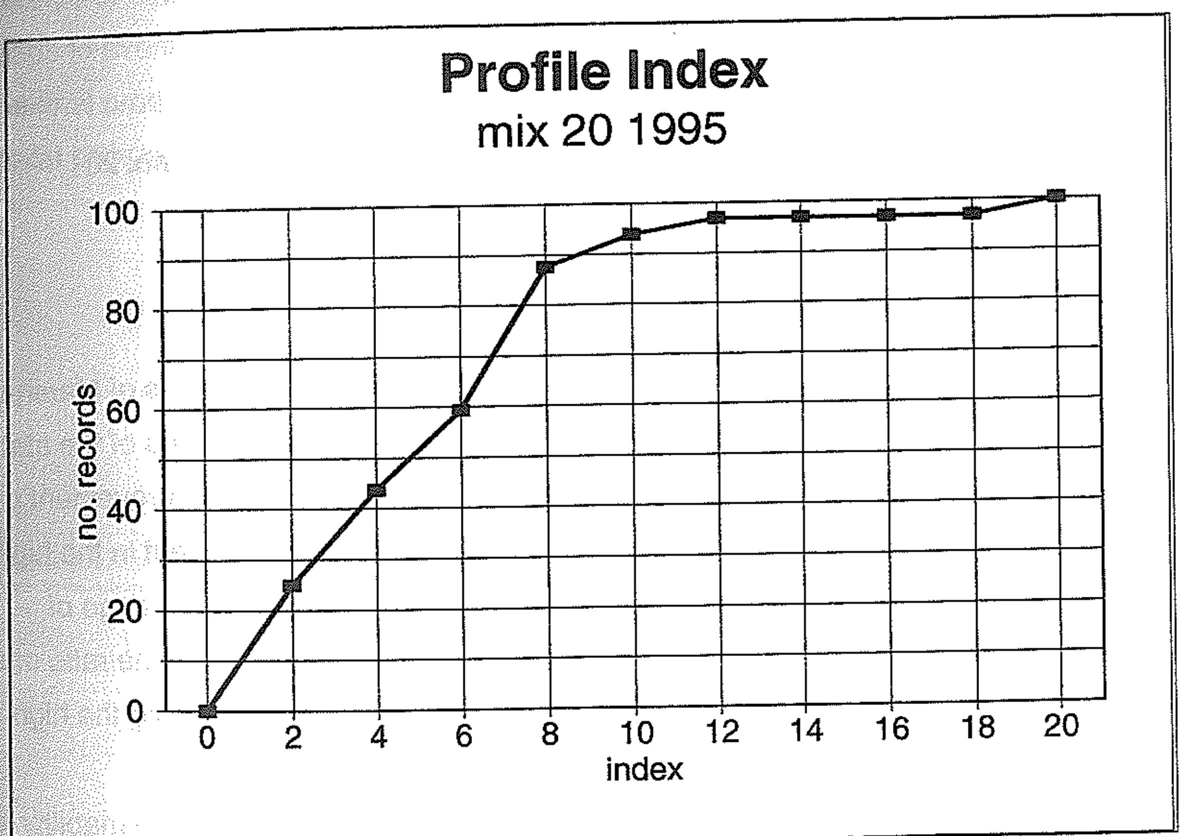


Figure 13a

Distribution of profile index, mix 20

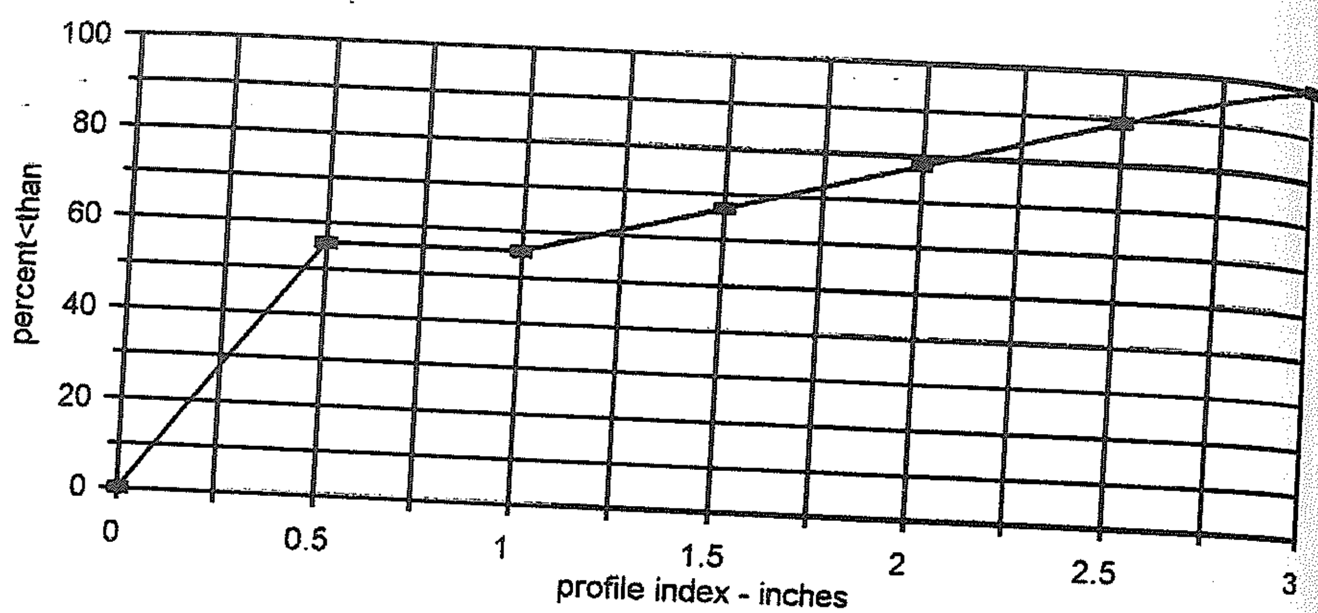


Figure 13b

Distribution of standard deviation -- profile index, mix 20

Process control quality

The current system produces product of good quality. In terms of Marshall stability there is no significant difference between the various regions of the state. The variability of production within a region could be reduced by improvement of the quality of certain producers. This lack of quality appears most evident in the high variability of the Marshall stability of some plants, table 11. Note the range of standard deviation. The low value is 122 and the high value is 411. The ratio of the high to the low is 3.36. Although the mean value of the plant producing the high standard deviation is also high there is opportunity for improvement.

There is also considerable variability of the mean values. This variability is not serious, however, since the means are significantly higher than is necessary for good products with reasonable values of standard deviation.

Better information can be obtained by observing data related to control limits for the process. Control limits, for both mean and standard deviation of stability, are constructed in table 11 for the plants in District 1 producing mix type 5. Although the output of three plants falls outside the control limits on the process, it should be noted that these values are outliners only because some of the others far exceed the specifications for mean value. In the case of each of the plants that fall outside the limits, their standard deviations are small.

Note that the results differ as to which production falls outside the process parameters. The worst results are those which fall outside the upper control limit for standard deviation indicating the out of control process.

The current system is indeed producing a good quality product. If, however, there were a major shift in the input quality to the process of production there is little chance of detection prior to the product being placed on the road. This type of system leads to events where significant compromise may be made at a sacrifice of quality of the final product. A better system would provide for a less costly rejection, i.e., one made prior to lay down.

Table 11
Marshall stability for district 1 population statistics and control limits

Plant	Mean	Standard Deviation	Number of observations	Lower control limit, mean	Upper control limit, deviation
1	1,936	162	125	1,798	275
2	1,693	122	30	1,735*	318
3	2,136	197	20	1,707	339
4	1,598	239	120	1,797*	275
5	1,875	184	122	1,797	275
6	1,958	251	60	1,771	291
7	2,275	212	47	1,760	295
8	1,650	182	73	1,779*	286
9	2,183	411	20	1,707	339*
				1,797	275*

* indicates points out of control

Operating Characteristic Curves

Louisiana's standard specification (1992) describes the departmental requirements for asphaltic concretes *[7]*. Marshall stability, compacted density, surface tolerance, anti-strip additive content, and gradation, with limits on the number 4, 40 and 200 sizes, are assessed for acceptance compliance and incorporated in the reduced payment schemes. The specifications also include limits on the deviation of asphalt content from the JMF, the proportion of crushed aggregate, Marshall flow, and voids contents. These do not attract penalties as the result of non compliance.

In this study, the critical acceptance compliance parameters of stability, density, surface tolerance, aggregate gradation, and antistrip content were examined to establish how the specification could be interpreted in terms of Operating Characteristic (OC) curves for the compliance scheme criteria.

The requirements are detailed in part V of the 1992 specification, especially clauses:

501.02b(2)	antistrip,
501.03(c)	gradation,
501.08(a)	density,
501.12	acceptance requirements.

Tables 1 and 2, in the 1992 specification, give the limits and penalties for the various parameters. These requirements are interpreted below in terms of the probabilities of acceptance derived from the statistics of the parameters and the sampling schemes applied.

Stability. The stability requirement is that the mean of four samples from a lot and all individual results of the four meet the specification requirement appropriate to the mix type. Should the requirement not be met then there is a declining scale of payment to a limit at which the engineer is empowered to reject the lot. Note that it is necessary to assume a value for the standard deviation of the product for this variability known scheme approach.

The Marshall stability requirement, for mix type 9, is that the mean of four tests from a lot exceed 1200 lbs, and no individual result should be below 1000 lbs, for 100 percent payment. There is then a declining scale of payment until the rejection limit that should the mean of four fall below 1000 lbs, the engineer is empowered to remove the materials or to pay only 50 percent of the bid price.

The interpretation as an OC curve is given in figures 14, 15 and appendix D. In this example, the standard deviation is taken as 200 lbs, a reasonable value (i.e. achievable by most producers) assumed from figure 5. Should the actual standard deviation differ from this value then the probability of acceptance will change. Two examples, for a standard deviation of 100 lbs and 400 lbs, are also given in appendix B. This analysis shows that the operating characteristics of the 1992 specification for stability differ for each mix type and, within a mix type, with each value of standard deviation.

The consequence for a producer is that achieving low variability (a standard deviation of 100 lbs) requires a very high mean stability to meet the specification.

Operating Characteristic for Stability

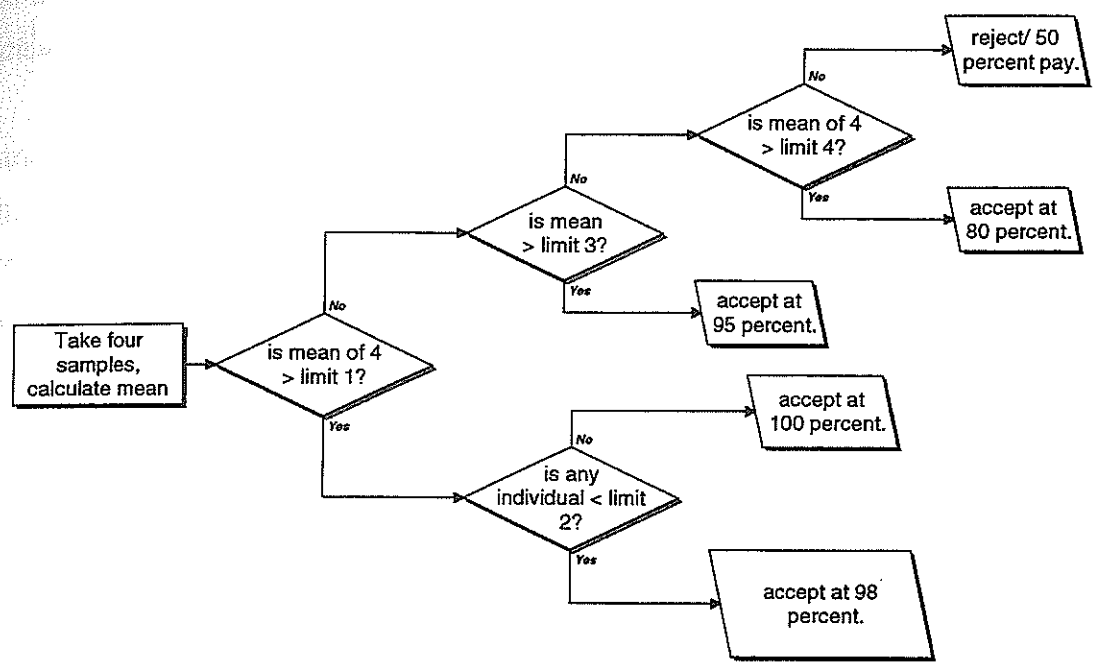


Figure 14

Operating characteristic for stability--interpretation of scheme

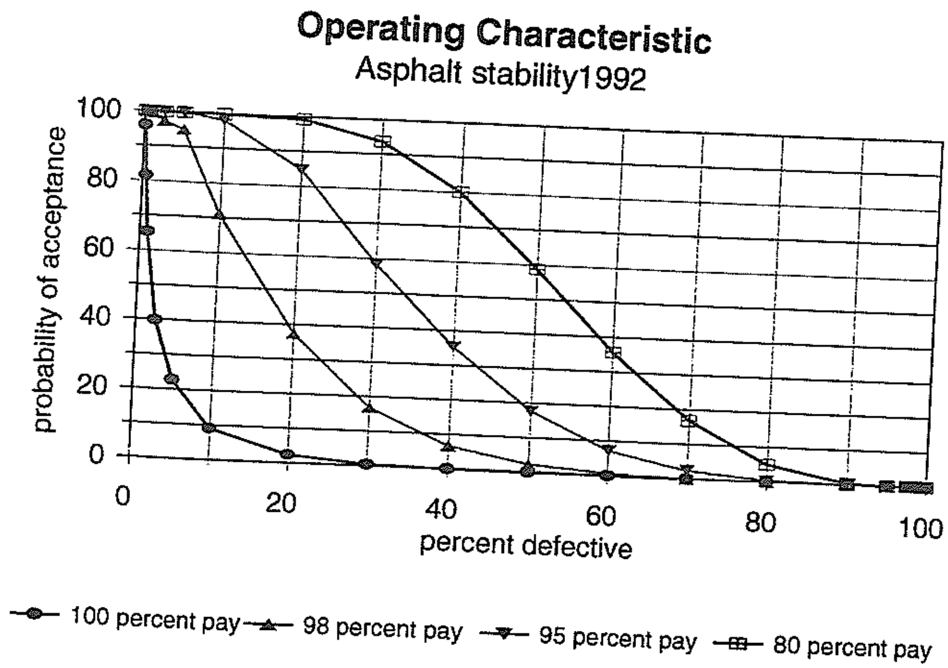


Figure 15

Operating characteristic curve for stability--mix 9, 1992 specification, sigma assumed 200 lbs

Gradation. The gradation requirements are very complex: a JMF gradation is determined within the envelope specified for the mix type, and tolerances are then established from this JMF for each of ten aggregate sizes. The material must meet all ten grading limits. Penalty clauses are applied to three sieve sizes, numbers 4, 40, and 200. Acceptance at 100 percent pay applies where the actual grading differs from the JMF tolerance limits by less than one percent (# 4 and 40), or half a percent (# 200). A rejection limit applies where the grading falls outside the JMF limits by more than eight percent (# 4), six percent (# 40) or three percent (# 200). The worst deficit is adopted to determine the penalty to be applied.

A tentative interpretation of this scheme is possible, as shown in figure 16a, b, but an operating characteristic curve can only be approximated for each sieve size. Figure 16c shows a probable interpretation for the number 200 criterion based on an approximation of the acceptance requirement as a (1,0) attributes scheme for the single gradation result for 100 percent pay and as a (1,0) scheme for the mean of three results for less than 100 percent pay. The 50 percent/reject criterion is also shown. Figure 16d shows possible operating characteristics for the # 200 sieve using a double sided percent-within-limits approach; note that the smallest sample size for such a scheme is three.

Antistrip. The requirements for antistrip agent again depend upon knowledge of the JMF, which is not in the pavement data file extracted. In mix type 1 data, out of 4384 records, only one failed to attract 100 percent pay for antistrip content, recorded at 99 percent. Practice allows averaging of two results, thus a 98 percent and a 100 percent is recorded as 99 percent. The consequence of the OC is that the average antistrip content is close to the specified minimum, even allowing uncertainties. Analysis of this clause of the specification is shown in fig 17a,b and appendix B.

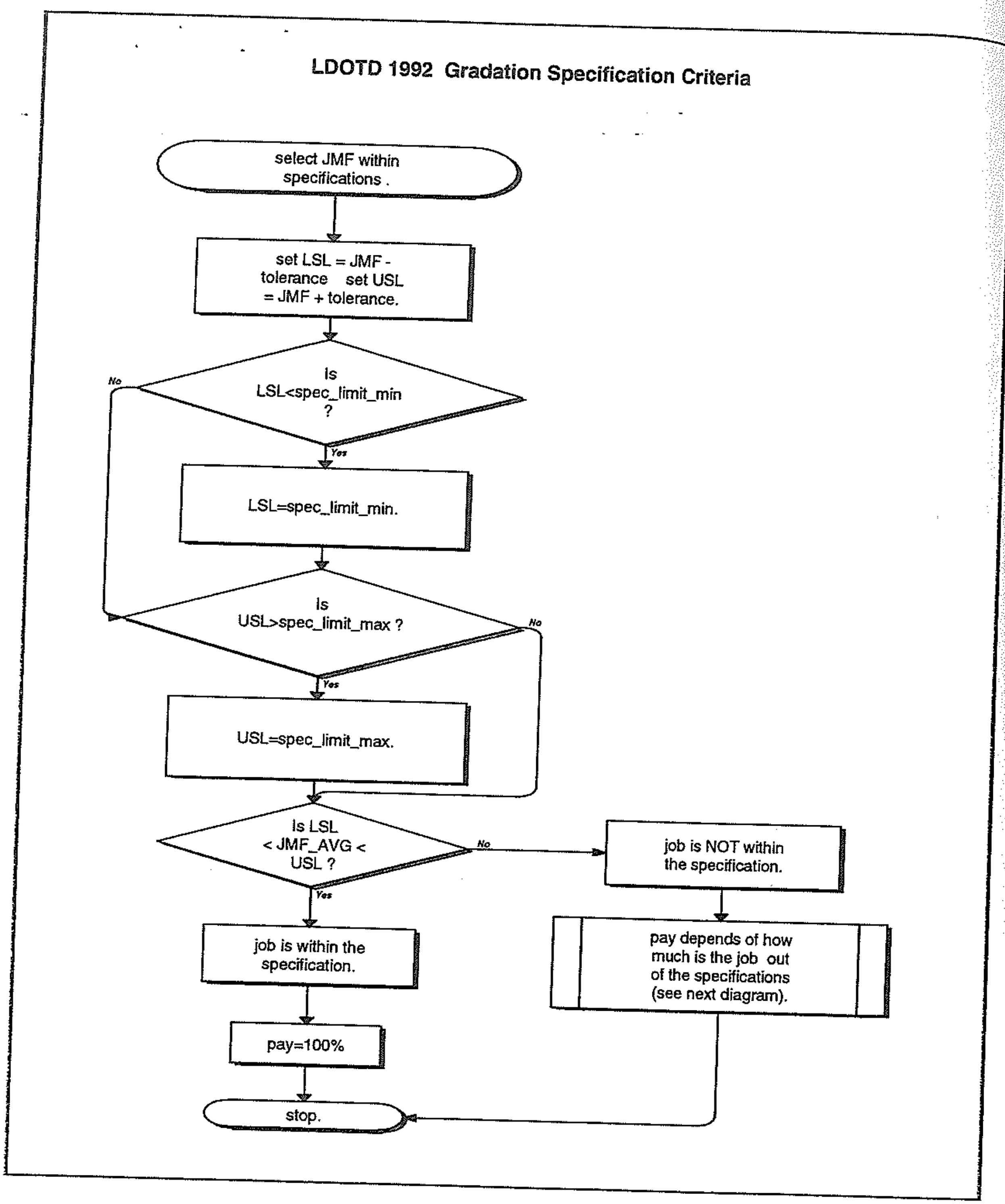


Figure 16a

DOTD gradation specification criteria 1992

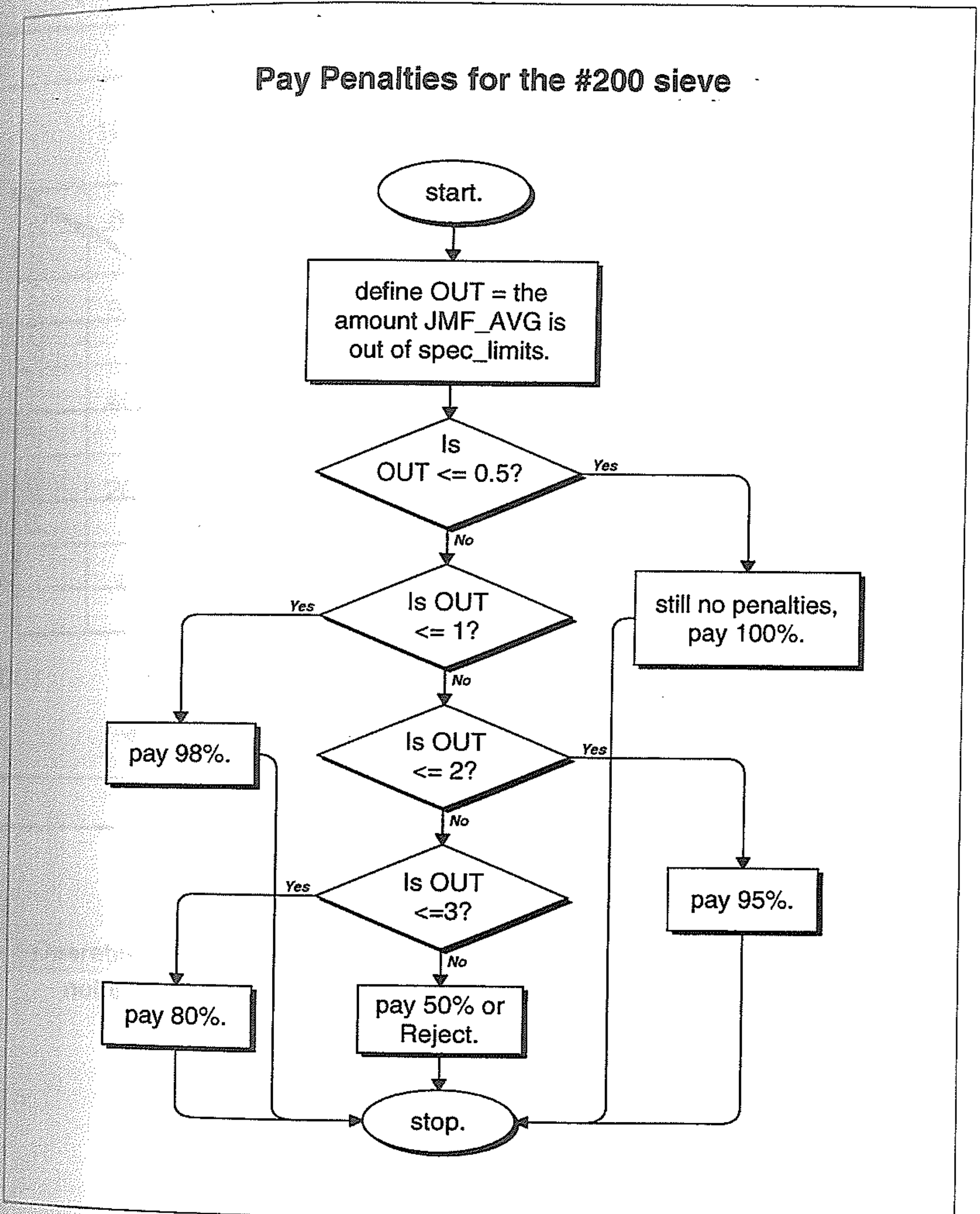


Figure 16b

Pay penalties for the passing number 200 sieve fraction

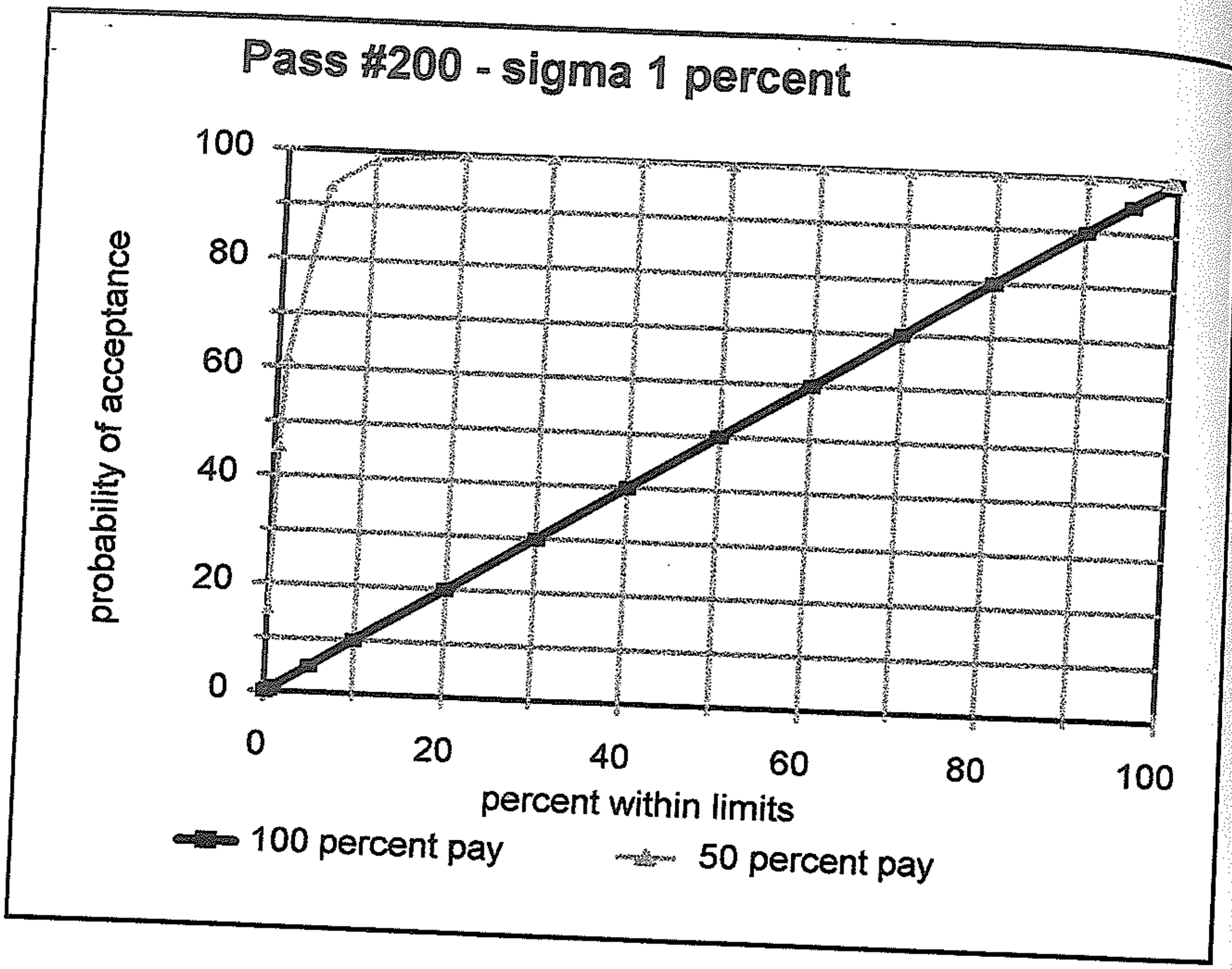


Figure 16c
Operating Characteristic for gradation - 1992 DOTD specification

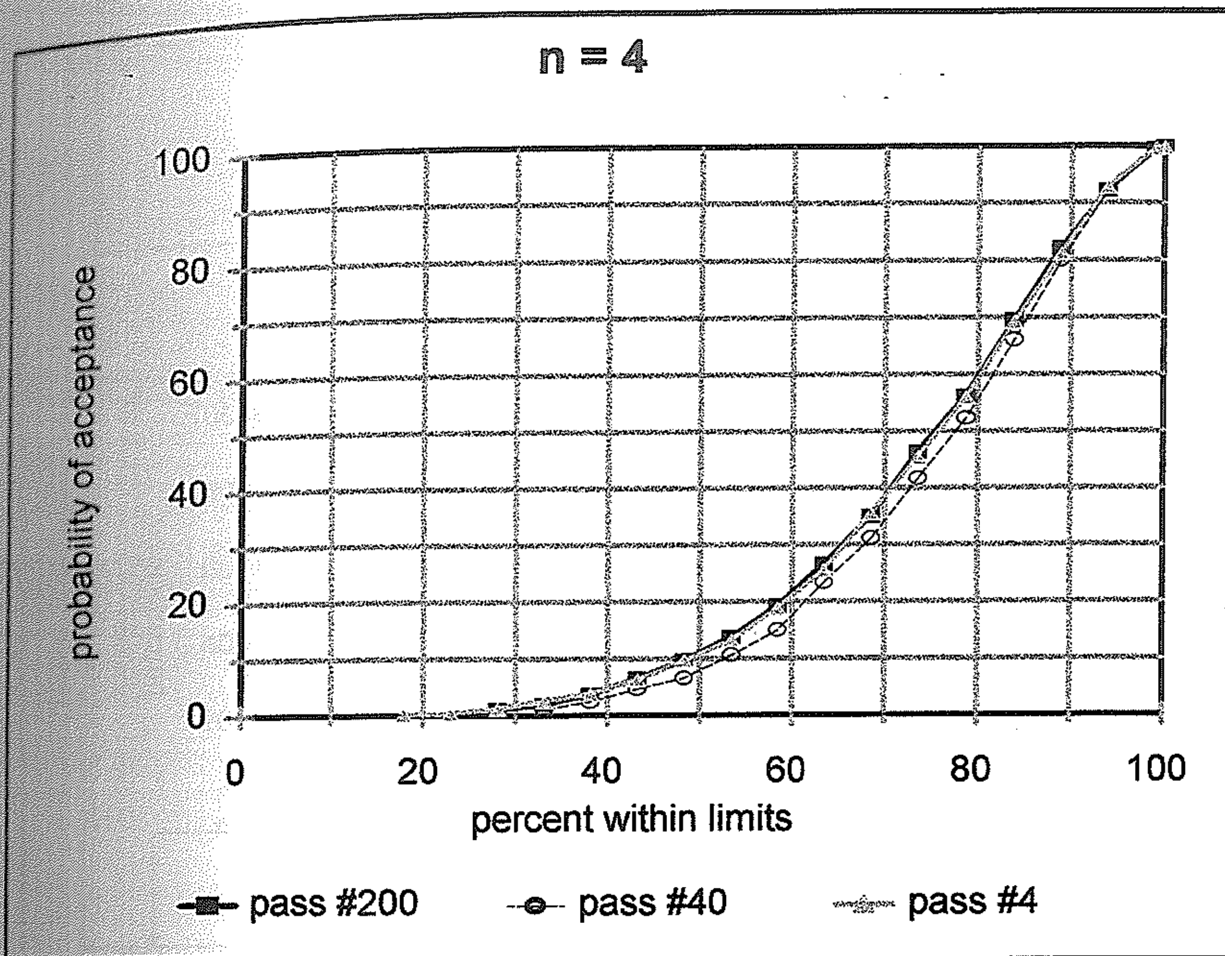


Figure 16d
Operating Characteristic for gradation - percent within limits approach

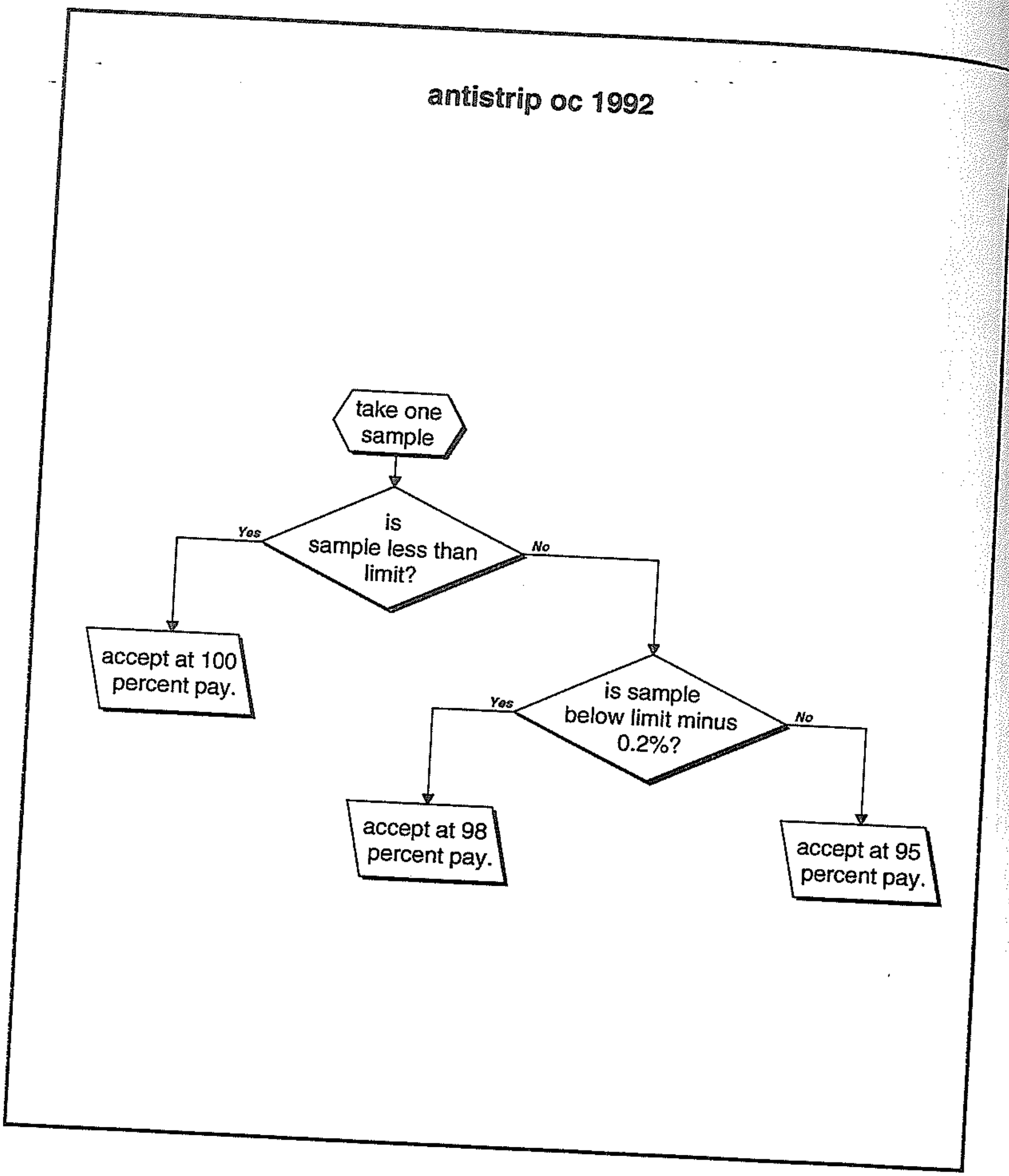


Figure 17a
Operating characteristic for antistrip--interpretation of scheme

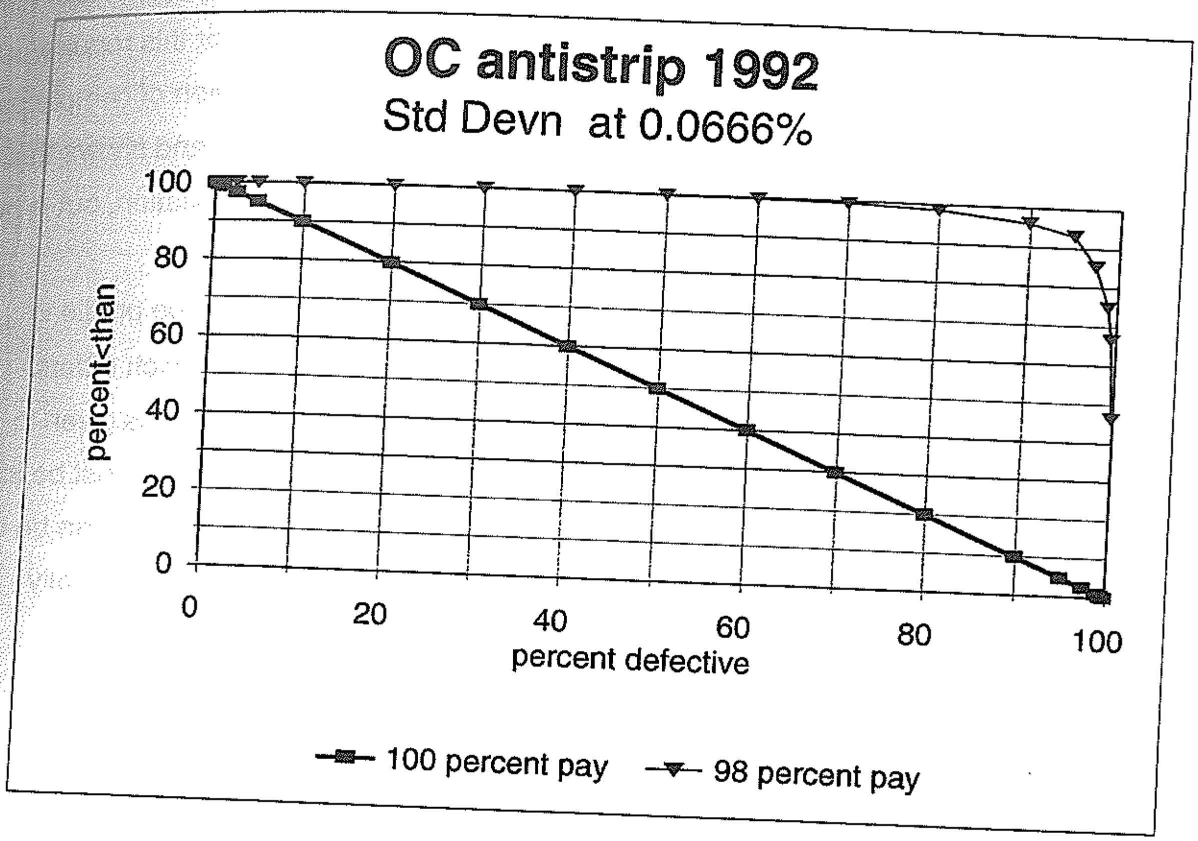


Figure 17b

Operating characteristic curve for antistrip–DOTD 1992 specification, assumed sigma 0.666 percent

Density. The density requirement is that the mean of five samples be greater than the specified minimum. This is defined as 95 percent of the design maximum density for base and shoulder course, and 96 percent for wearing course. There is then a declining scale of payment until the rejection limit, when the density falls below 92 or 93 percent respectively. An interpretation of the OC curve for this requirement is given in figures 18-19, for an assumption of the standard deviation of compacted density of one percent. Appendix B gives the derivation of the OC and shows that the probability of acceptance is dependent on the sample standard deviation, but is not affected by the specification minimum.

Profile. The requirements for profile are simple. One average profile is compared to acceptance limits with a declining scale of payment, which differs depending upon the type of construction. An interpretation of the OC is given in figures 20, 21, and the derivation in appendix B. Again, the variability must be known or assumed. Since limited data were analyzed, only tentative comments can be made on the effect of the compliance clause. It would appear to allow a substantially rougher profile than desired.

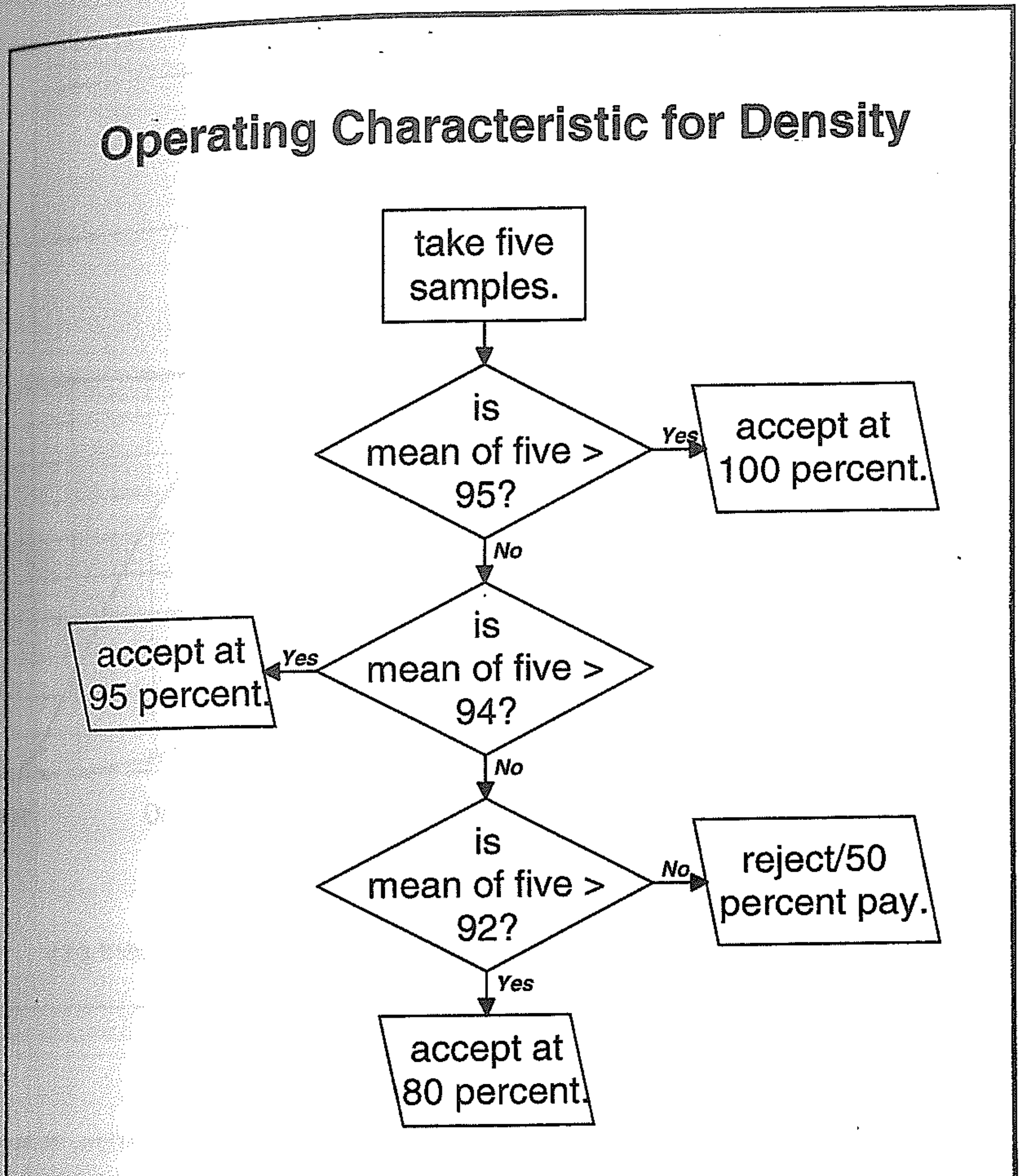


Figure 18

Operating characteristic for density - interpretation of DOTD 1992 scheme

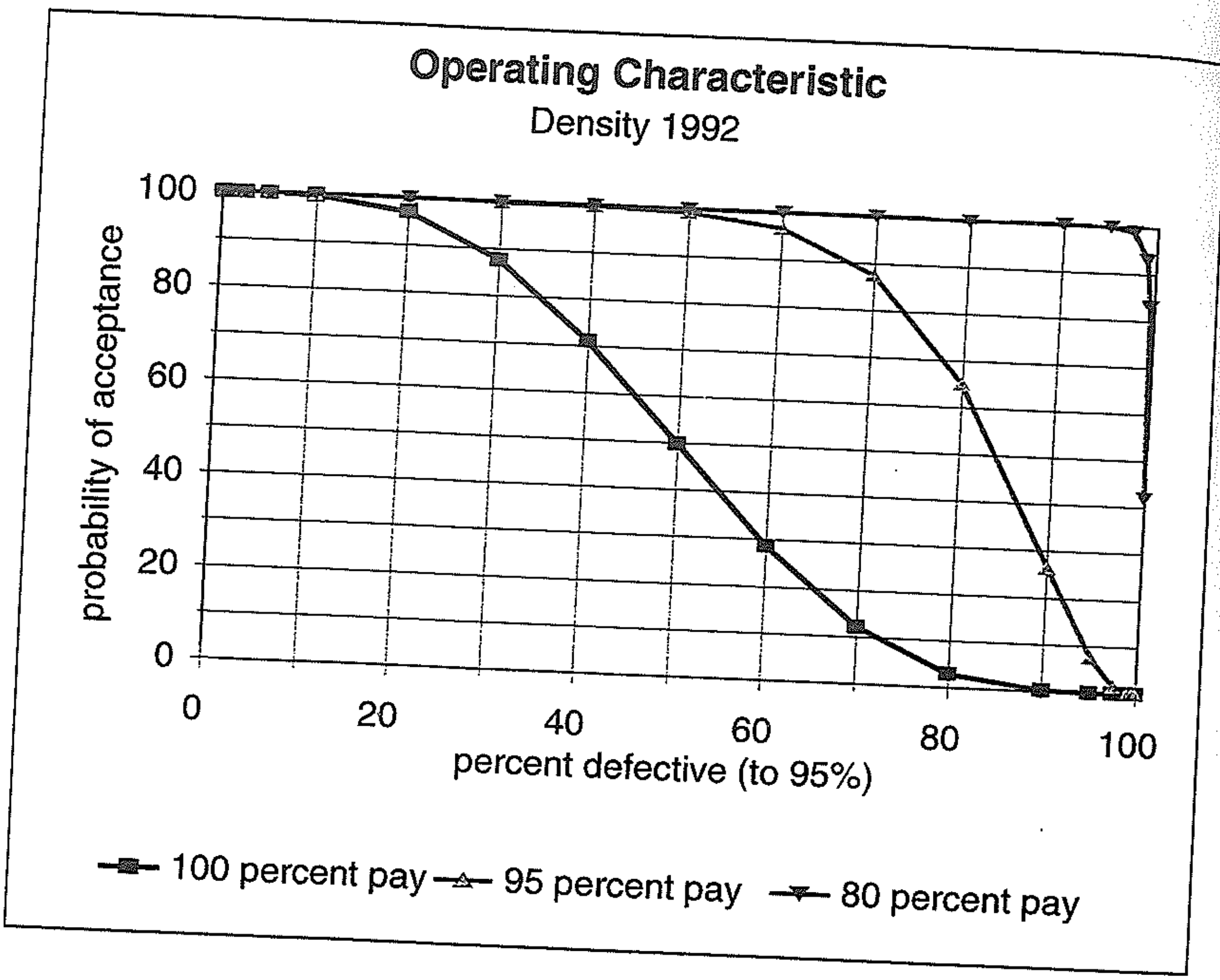


Figure 19

Operating characteristic curve for density, DOTD 1992 specification, assumed sigma one percent

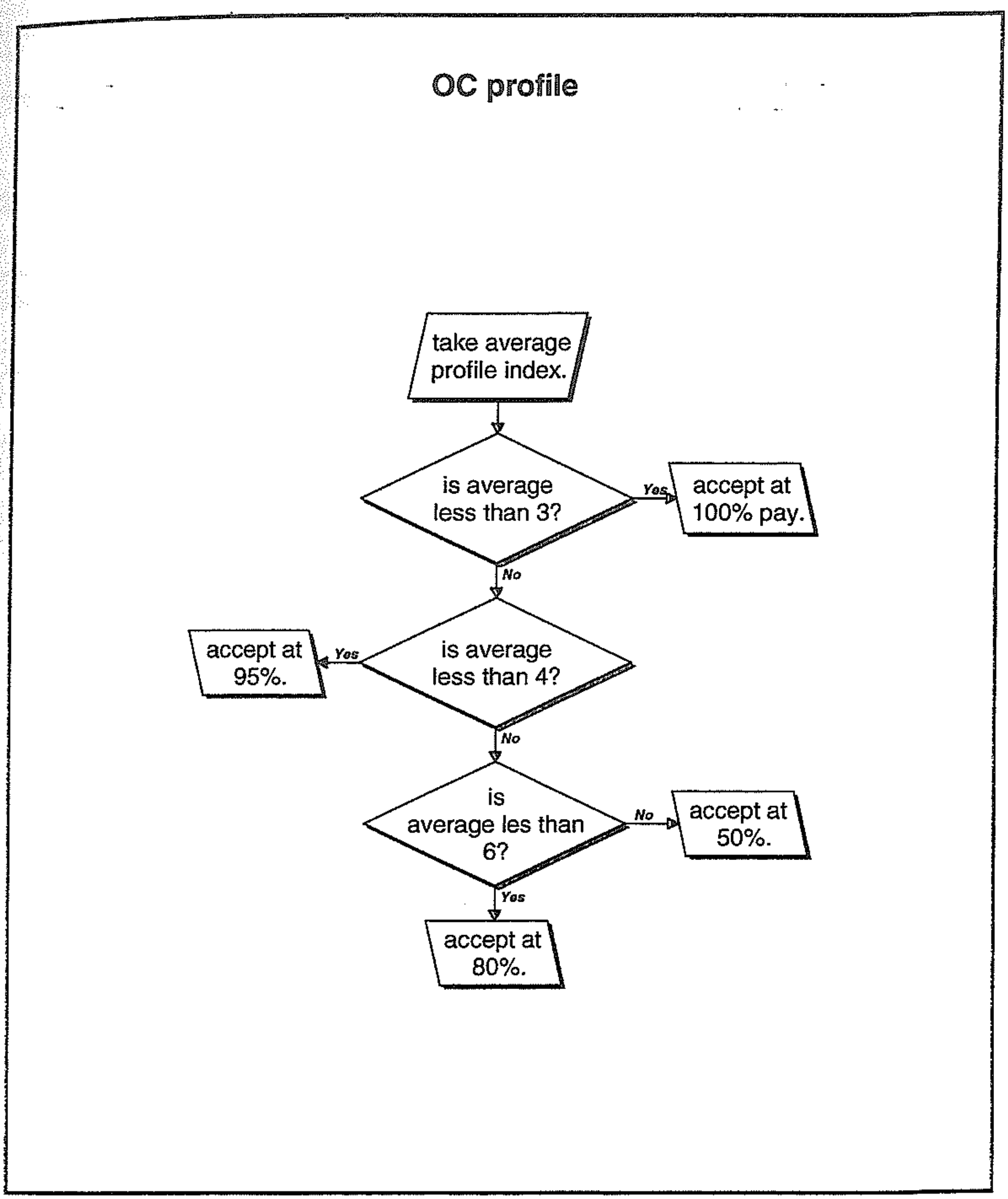


Figure 20

Operating characteristic for profile - interpretation of DOTD 1992 scheme

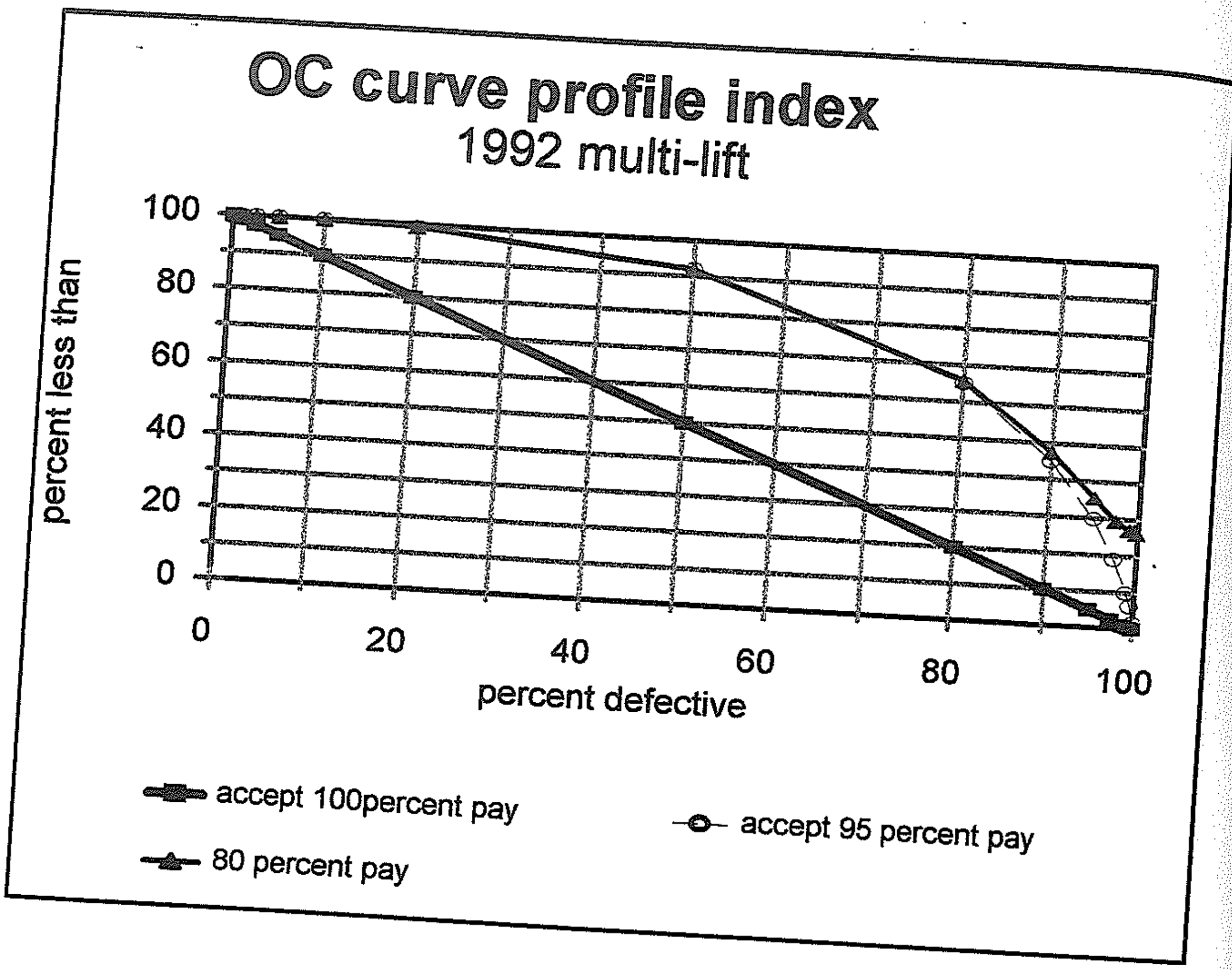


Figure 21
Operating Characteristic - profile, 1992 DOTD specification

DISCUSSION

Process quality criteria

The intent of the DOTD standard specifications for asphaltic concrete is that the product meets the requirements for 100 percent payment. So that the product would satisfy this requirement, the specifications further define who is responsible for what. The specifications state that contractor shall be responsible for design, production, transportation, and lay down of the mixtures. Likewise, the specifications state that quality assurance for acceptance will be the DOTD's responsibility. Sounds simple enough. However, within these two broad definitions of responsibilities are complex clauses for control of various entities that makeup the process of designing, producing, laying, compacting, and final finishing of the mixture on the roadway. The clauses further define the actions that will be taken (by the contractor) when certain control requirements are not met. Furthermore, the 15 different types of mixes (binder and wearing course) with 14 different categories of roadway construction add to the complexities of the specification application for control and acceptance.

The quality of the mixture is evaluated during two phases:

1. mixture produced at the plant, and
2. mixture hauled, laid and compacted.

Table 2 is an overview of the current specifications for the quality control (QC) and quality assurance (QA) plan *[8]*. Following sections discuss some of the quality requirements and what actions are required when the quality requirements are not met.

Materials, equipment and processes. All materials must be source approved. Proper stockpiling is required and samples are tested for conformance to general specifications for materials. Asphalt cements are tested for contamination. Deficient material receives reduced pay. Stockpiled and individual bins are sampled and tested. It is not clear from the specifications what actions are taken if the tests on stockpile and bin samples indicate deficiencies in the measured characteristics.

In addition to the materials requirement, a separate section of the specification

DISCUSSION

Process quality criteria

The intent of the DOTD standard specifications for asphaltic concrete is that the product meets the requirements for 100 percent payment. So that the product would satisfy this requirement, the specifications further define who is responsible for what. The specifications state that contractor shall be responsible for design, production, transportation, and lay down of the mixtures. Likewise, the specifications state that quality assurance for acceptance will be the DOTD's responsibility. Sounds simple enough. However, within these two broad definitions of responsibilities are complex clauses for control of various entities that makeup the process of designing, producing, laying, compacting, and final finishing of the mixture on the roadway. The clauses further define the actions that will be taken (by the contractor) when certain control requirements are not met. Furthermore, the 15 different types of mixes (binder and wearing course) with 14 different categories of roadway construction add to the complexities of the specification application for control and acceptance.

The quality of the mixture is evaluated during two phases:

1. mixture produced at the plant, and
2. mixture hauled, laid and compacted.

Table 2 is an overview of the current specifications for the quality control (QC) and quality assurance (QA) plan *[8]*. Following sections discuss some of the quality requirements and what actions are required when the quality requirements are not met.

Materials, equipment and processes. All materials must be source approved. Proper stockpiling is required and samples are tested for conformance to general specifications for materials. Asphalt cements are tested for contamination. Deficient material receives reduced pay. Stockpiled and individual bins are sampled and tested. It is not clear from the specifications what actions are taken if the tests on stockpile and bin samples indicate deficiencies in the measured characteristics.

In addition to the materials requirement, a separate section of the specification is devoted to the equipment used in producing, placing and compacting of asphaltic concrete mixtures [8]. It includes methods and equipment for handling and storing materials and transporting asphaltic concrete to the job site. Before any mixture can be produced, the plant and the paving equipment has to be certified.

Job-mix formula (JMF). The contractor designs the mix he plans to use on the project. The DOTD approves the mix. This design then governs the subsequent requirements for daily QC testing. A new JMF is required whenever there is a change in the source of material, equipment change, or whenever the mixture falls outside the specification limits. Operation may also be ceased if non-conformance continues over extended period.

Control charts. Control charts are required for each lot, i.e. 1000 tons of consecutive mix to the same JMF. Whenever the gradation, asphalt content, and percent crushed are outside the JMF tolerance, adjustments are required to bring the process into control. It is questionable if the charts are plotted in the first place and, if they are, how much use is made of the charts to maintain control. This is one phase of the QC requirement the DOTD needs to carefully scrutinize.

Surface profile. When this phase of QC testing indicates that the surface olerance is deficient, the contractor is to cease paving operation immediately and ıake corrections to the lay down and finishing operation before resuming paving peration. Only after the corrections are made does the DOTD conduct acceptance sting.

Inspection. In addition to the QC testing, the results of which generate some ion, there is also a subjective inspection that may require action by the DOTD. an or rich looking mixes, or segregated mixes may be rejected before leaving the nt. Likewise, mix exhibiting deficiencies before placement such as segregation, amination, lumps, non-uniform coating, or other such deficiencies, apparent visual inspection, can also be rejected.

ess issues

In describing the quality control procedures for a production process it is is devoted to the equipment used in producing, placing and compacting of asphaltic concrete mixtures [8]. It includes methods and equipment for handling and storing materials and transporting asphaltic concrete to the job site. Before any mixture can be produced, the plant and the paving equipment has to be certified.

Job-mix formula (JMF). The contractor designs the mix he plans to use on the project. The DOTD approves the mix. This design then governs the subsequent requirements for daily QC testing. A new JMF is required whenever there is a change in the source of material, equipment change, or whenever the mixture falls outside the specification limits. Operation may also be ceased if non-conformance continues over extended period.

Control charts. Control charts are required for each lot, i.e. 1000 tons of consecutive mix to the same JMF. Whenever the gradation, asphalt content, and percent crushed are outside the JMF tolerance, adjustments are required to bring the process into control. It is questionable if the charts are plotted in the first place and, if they are, how much use is made of the charts to maintain control. This is one phase of the QC requirement the DOTD needs to carefully scrutinize.

Surface profile. When this phase of QC testing indicates that the surface
olerance is deficient, the contractor is to cease paving operation immediately and
nake corrections to the lay down and finishing operation before resuming paving
peration. Only after the corrections are made does the DOTD conduct acceptance
sting.

Inspection. In addition to the QC testing, the results of which generate some
ion, there is also a subjective inspection that may require action by the DOTD.
an or rich looking mixes, or segregated mixes may be rejected before leaving the
nt. Likewise, mix exhibiting deficiencies before placement such as segregation,
amination, lumps, non-uniform coating, or other such deficiencies, apparent
n visual inspection, can also be rejected.

ess issues

In describing the quality control procedures for a production process it is

norma
actual
proper
For the
linked i
system,
respecti
be cost
C
concern
product.
the produ
these req
anti-strip
standards
The norm
screen(s)
addition of
appropriat
result. Lack
improper p
maintenanc
malfunction
can result in
quality probl
The s
The current
process. The
continued.
As with

Stability

Take four samples.

- If no sample falls below the specified minimum, accept the product at 100 percent pay.
- If one sample falls below, accept at 95 percent pay.
- If two samples fall below, accept at 80 percent pay.
- If three samples fall below the specified minimum, reject the product.

Figure 22 shows the OC curve and appendix C the derivation of this scheme.

Grading

A more complex requirement is needed for grading as a two sided limit specification is needed. A very tentative scheme is presented in the section "Recommended Action."

Density

Take five samples.

- If no more than one sample falls below the specified minimum, accept at 100 percent pay.
- If two samples fall below, accept at 95 percent pay.
- If three or more fall below, reject the product.

Figure 23a and 23b show the OC curve and appendix C the derivation.

Antistrip

Take two samples.

- If no result falls below the minimum limit, accept at 100 percent pay.
- If one sample fails, accept at 80 percent pay.
- If both samples fail, reject the product.

Profile

Take two samples.

- If no result falls below the minimum limit, accept at 100 percent pay.
- If one sample fails, accept at 80 percent pay.
- If both samples fail, reject the product.

Figure 24 shows the OC curve and appendix C the derivation for this scheme, which could apply to both antistrip and profile.

Clearly any number of attributes schemes can be developed but the efficiency is severely constrained by the need to use small sample sizes for most quality parameters.

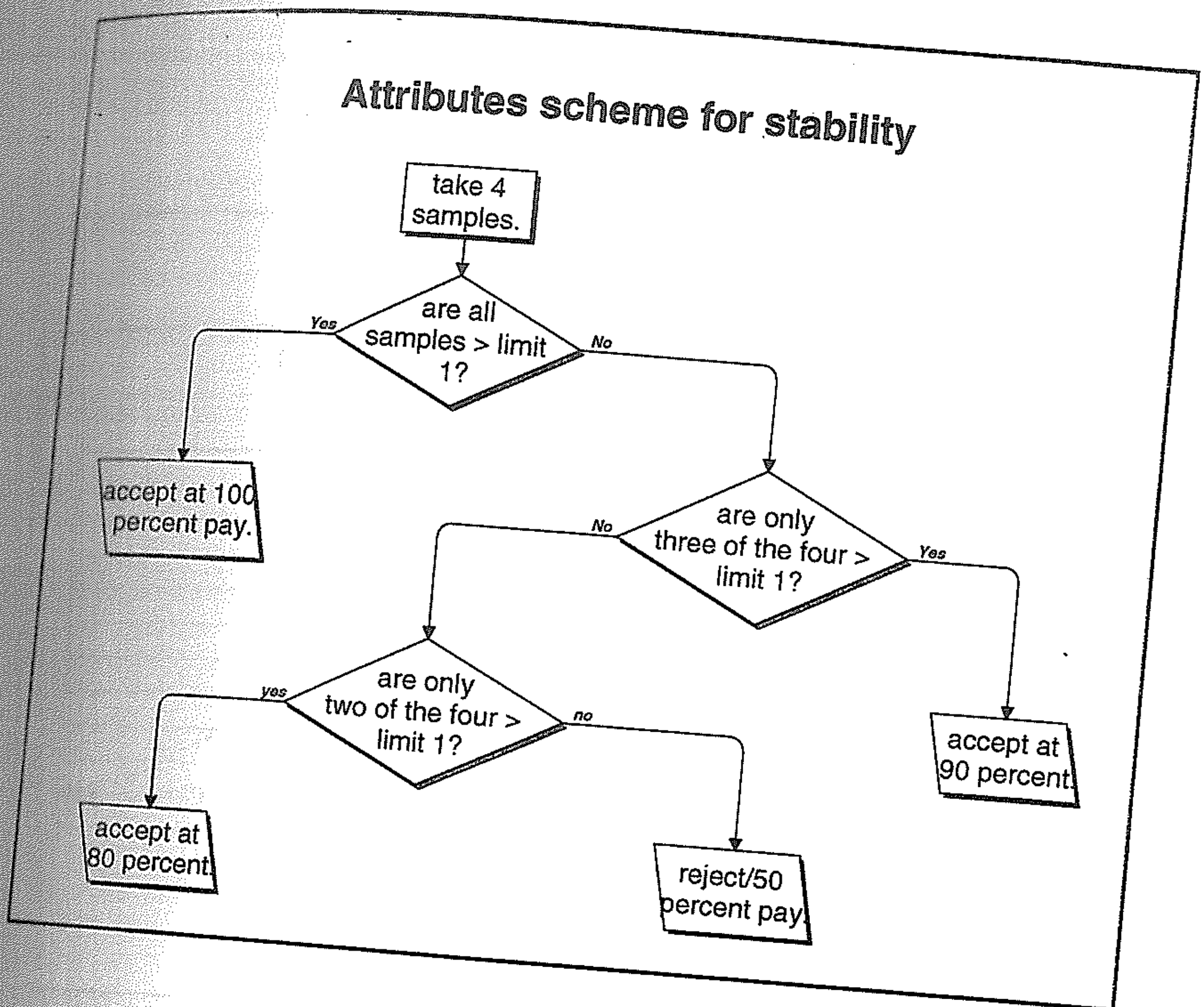


Figure 22a

Attributes scheme for stability, n = 4

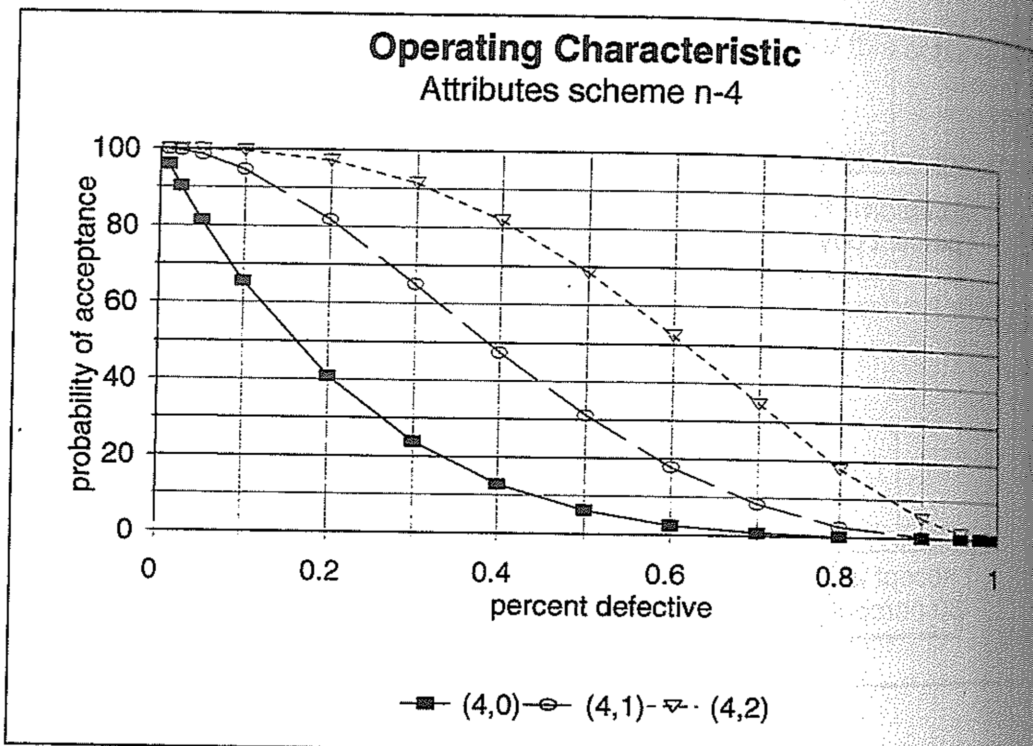


Figure 22b

Attributes OC curve for stability, n = 4

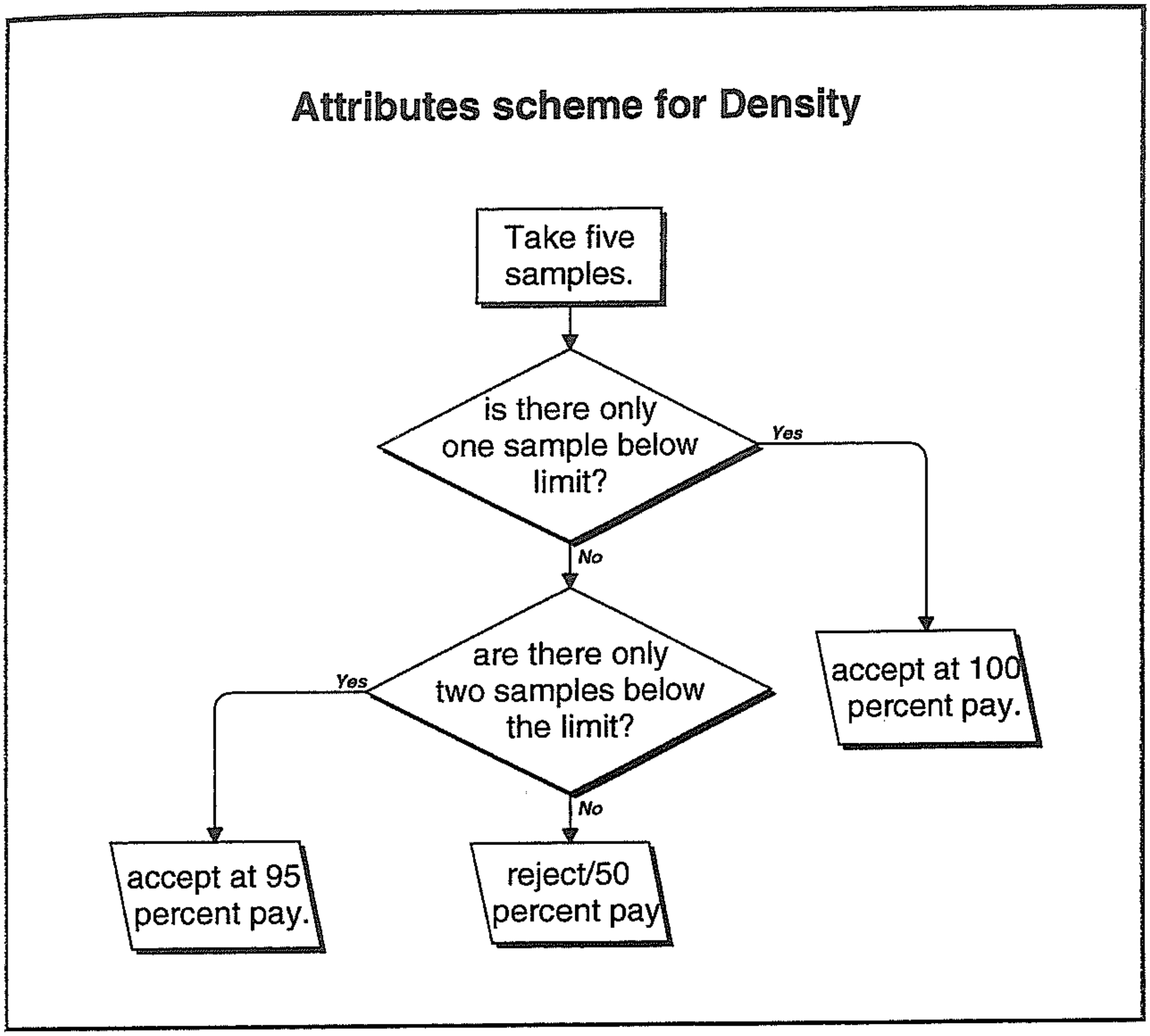


Figure 23a

Attributes OC scheme for density, n = 5

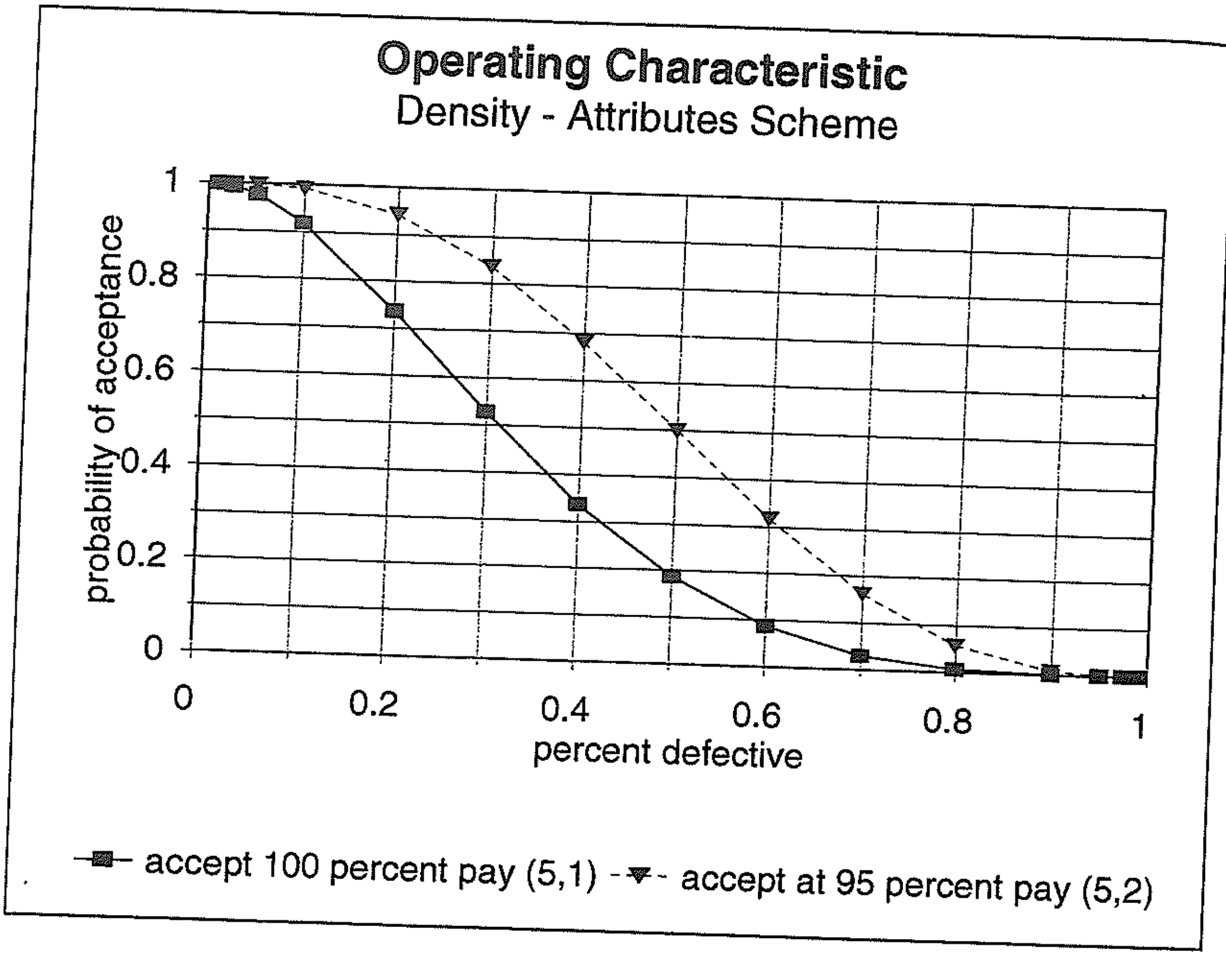


Figure 23b

Attributes OC curve for density, n = 5

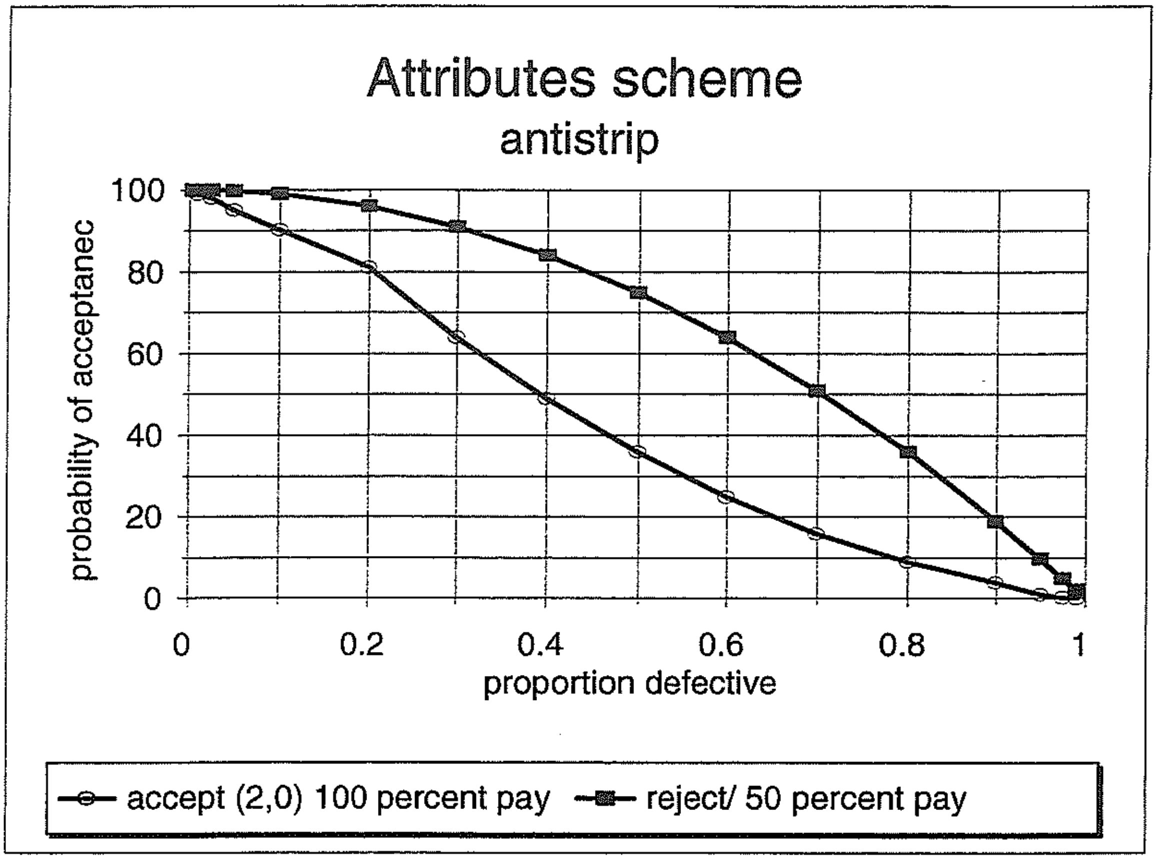


Figure 24b

Attributes OC curve for antistrip, n = 2

Unknown sigma schemes

The use of unknown sigma schemes has the great advantage that the consumer's risk can be reduced for the same sample size, and that the schemes are independent of the value of sigma. Thus, the producer has the option of producing a product with a high mean value and high variability or a low mean and low variability, yet the risks are assessed on the same basis. A product with a low mean and a high variability will be less likely to be accepted; thus this type of scheme exerts pressure for reduction in variability of the process. The disadvantages are that application of this type of scheme involves calculation of the mean and sample standard deviation of the product, and that the result is subject to interpretation of the calculation accuracy. Many pocket calculators are able to calculate standard deviation by the press of a function key, which should resolve any issue related to the difficulty of calculation. The issue of reporting accuracy (for example, how is a value of 0.6785 interpreted) can readily be determined by an appropriate reporting format.

A possible scheme, which could be applied to all asphalt quality criteria, except gradation, for DOTD could be:

- Take four samples.
- If the mean of the four less the specification minimum, divided by the sample standard deviation, is greater than k_a, accept the product at 100 percent pay.
- If the mean of the four less the specification minimum, divided by the sample standard deviation is less than "k_r," reject the product (or accept at 50 percent pay).

Any intermediate result should be accepted at 80 percent pay.

Table 12

Probability of acceptance for n = 4 with different k values

k value	1 percent defective	10 percent defective	50 percent defective	Reference page
-0.145	99.9	99.8	60.5	186
0.123	99.9	99.0	41.1	170
0.443	99.9	95.0	22.0	154
0.924	99.0	76.0	8.1	138
1.081	97.6	67.6	6.0	130
1.419	91.0	50.0	3.3	176

Clearly any number of schemes can be developed and the risks adjusted by judicious selection of the k values. Figure 25 gives a scheme for k =1.419 and 0.123, with a sample size of four. Table 12 gives a selection of k values and the related probabilities for a sample size n = 4.

Comparison of schemes

In the context of the foregoing discussion, the new unknown sigma compliance clause is tabled for consideration. The operating characteristics of the proposed clauses are compared with existing practice in table 13 and figure 26. It is important to note that to retain the small sample sizes appropriate to short run processes, it is necessary to accept higher risks for both producer and consumer. As the general levels of quality achieved have been shown to be very high, this change is unlikely to affect quality or performance, in the short term. The potential effects must be carefully evaluated as described below to ensure that any relaxation of control does not reduce quality.

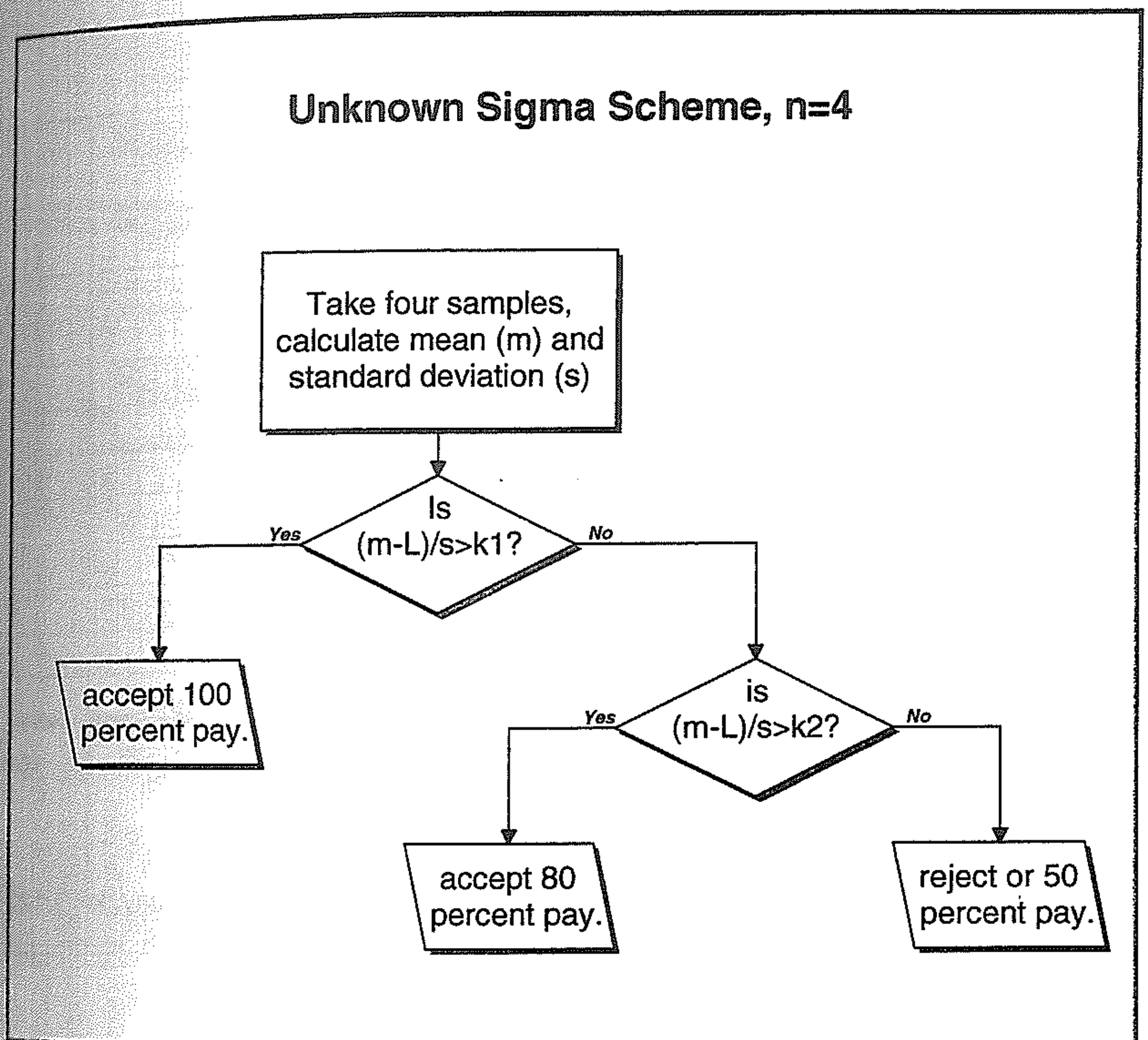


Figure 25a

Unknown sigma scheme, n = 4

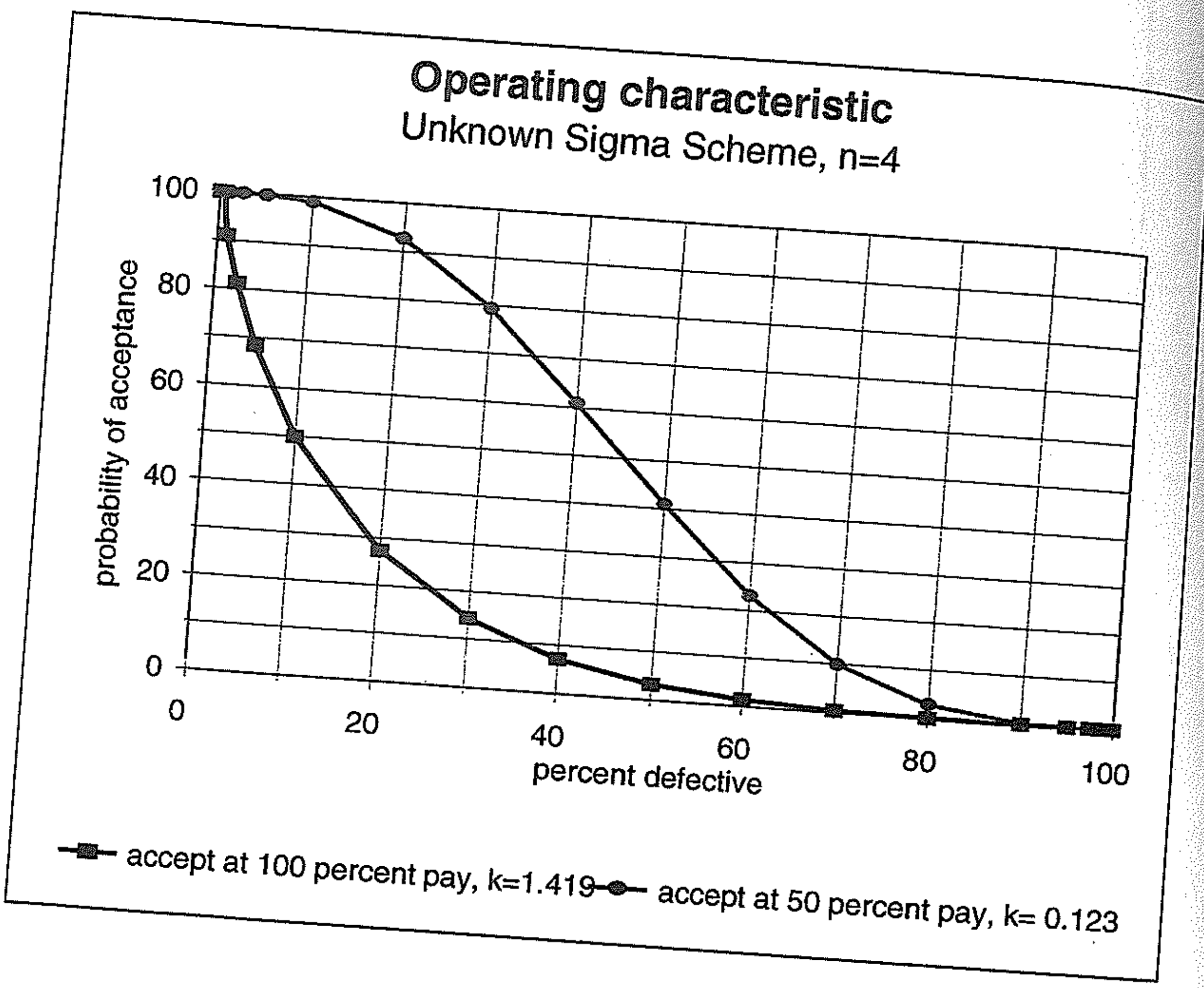


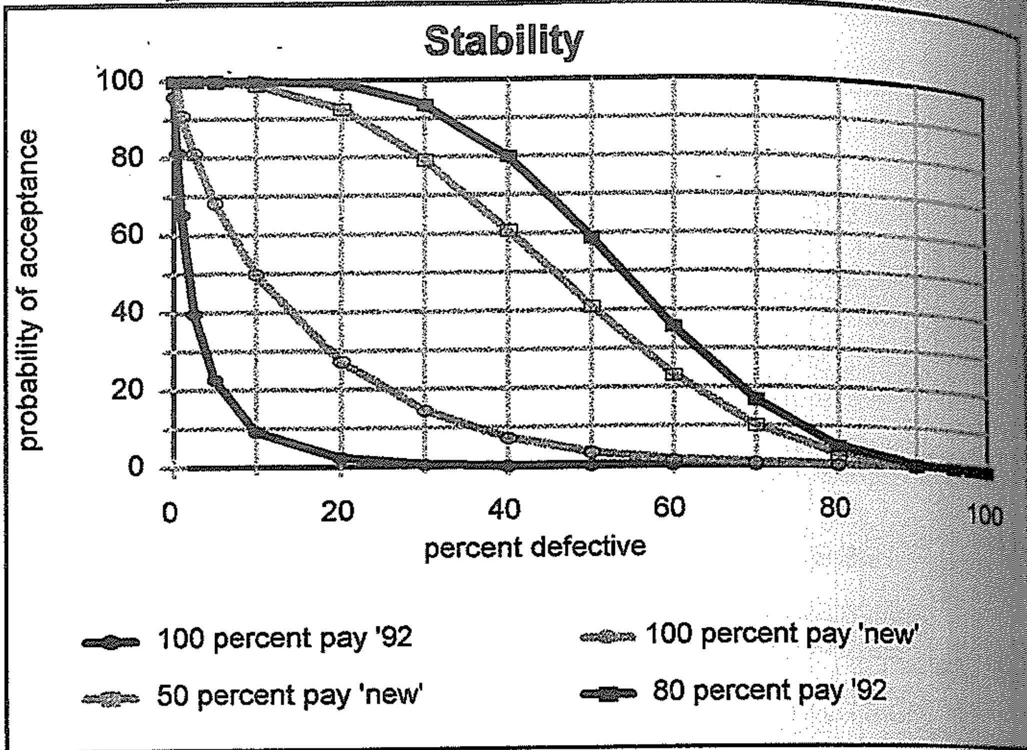
Figure 25b

Unknown sigma scheme operating characteristic curve,

n = 4, k1 = 1.419, k2 = 0.123

Table 13 Comparison of Operating Characteristics

percent defective	LADOTD 1992 Specification							Attributes scheme							Unknown sigma scheme	
	Stability Criteria for Mix type 9 (Standard deviation assumed as 200				Density Criteria for mix type (stand. dev'n assumed as			sample of five		sample of two		sample of four			n=4 k=1.419 k=1.23	
	Probability of Acceptance to Pay Factor				Probability of Acceptance to pay factor			Probabil of acceptance to pay factor		to pay factor		to pay factor			Probability of Acceptance to pay factor	
p	100	98	95	80	100	95	80	100	95	100	80	100	90	80	100	50
0.1	95.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.8	100.0	99.6	100.0	100.0	100.0	100
0.5	81.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	9.0	100.0	98.0	100.0	100.0	100.0	100
1.0	85.3	99.8	100.0	100.0	100.0	100.0	100.0	99.9	100.0	8.0	100.0	98.1	99.9	100.0	91.0	100
2.5	39.9	97.3	100.0	100.0	100.0	100.0	100.0	99.4	100.0	95.1	99.9	90.4	90.8	100.0	81.2	100
5.0	22.8	95.0	100.0	100.0	100.0	100.0	100.0	97.7	99.9	90.0	99.8	81.5	98.6	100.0	88.4	99.9
10.0	9.2	71.2	98.4	100.0	99.8	100.0	100.0	91.9	99.1	81.0	99.0	85.6	94.8	99.6	5.0	9.9
20.0	2.3	37.4	84.9	99.3	97.0	100.0	100.0	73.7	94.2	84.0	98.0	41.0	81.9	97.3	27.3	92.7
30.0	0.4	16.8	58.4	93.8	87.7	100.0	100.0	52.8	83.7	49.0	91.0	24.0	85.2	91.8	14.5	79.4
40.0	0.1	6.7	35.5	80.1	71.2	99.9	100.0	33.7	68.3	38.0	84.0	13.0	47.5	82.1	7.3	8.1
50.0	0.0	2.3	17.8	58.9	50.0	99.4	100.0	18.8	50.0	25.0	75.0	8.3	31.3	68.8	3.3	41.1
60.0	0.0	0.6	7.2	35.8	28.8	99.7	100.0	8.7	31.7	16.0	84.0	2.6	17.9	52.5	1.3	23.3
70.0	0.0	0.1	2.4	18.9	12.3	87.5	100.0	3.1	10.3	9.0	51.0	0.8	8.4	34.8	0.4	10.2
80.0	0.0	0.0	0.3	4.8	3.0	65.2	100.0	0.7	5.8	4.0	36.0	0.2	2.7	18.1	0.1	2.9
90.0	0.0	0.0	0.0	0.5	0.2	28.8	100.0	0.0	0.9	1.0	19.0	0.0	0.4	5.2	0.0	0.3
95.0	0.0	0.0	0.0	0.0	0.0	7.8	99.9	0.0	0.1	0.3	9.8	0.0	0.0	1.4	0.0	0
97.5	0.0	0.0	0.0	0.0	0.0	1.8	99.0	0.0	0.0	0.1	4.9	0.0	0.0	0.4	0.0	0
99.0	0.0	0.0	0.0	0.0	0.0	0.1	93.2	0.0	0.0	0.0	2.0	0.0	0.0	0.1	0.0	0
99.5	0.0	0.0	0.0	0.0	0.0	0.0	83.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	42.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0



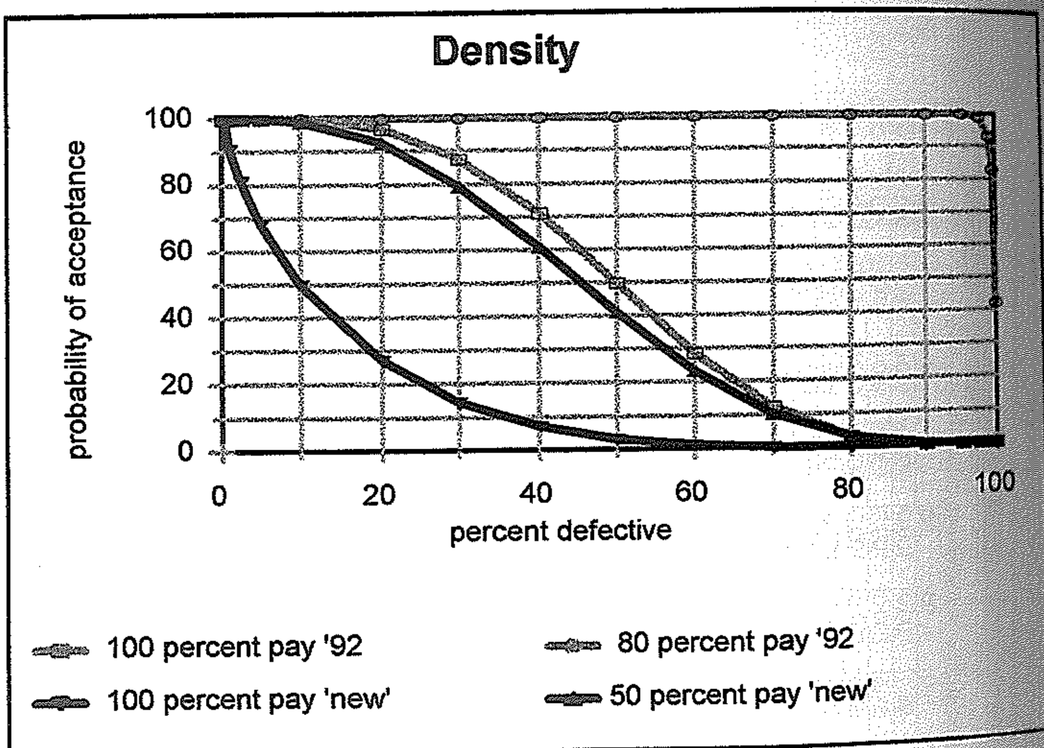


Figure 26
Comparison of 1992 and proposed OC curves

It is proposed that the simpler set of variability unknown criteria above be adopted and used for all the quality parameters selected (initially stability and density). This will allow the users to build familiarity with the scheme quickly and reduce any risk of confusion between the schemes for different quality parameters. If it is necessary to vary the application of the schemes for different parameters, to reflect the perceived importance of the particular parameter, this can be achieved by applying different penalty levels. The scheme is shown with the current specification requirements in figure 26.

Clearly it is difficult to match closely the existing OC compliance requirements for stability with such simple schemes. However, as the quality of current product measured by stability is extremely high, it may be that the simpler variability unknown scheme could be adopted with little loss of quality.

It is also possible to consider abandoning the specification acceptance limit for stability (except as a producer quality control requirement) because very high stabilities are routinely achieved. The change to Superpave design procedures will place emphasis on gyratory compaction results.

The question of gradation remains to be solved. It is proposed that consideration be given to a radical change, placing acceptance compliance requirements only on the percent passing the number 200 sieve and using only an upper limit. With, however, four samples judged by the same unknown variability scheme, This will need particularly careful evaluation for a trial period, as proposed for all the parameters. A direction for change is indicated but an extension of this study is suggested to fully explore this issue.

The requirement for antistrip content also requires further study to be sure that the current data set and analysis is complete and relevant. The density compliance clause could be changed to the same format as for stability. The profile clause should not be changed as insufficient data were available to evaluate the effect of any change.

Indeed, it is suggested that a simpler approach be adopted overall. The contractor could be required to keep plant process control charts for all output on a continuous basis. These charts to be available for inspection by DOTD on demand, as one of the requirements for plant approval under clause number 503 of the 1992 specification. DOTD could introduce specification acceptance compliance clauses based on volumetric controls and perhaps a less complex gradation requirement, together with the compacted density and profile.

A necessary step before implementation of the proposed new specification acceptance clauses is an evaluation of the impact of the changes on current practice. It is suggested this be done in two stages. First, a review of previous years' records to see what effect if any the new specification would have had. Second, a trial period of a year during which the new clauses would be applied to shadow the existing specification to see if the decision reached under the new clauses, when advised to the contractor, would result in any changes.

The review of previous records has been carried out and the results are given in table 14.

CONCLUSIONS

Current quality

The quality of asphaltic concrete currently accepted by DOTD is in more than adequate compliance with the relevant specifications. The material not meeting specification standards limits is in very small proportion with regard to Marshall stability. Higher defective levels exist for density and even higher for antistrip content and profile index. The latter results are tentative at this stage. There has been a significant reduction in variability over the past eight years. Density variability has reduced slightly.

MATT database

This is an invaluable source and offers great potential for further studies of the quality of departmental road works. A more detailed study of the output of individual plants could also be of value in estimating the potential impact of any specification changes. However, MATT is maintained in an outdated format which complicates analysis and deters attempts to apply the data more broadly to studies of quality issues.

Current specifications

The current specifications are difficult to interpret in statistical terms. The clauses are complex and in some instances cannot yet be analyzed statistically. This may mean that the anticipated performance of the clauses differs from the strict statistical interpretation. The effects of this on quality cannot be quantified.

Revised specification clauses

It is a reasonable supposition that current quality levels have developed by default, rather than by a clear perception of the statistical control and acceptance compliance criteria.

It is considered, therefore, that simple schemes having closely similar operating characteristics to existing schemes should be adopted. Specification clauses must not allow for any ambiguity in interpretation. It is also considered that the penalty clause application could be reduced to an accept at 100 percent pay, accept at 80 percent pay and reject/accept at 50 percent pay sequence, to give simpler application.

Trial of new clauses

Algorithms have been written to process all existing data sets against the revised clauses and to output the penalties decided by the unknown sigma schemes. These are then compared with the current data in table 13. Any changes in penalty rates to better match the outcomes could be applied for a second stage of the validation trial. This second stage will consist of running the revised schemes in parallel with the current specification for a period. Producers would be asked to advise what action they would propose in response to the acceptance compliance decisions indicated by the revised schemes.

The potential impact of the schemes, and their acceptability to producer and consumer, will thus be able to be judged before formal implementation. Of course, the schemes may be modified as a result of the experience and a final form selected for formal implementation.

Implementation of the new specification

After the trial period, a training program will be developed to introduce the new scheme, and to demonstrate the new procedures required in practice. Before this, and preferably before the second stage trial outlined above, an introduction to the new schemes should be prepared as a seminar. The seminar should be presented to quality control personnel, from the DOTD and from industry, to assess the response of practitioners and to clarify any issues requiring elucidation.

Table 14

Specification comparison – Marshall stability data

Mean	Standard deviation	Minimum stability	Percentage defective	Percentage payment 1992 Specs.	Projected new
1,748	106	1,657	1	95	100
1,829	149	1,634	1	100	100
1,757	127	1,578	2	95	100
1,757	127	1,578	2	95	100
1,800	200	1,501	7	100	100
1,800	201	1,499	7	98	100
1,609	91	1,487	12	80	80
1,657	160	1,500	16	95	80
1,587	96	1,455	18	80	80
1,645	163	1,499	19	80	80
1,606	175	1,345	27	80	80
1,537	198	1,243	43	80	80
1,499	31	1,456	52	50	50
1,499	107	1,367	61	50	50

A variability unknown scheme has been developed and compared with the existing procedures. The scheme uses existing test procedures but applies the same sampling and compliance judgement methods for each parameter (except gradation) to simplify implementation and understanding of the revised scheme. The proposed scheme is simpler to operate than a percent within limits approach and represents a useful transition stage.

A percent-within-limits scheme can be derived using the NQI OCPLOT software for the gradation acceptance requirements. However, important engineering judgements of the significance of the various parameters and consideration of the current variability in those parameters is necessary to establish appropriate acceptable quality and rejectable quality limits.

Objective C

Present findings of research in a one-day workshop for DOTD and contractor personnel to be held in conjunction with the FHWA Demo 89 two-day workshop, Materials Control and Acceptance - Quality Management.

The FHWA workshop was not available in the contract period and the presentation of findings of the research was therefore deferred.

Recommended action

1. Consideration be given to replacing the specification compliance clauses of the 1992 DOTD specification for Marshall stability and density with the following:

   Take four samples, calculate the mean (m) and standard deviation (s).
   If (m - 1.419s) > the specified minimum, accept the product at 100 percent pay;
   If (m - 1.419s) < the specified minimum < (m -0.123s), accept the product at 80 percent pay;
   If (m - 0.123s) < the specified minimum, reject the product or, at the engineer's discretion, accept at 50 percent pay.

A variability unknown scheme has been developed and compared with the existing procedures. The scheme uses existing test procedures but applies the same sampling and compliance judgement methods for each parameter (except gradation) to simplify implementation and understanding of the revised scheme. The proposed scheme is simpler to operate than a percent within limits approach and represents a useful transition stage.

A percent-within-limits scheme can be derived using the NQI OCPLOT software for the gradation acceptance requirements. However, important engineering judgements of the significance of the various parameters and consideration of the current variability in those parameters is necessary to establish appropriate acceptable quality and rejectable quality limits.

Objective C

Present findings of research in a one-day workshop for DOTD and contractor personnel to be held in conjunction with the FHWA Demo 89 two-day workshop, Materials Control and Acceptance - Quality Management.

The FHWA workshop was not available in the contract period and the presentation of findings of the research was therefore deferred.

Recommended action

1. Consideration be given to replacing the specification compliance clauses of the 1992 DOTD specification for Marshall stability and density with the following:

   Take four samples, calculate the mean (m) and standard deviation (s).
   If (m - 1.419s) > the specified minimum, accept the product at 100 percent pay;
   If (m - 1.419s) < the specified minimum < (m -0.123s), accept the product at 80 percent pay;
   If (m - 0.123s) < the specified minimum, reject the product or, at the engineer's discretion, accept at 50 percent pay.

2. The gradation acceptance requirement be replaced by the following applied to the number 4, 40, and 200 sieve sizes:

   Take three samples, calculate the mean (m) and standard deviation (s),

   If [(jmf +/- M100-m)/s] > 1.499, accept at 100 percent pay;

   If [(jmf +/- M50-m)/s]<- 0.072, accept at 50 percent pay or reject the product.

sieve size	M100	M50
4	1	8
40	1	6
200	0.5	3

3. The effect of relying only on a requirement for the pass number 200 sieve fines fraction should be evaluated.

4. The antistrip and profile requirements remain unchanged for the present.

5. A parallel trial should be implemented for 12 months to compare the operation of the proposed scheme with current practice before formal implementation.

6. Consideration should be given to revising the format of the MATT database to adopt a more user friendly relational data base format. Consideration should also be given to reducing data capture to that most likely to be of immediate value in tracking and evaluating the quality of asphalt and other products.

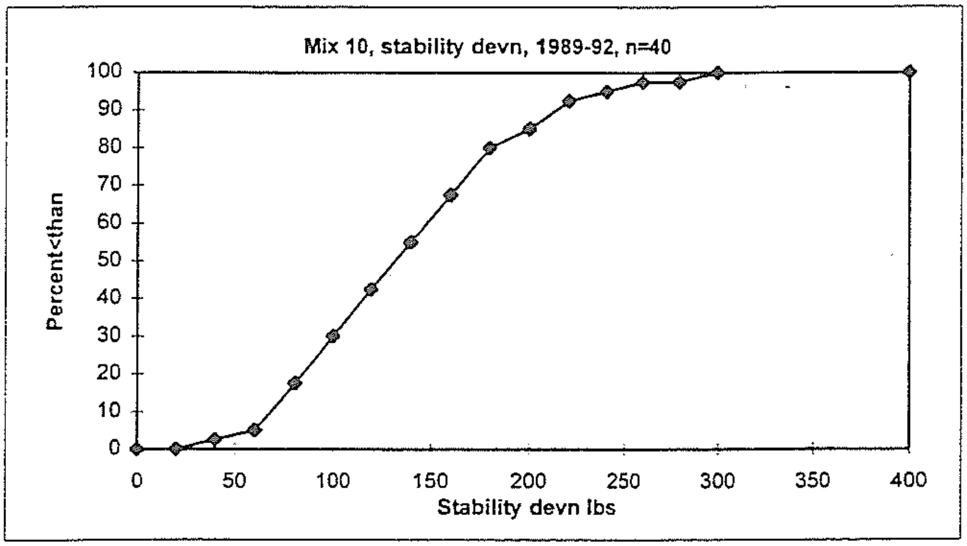
10. Metcalf, J.B., *Some Aspects of Statistical Quality Control for Bituminous Concrete.* Proc. 3rd International Asphalt Conference, Australian Asphalt Paving Association, 1976, 3/7 p.15.

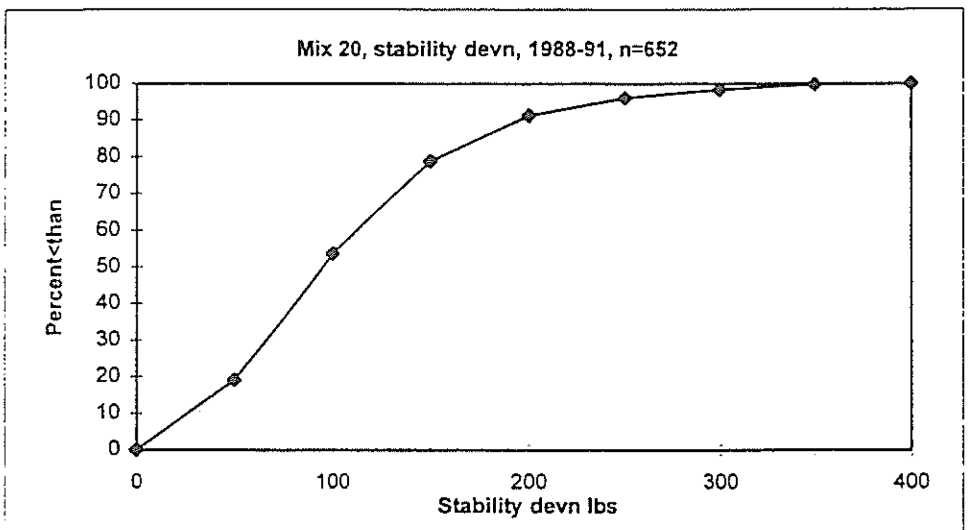
11. Metcalf, J.B., and Ray, T.G., *Evaluation and Modification of a Statistical Specification for Hot Mix.* Quality Management for Hot Mix Asphalt, ASTM STP 1299,1996, pp.19-27.

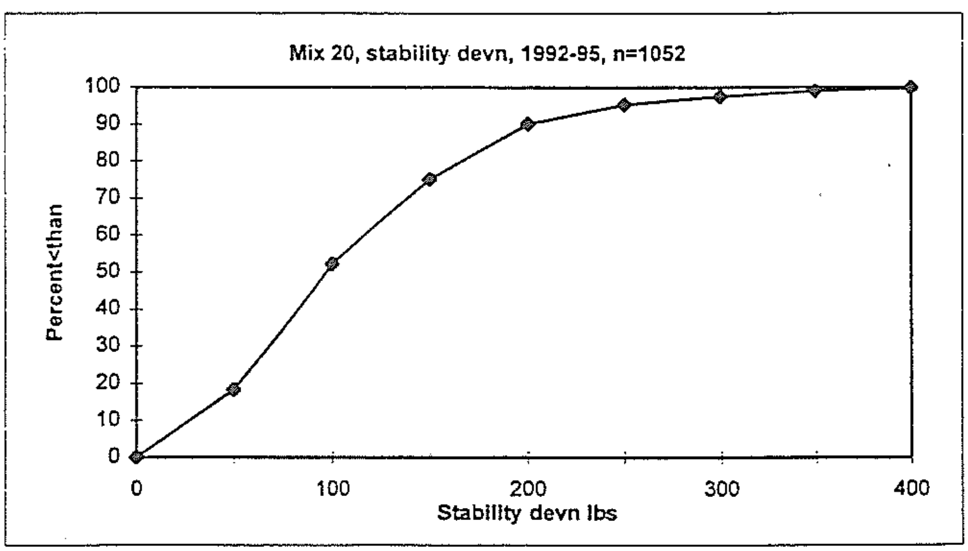
12. Metcalf, J.B., and Ray, T.G., *An Analysis of Asphalt Concrete Quality Measures Against Statistical Specification Requirements.* Proc. Roads 96 Conference (3) pp.247-258. ARRB Transport Research, Melbourne,1996.

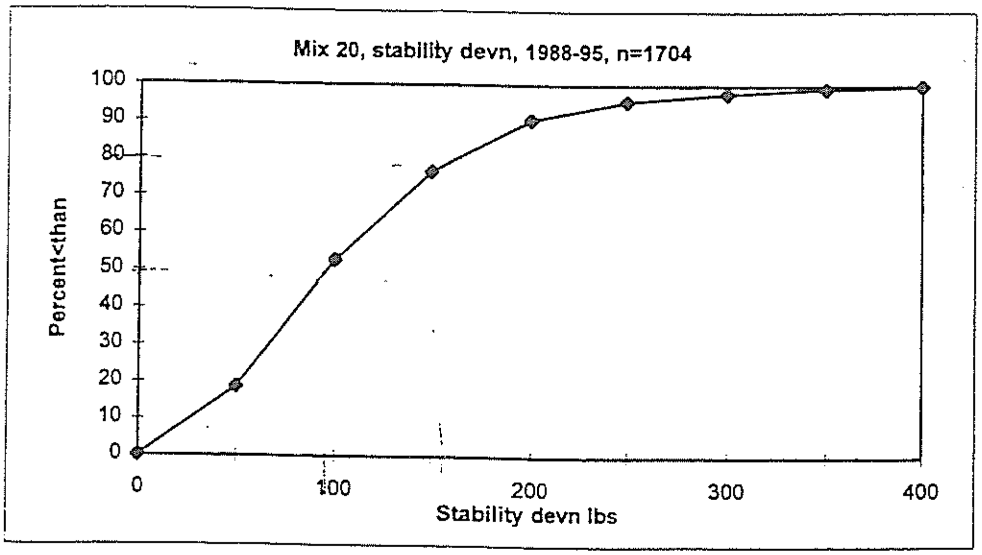
Appendix A

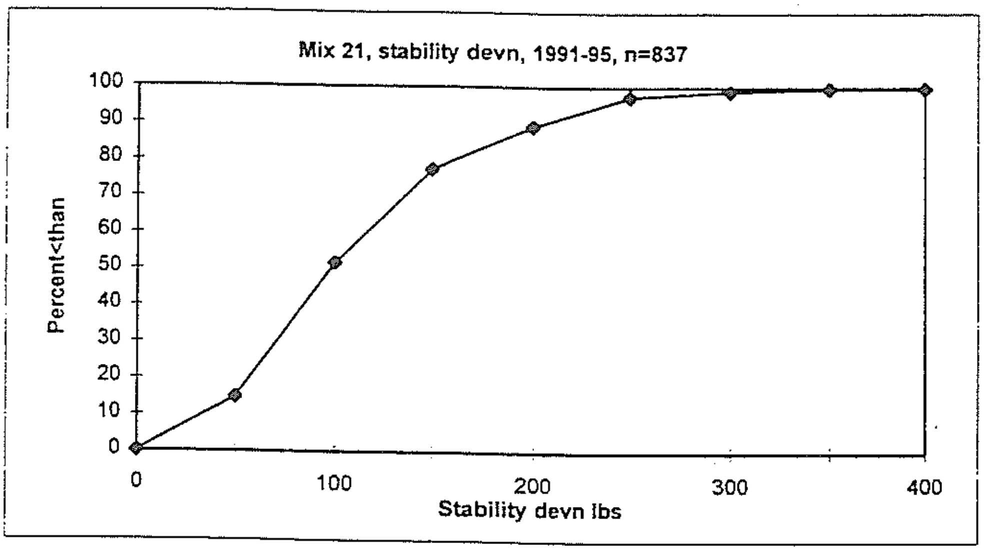
Quality Parameter Distributions

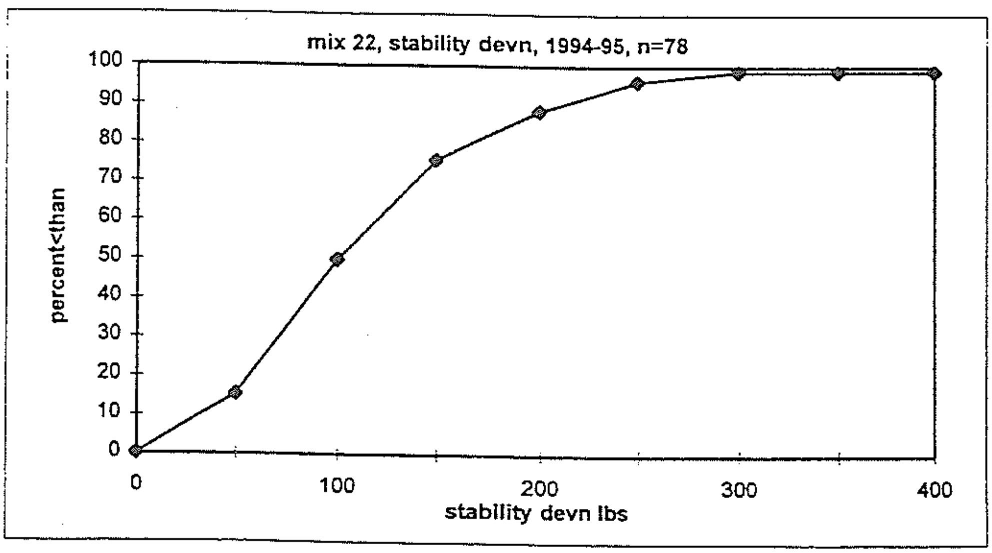

Mix 10, stability devn, 1989-92, n=40
Percent<than
Stability devn lbs
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400

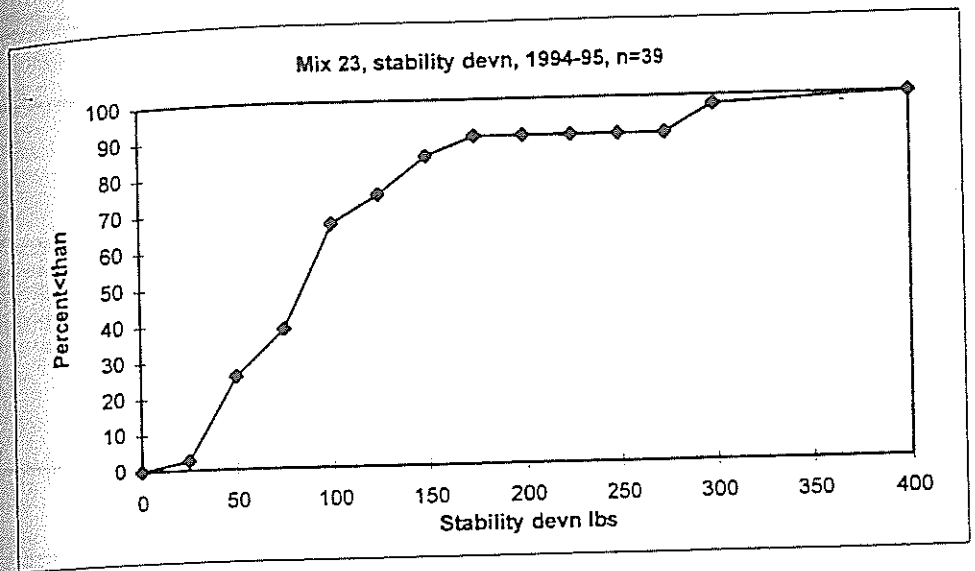

Mix 20, stability devn, 1988-91, n=652
Percent<than
Stability devn lbs
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400

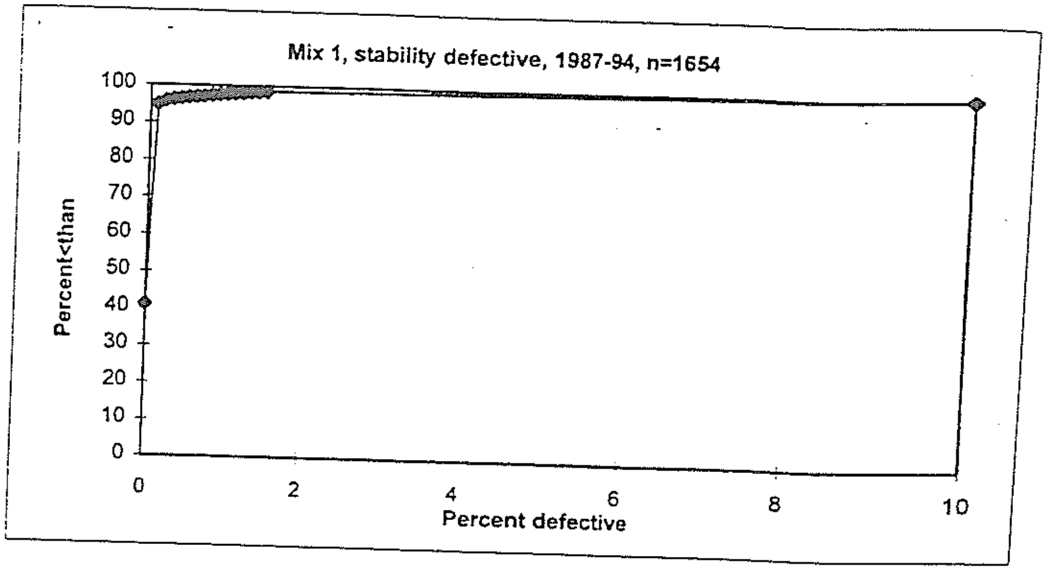

Mix 20, stability devn, 1992-95, n=1052
Percent<than
Stability devn lbs
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400


Mix 20, stability devn, 1988-95, n=1704
Percent<than
Stability devn lbs
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400

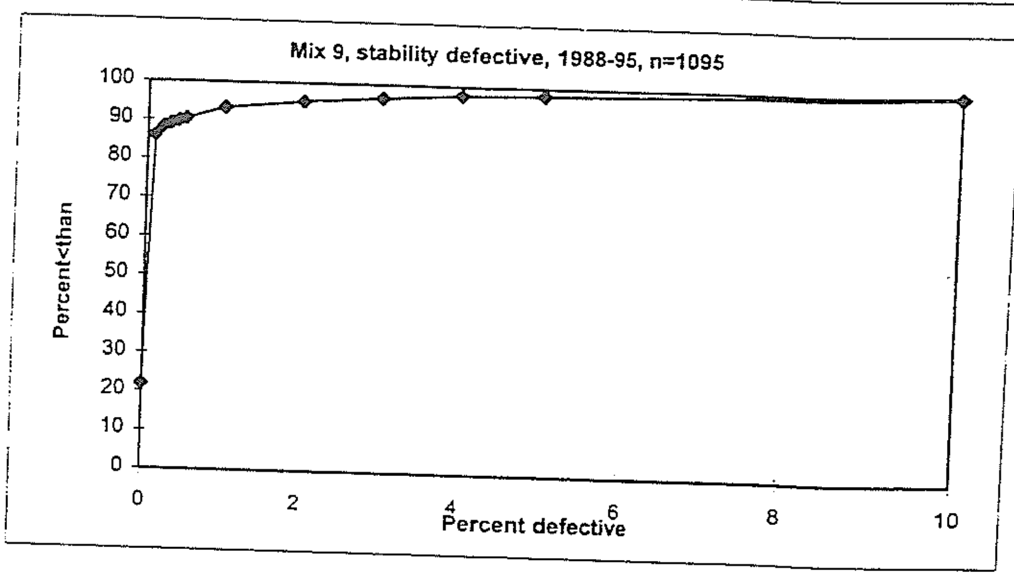

Mix 21, stability devn, 1991-95, n=837
Percent<than
Stability devn lbs
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400


mix 22, stability devn, 1994-95, n=78
percent<than
stability devn lbs
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400

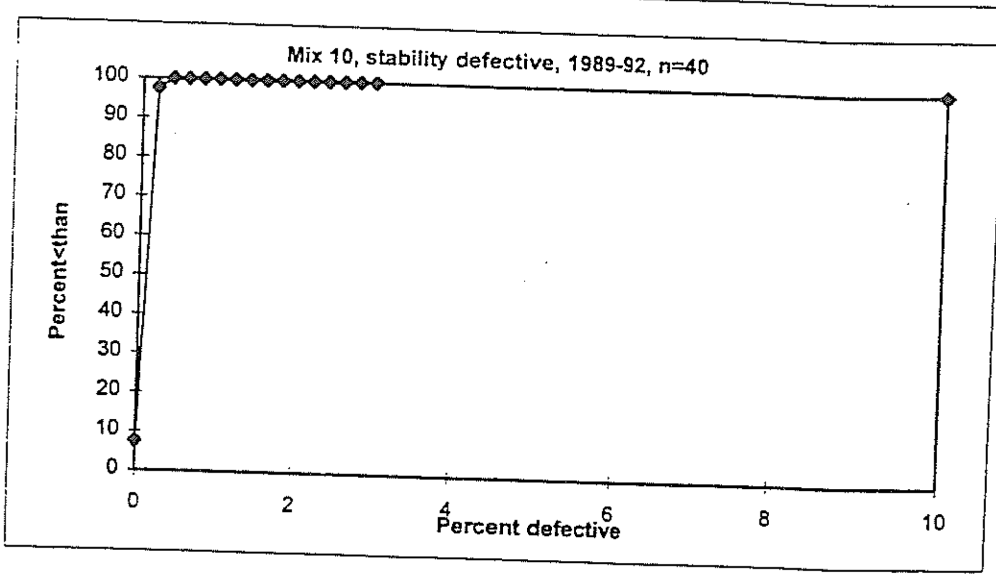

Mix 23, stability devn, 1994-95, n=39
Percent<than
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Stability devn lbs



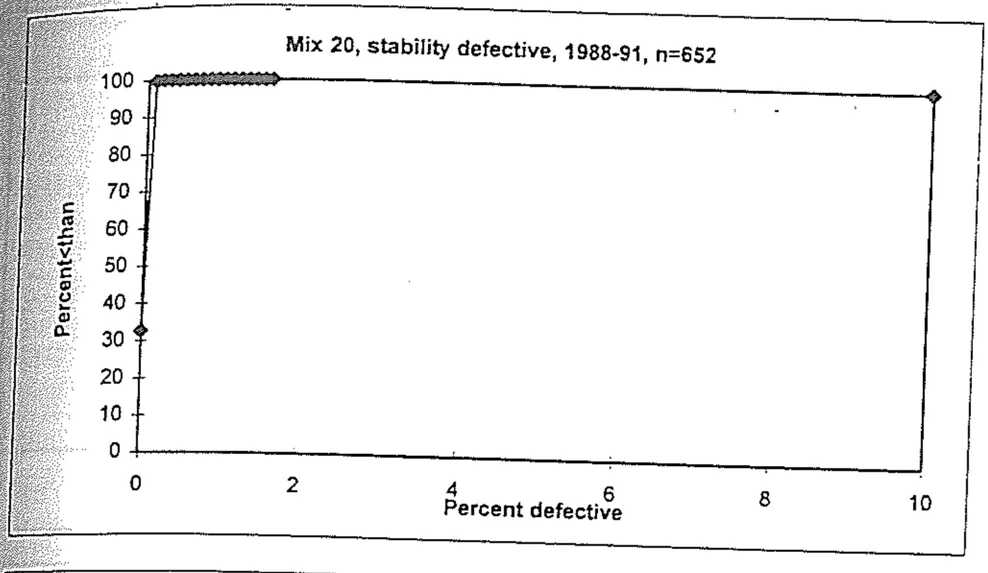
Mix 1, stability defective, 1987-94, n=1654
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

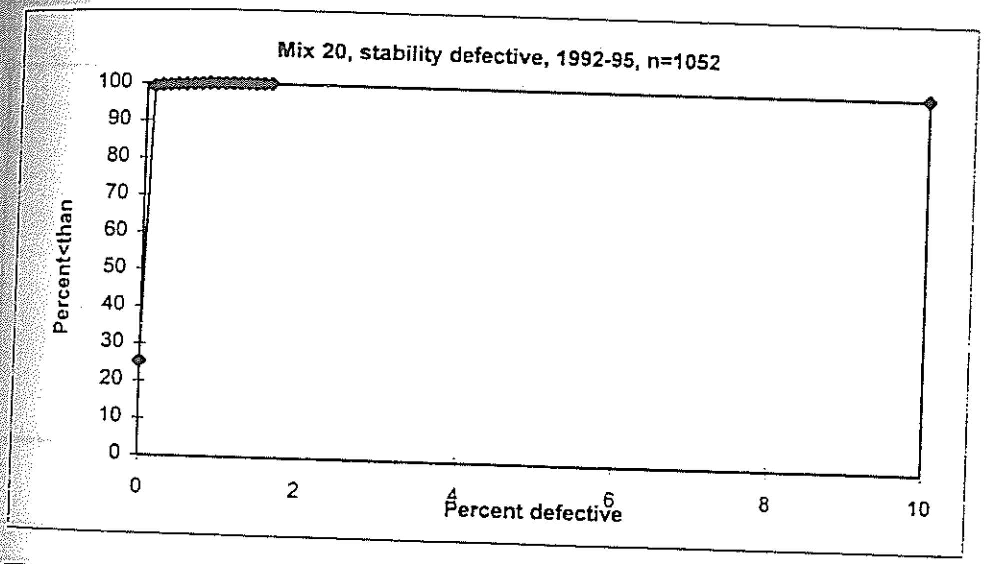


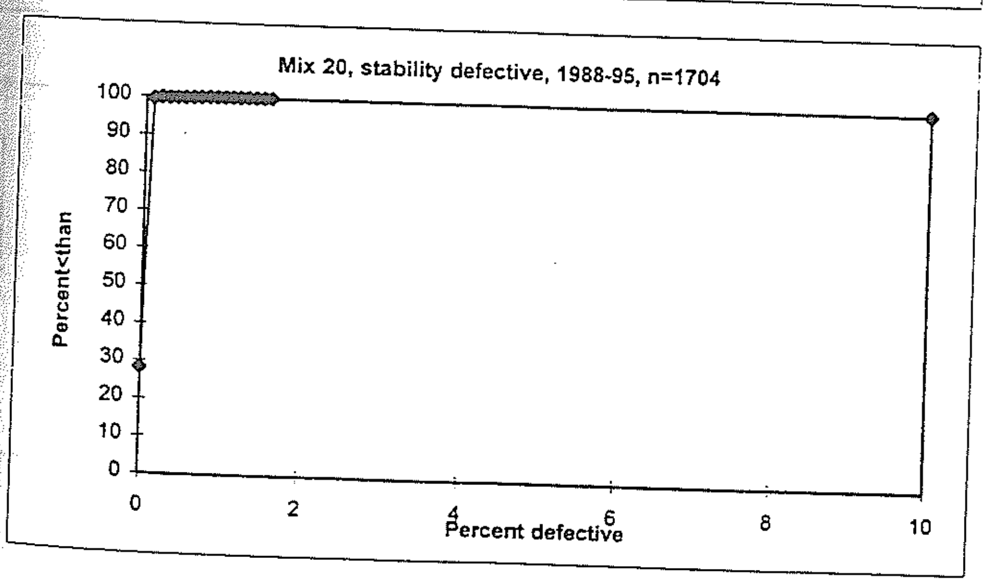
Mix 9, stability defective, 1988-95, n=1095
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

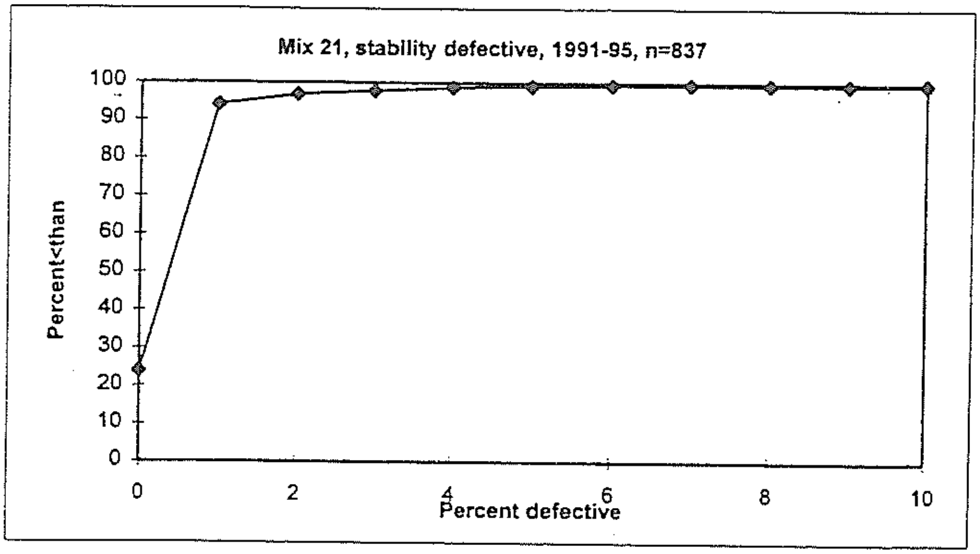


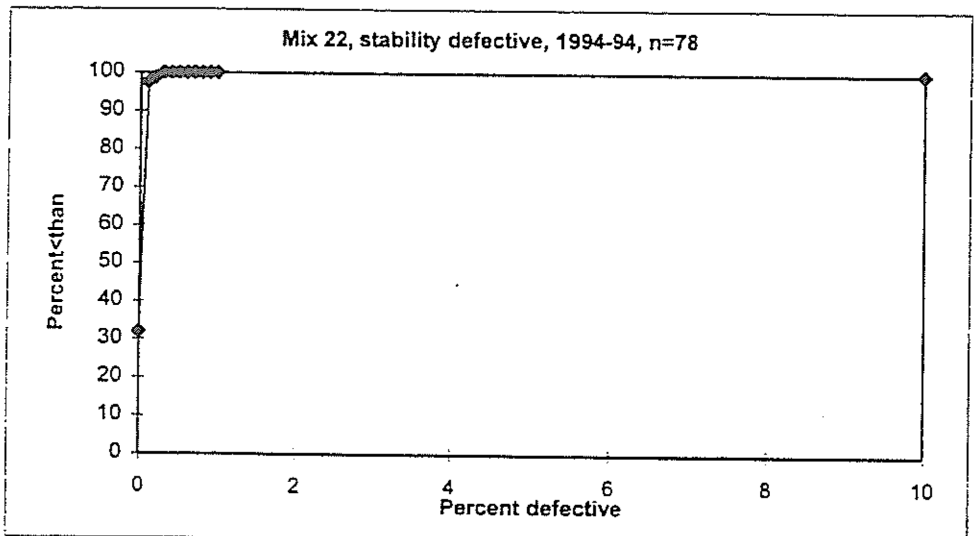
Mix 10, stability defective, 1989-92, n=40
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

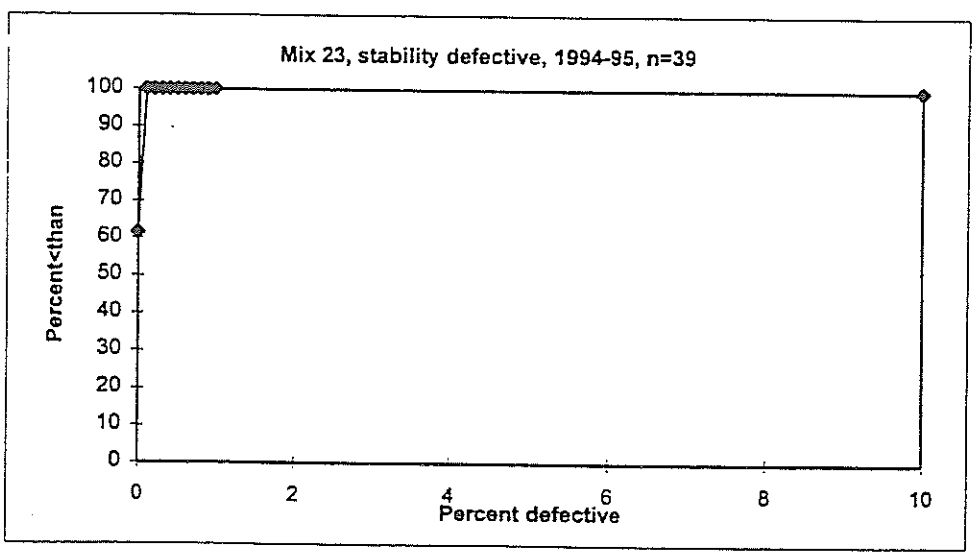

Mix 20, stability defective, 1988-91, n=652
Percent<than
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Percent defective

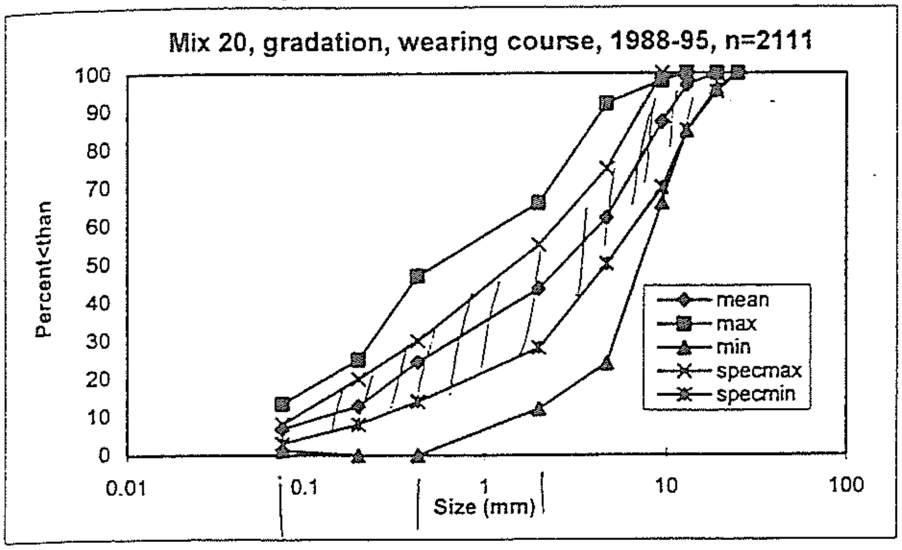

Mix 20, stability defective, 1992-95, n=1052
Percent<than
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Percent defective

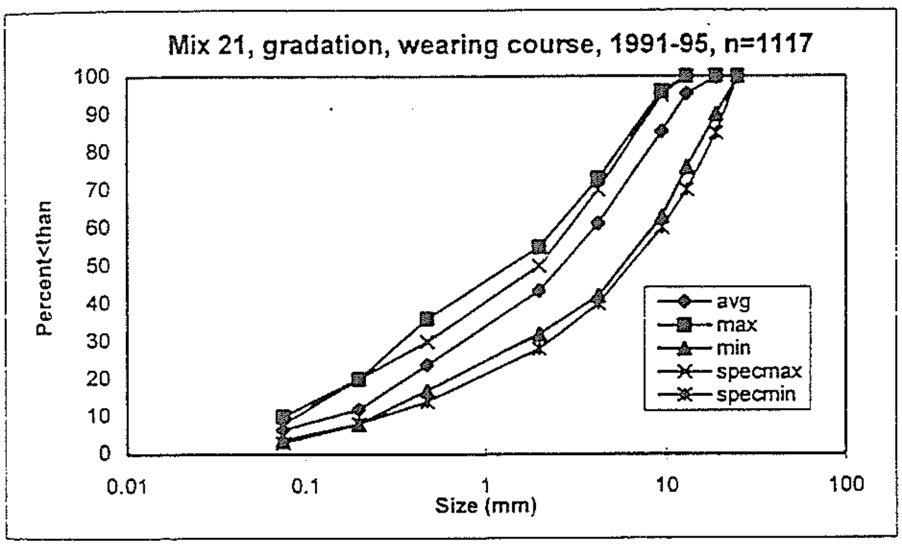

Mix 20, stability defective, 1988-95, n=1704
Percent<than
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Percent defective

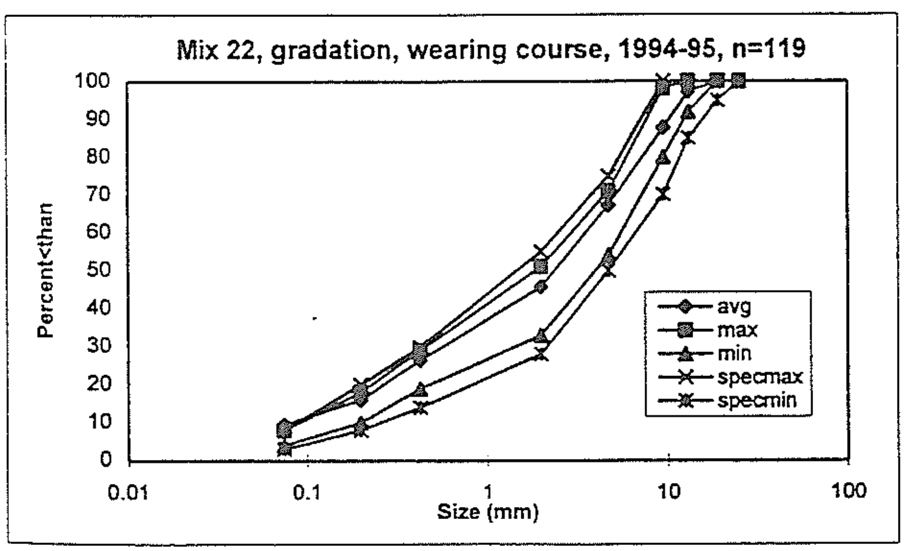

Mix 21, stability defective, 1991-95, n=837
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

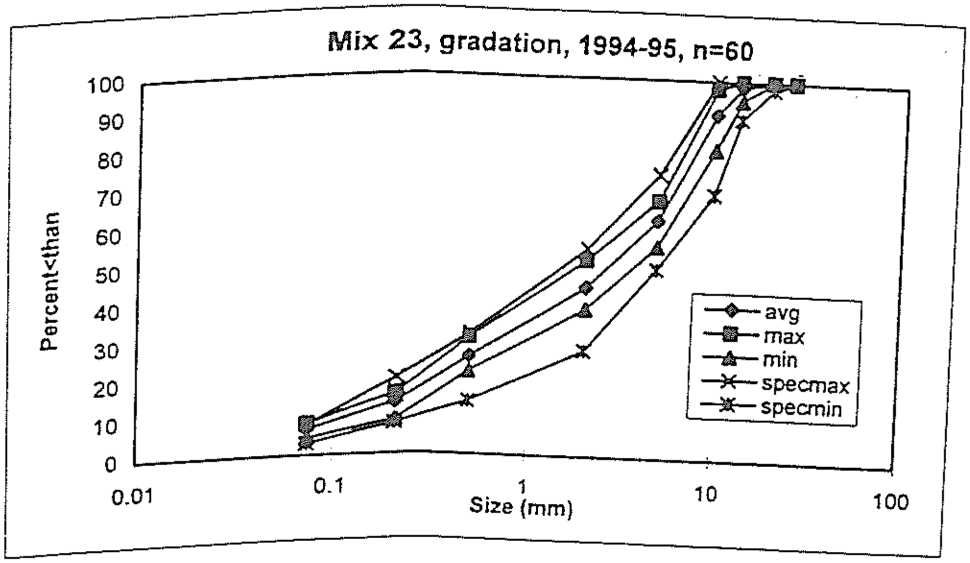

Mix 22, stability defective, 1994-94, n=78
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

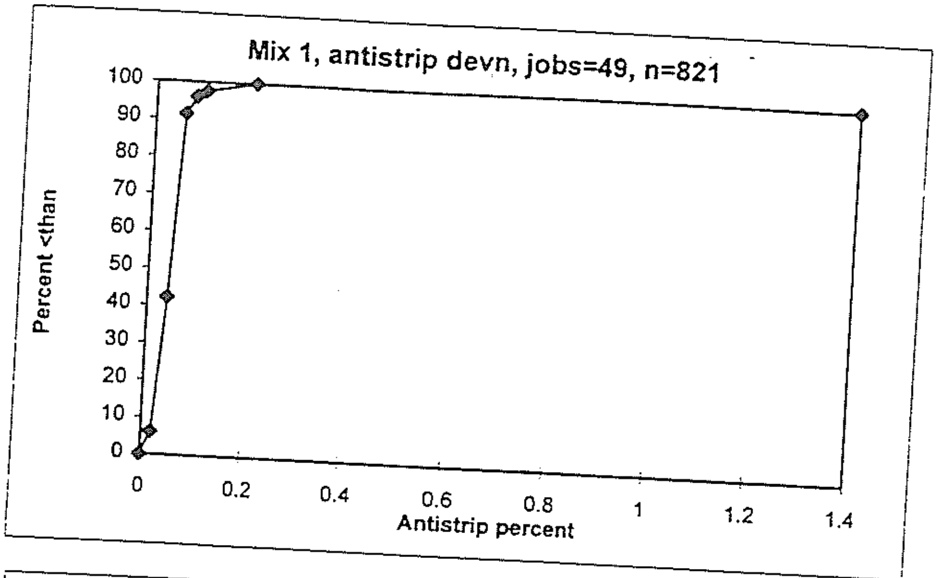

Mix 23, stability defective, 1994-95, n=39
Percent<than
Percent defective
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10

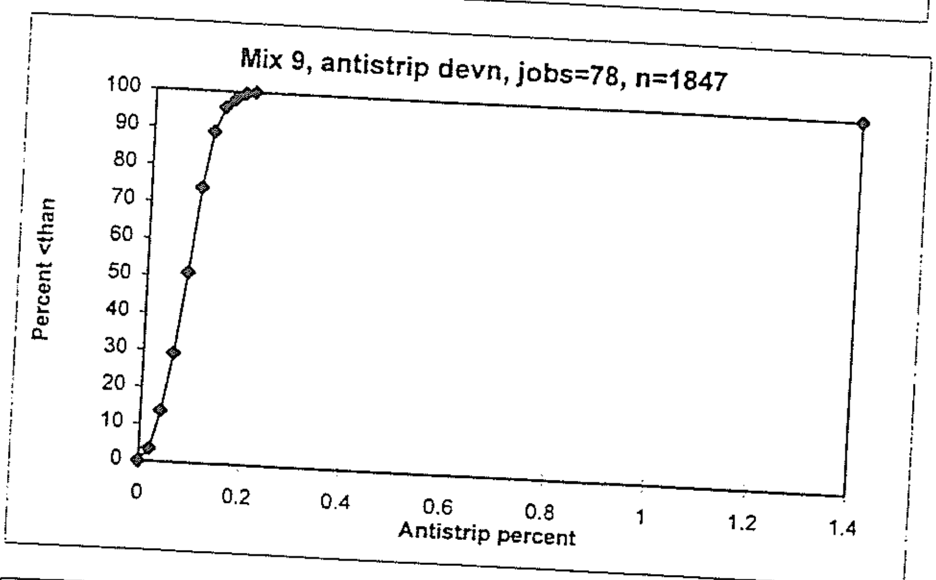

Mix 20, gradation, wearing course, 1988-95, n=2111
Percent<than
Size (mm)
mean
max
min
specmax
specmin

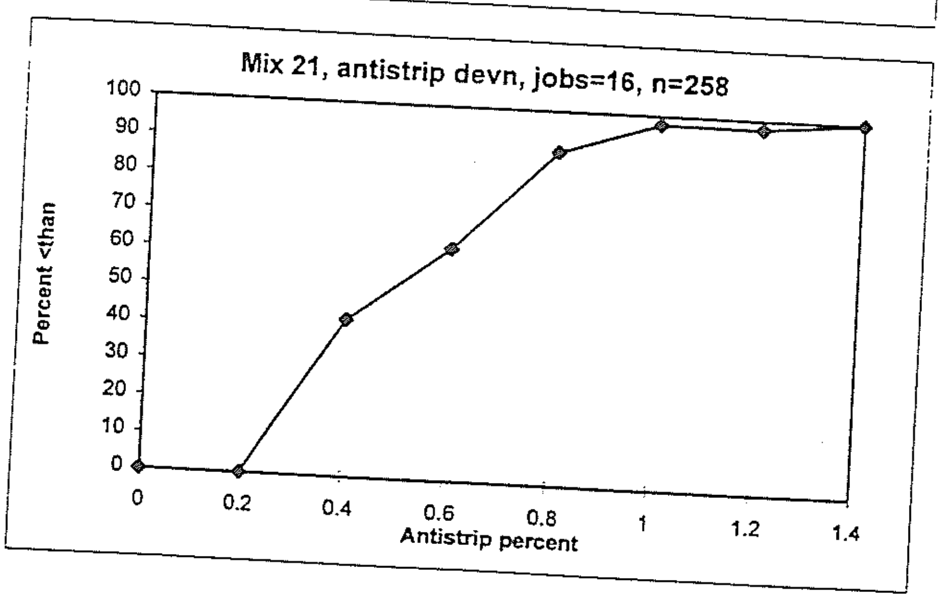

Mix 21, gradation, wearing course, 1991-95, n=1117
Percent<than
Size (mm)
avg
max
min
specmax
specmin

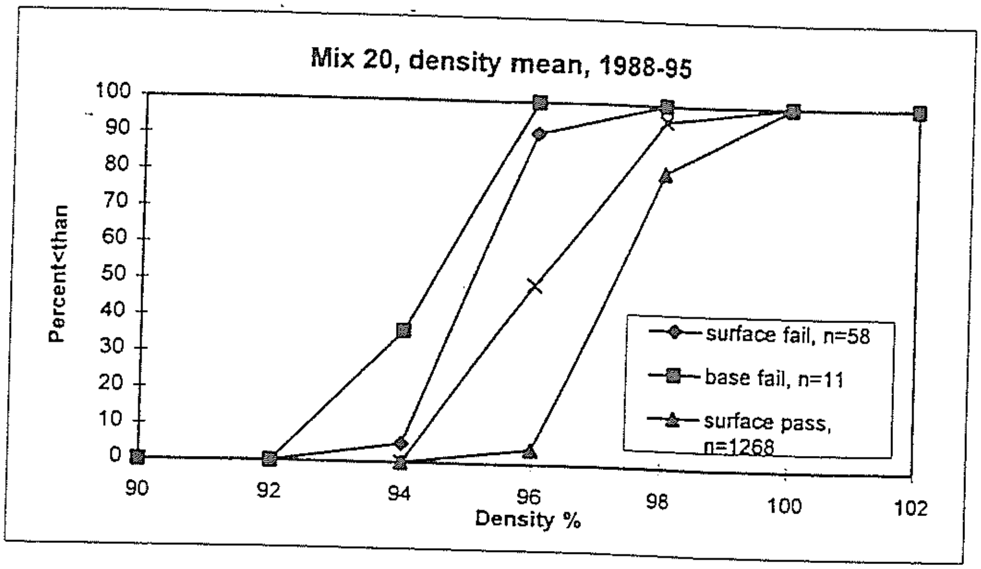

Mix 22, gradation, wearing course, 1994-95, n=119
Percent<than
Size (mm)
avg
max
min
specmax
specmin

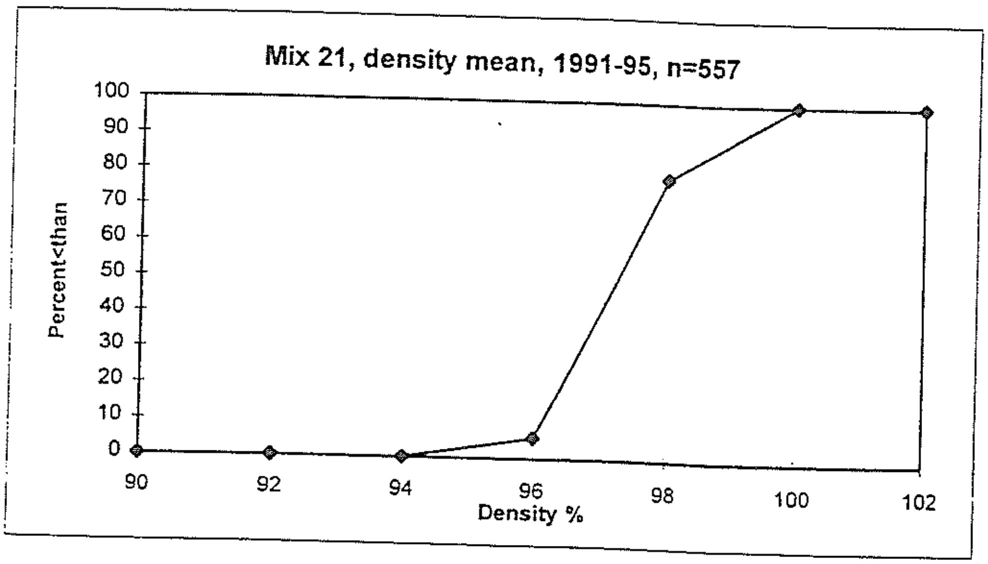

Mix 23, gradation, 1994-95, n=60
Percent<than
Size (mm)
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10
100
avg
max
min
specmax
specmin

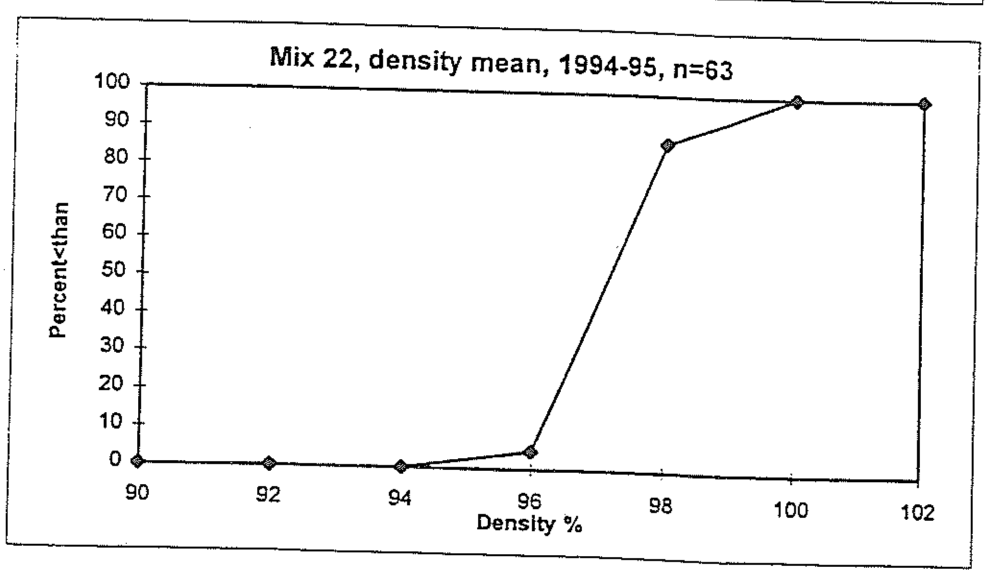

Mix 1, antistrip devn, jobs=49, n=821
Percent <than
Antistrip percent
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4

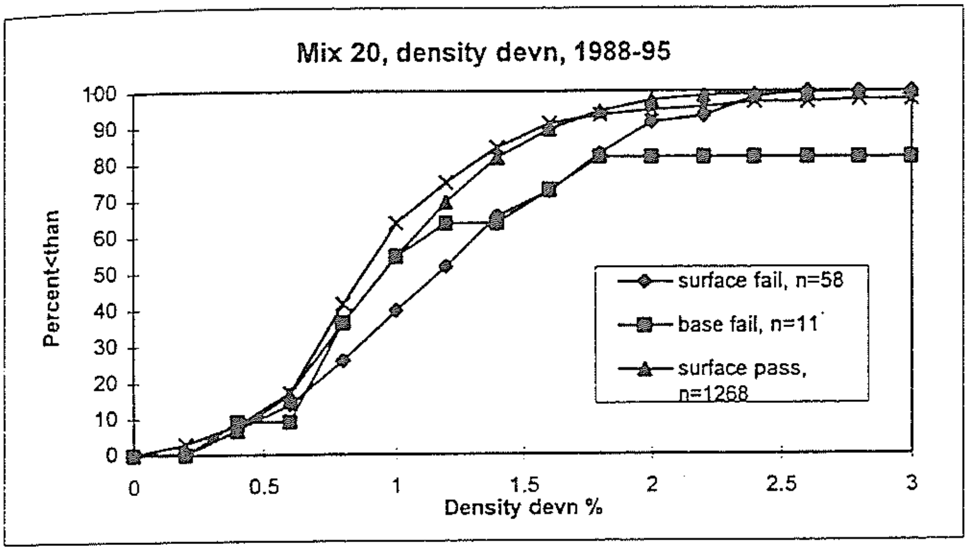

Mix 9, antistrip devn, jobs=78, n=1847
Percent <than
Antistrip percent
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4

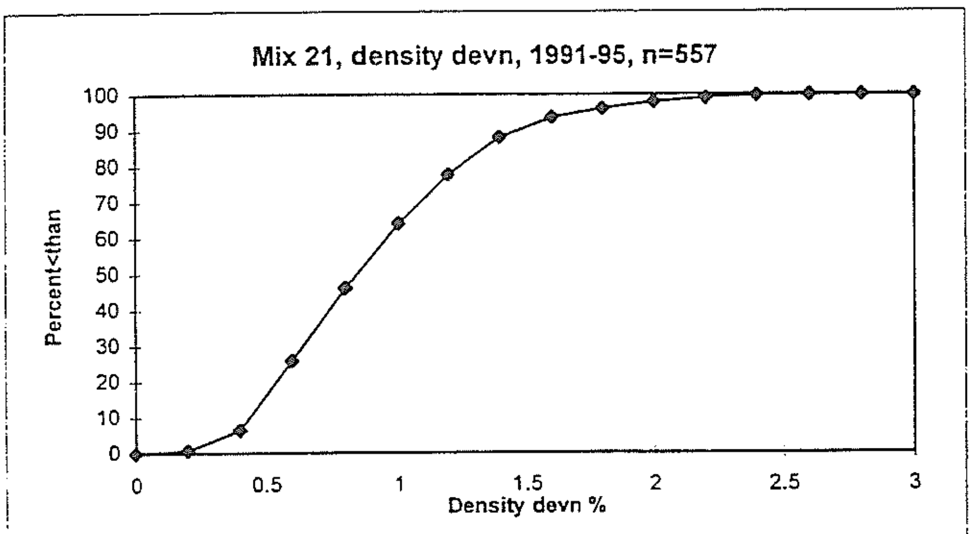

Mix 21, antistrip devn, jobs=16, n=258
Percent <than
Antistrip percent
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4

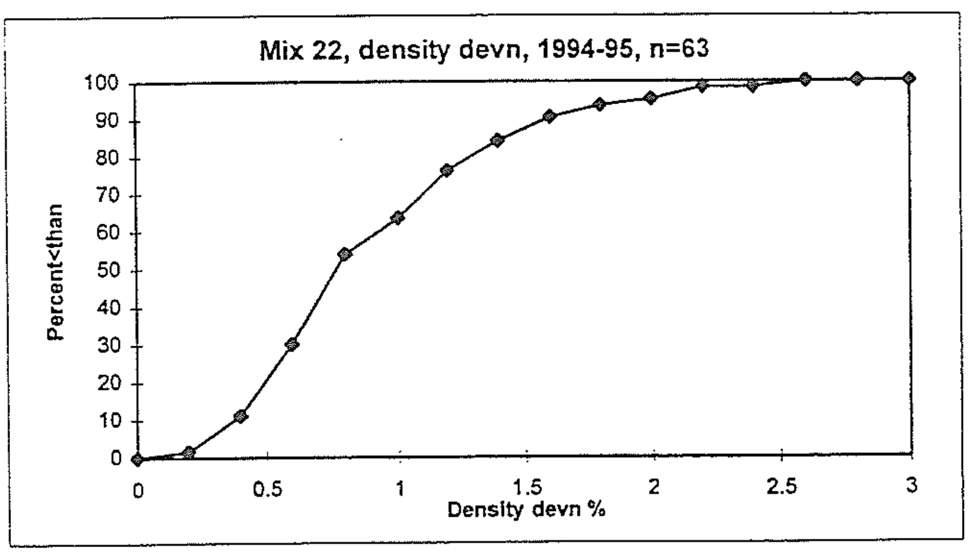

Mix 20, density mean, 1988-95
Percent<than
Density %
surface fail, n=58
base fail, n=11
surface pass, n=1268
100
90
80
70
60
50
40
30
20
10
0
90
92
94
96
98
100
102

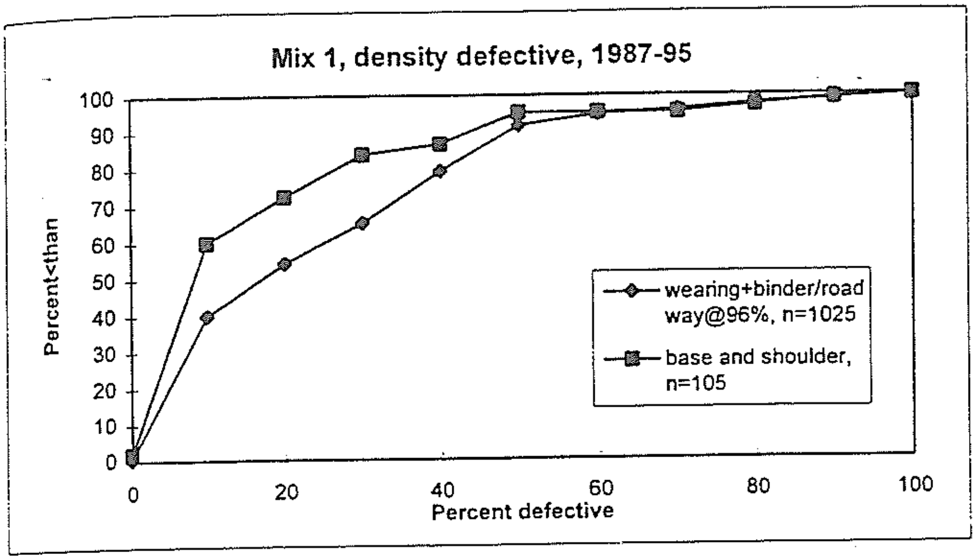

Mix 21, density mean, 1991-95, n=557
Percent<than
Density %
100
90
80
70
60
50
40
30
20
10
0
90
92
94
96
98
100
102

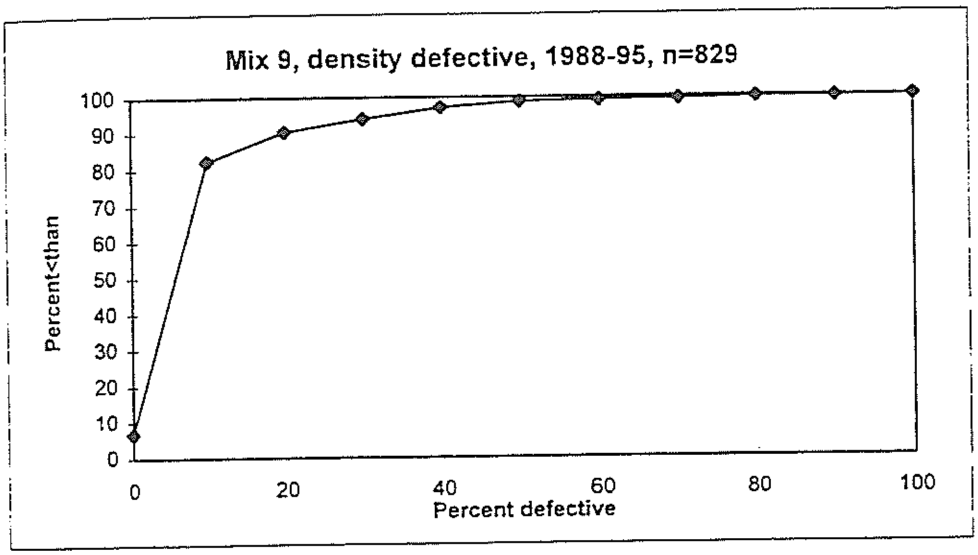

Mix 22, density mean, 1994-95, n=63
Percent<than
Density %
100
90
80
70
60
50
40
30
20
10
0
90
92
94
96
98
100
102

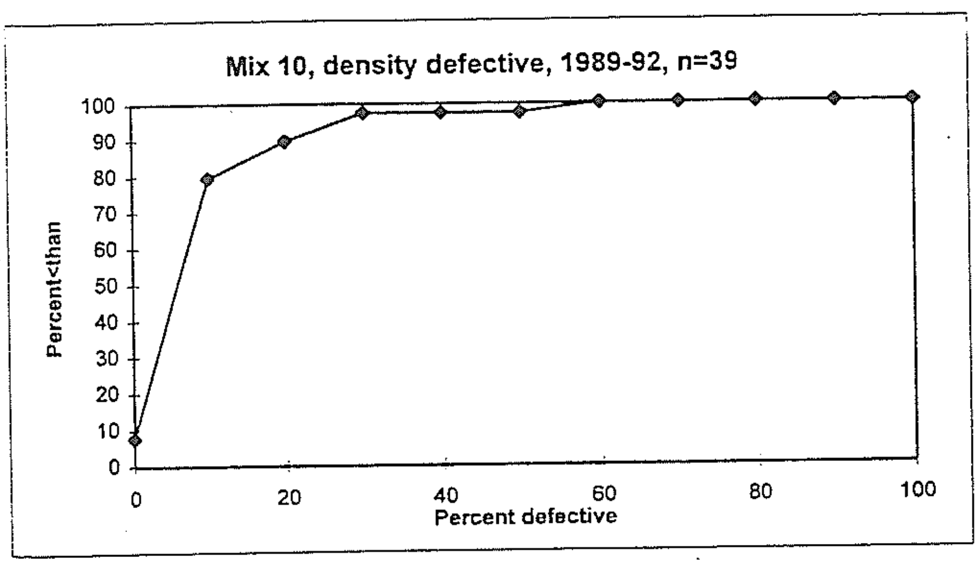

Mix 20, density devn, 1988-95
Percent<than
Density devn %
surface fail, n=58
base fail, n=11
surface pass, n=1268
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3

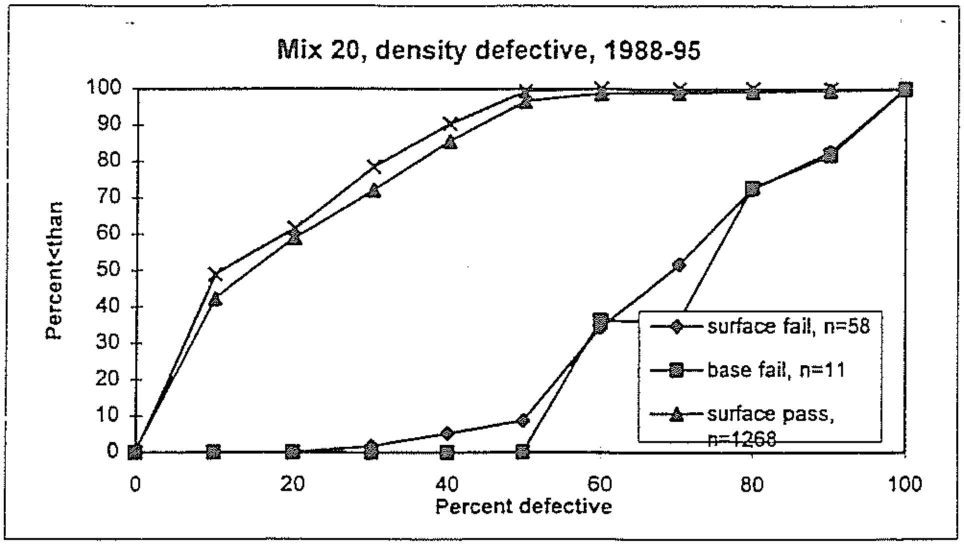

Mix 21, density devn, 1991-95, n=557
Percent<than
Density devn %
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3


Mix 22, density devn, 1994-95, n=63
Percent<than
Density devn %
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3

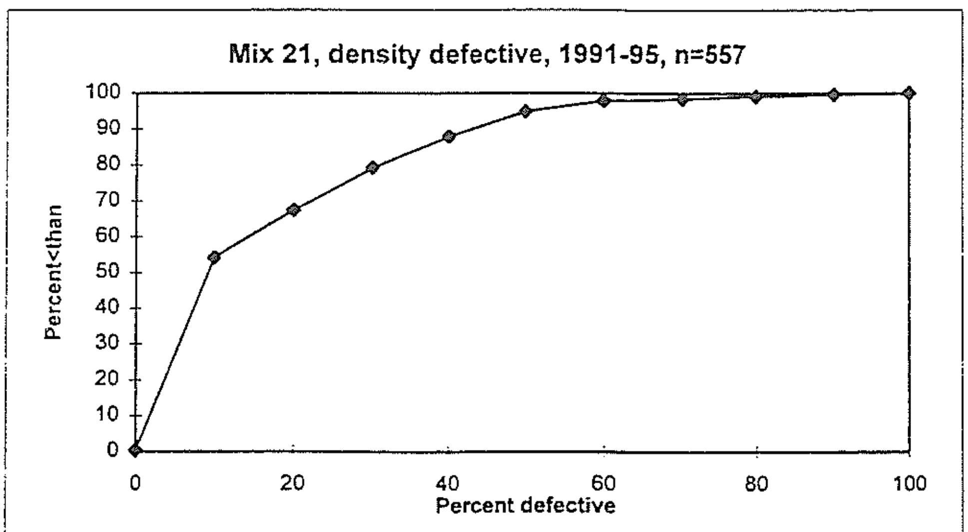

Mix 1, density defective, 1987-95
Percent<than
Percent defective
wearing+binder/road way@96%, n=1025
base and shoulder, n=105
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100


Mix 9, density defective, 1988-95, n=829
Percent<than
Percent defective
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

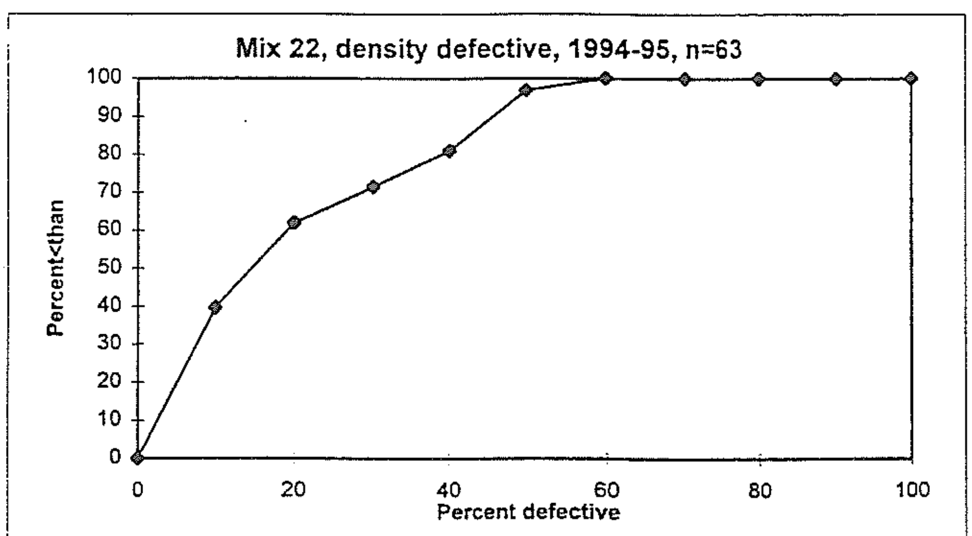

Mix 10, density defective, 1989-92, n=39
Percent<than
Percent defective
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100



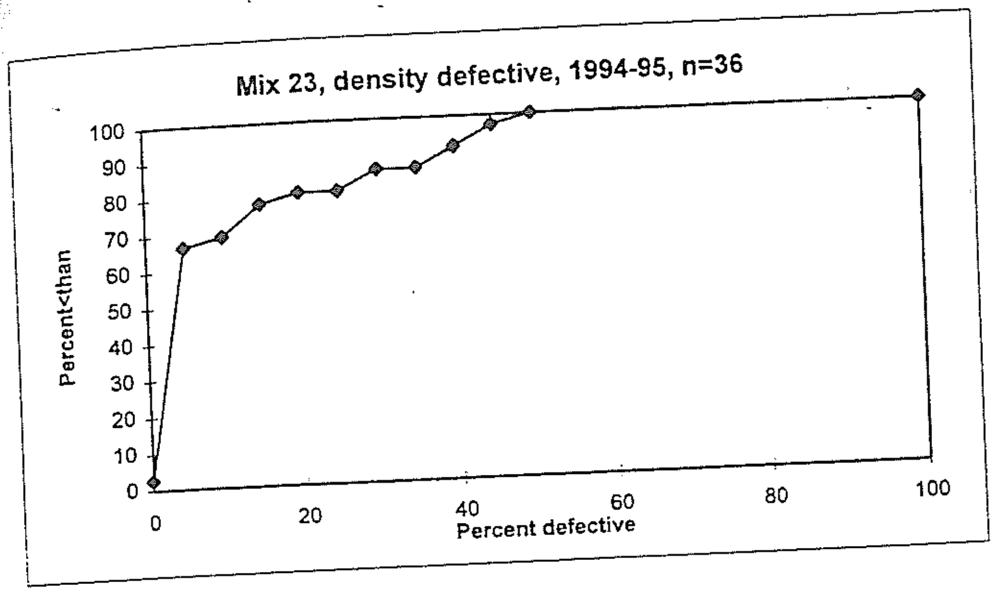
Mix 20, density defective, 1988-95
Percent<than
Percent defective
surface fail, n=58
base fail, n=11
surface pass, n=1268

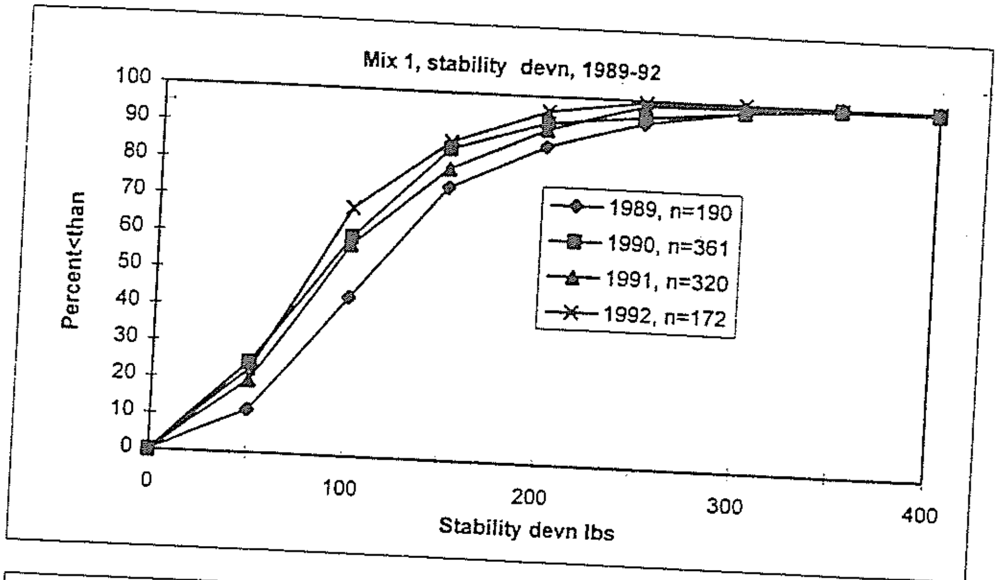


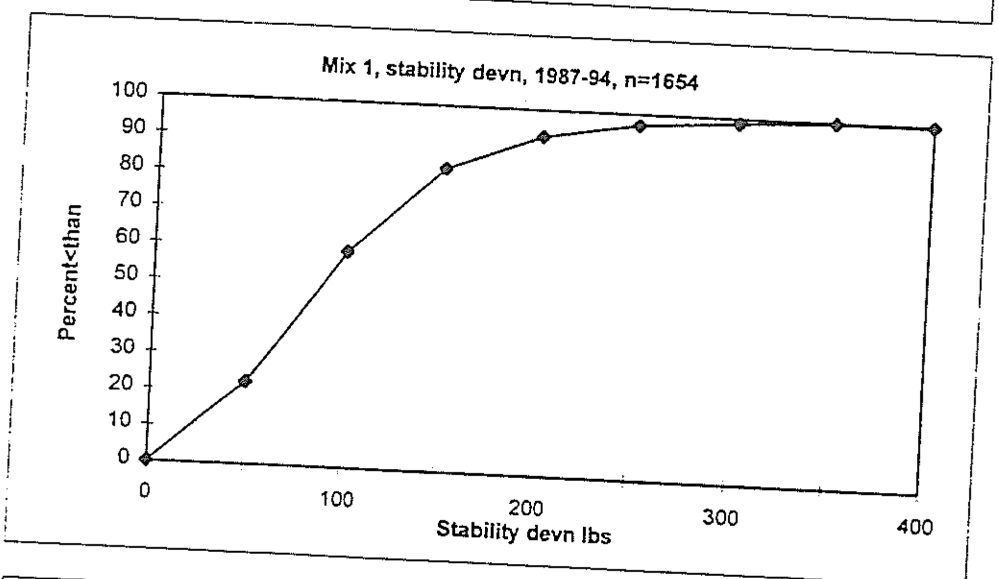
Mix 21, density defective, 1991-95, n=557
Percent<than
Percent defective

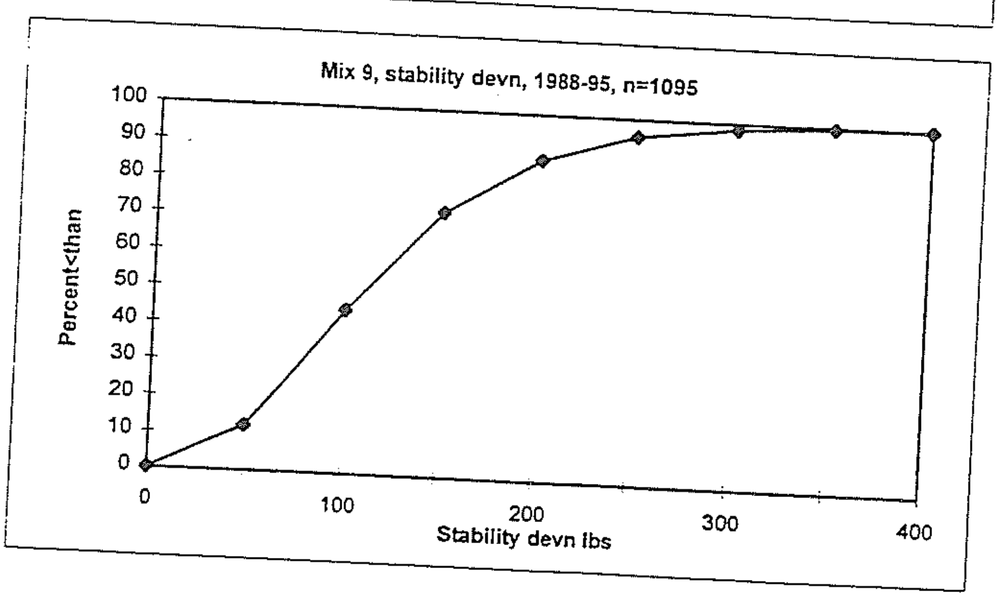


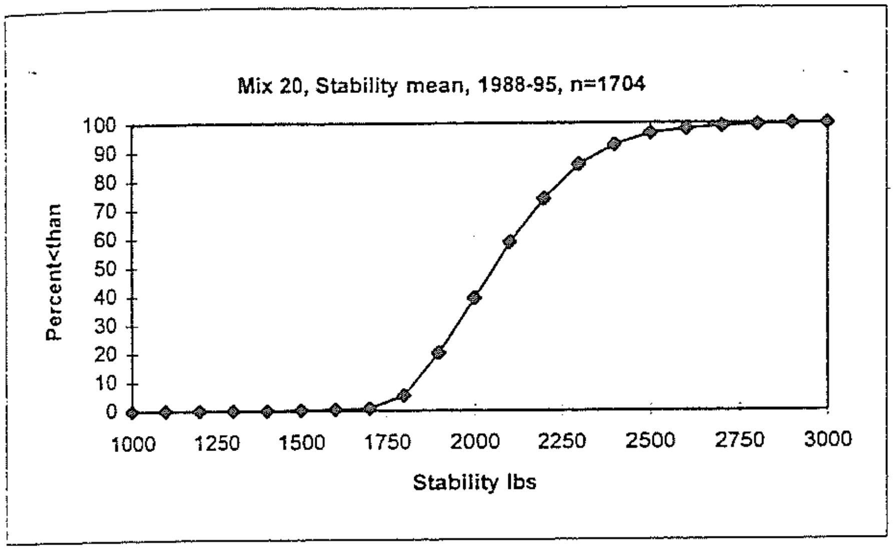
Mix 22, density defective, 1994-95, n=63
Percent<than
Percent defective


Mix 23, density defective, 1994-95, n=36
Percent<than
Percent defective
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

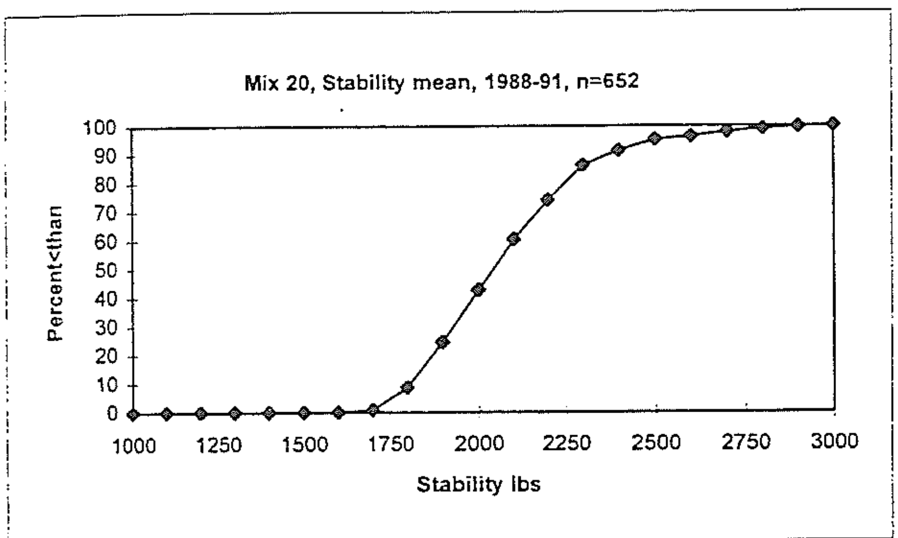

Mix 1, stability devn, 1989-92
Percent<than
Stability devn lbs
1989, n=190
1990, n=361
1991, n=320
1992, n=172
0
100
200
300
400
10
20
30
40
50
60
70
80
90


Mix 1, stability devn, 1987-94, n=1654
Percent<than
Stability devn lbs
0
100
200
300
400
10
20
30
40
50
60
70
80
90

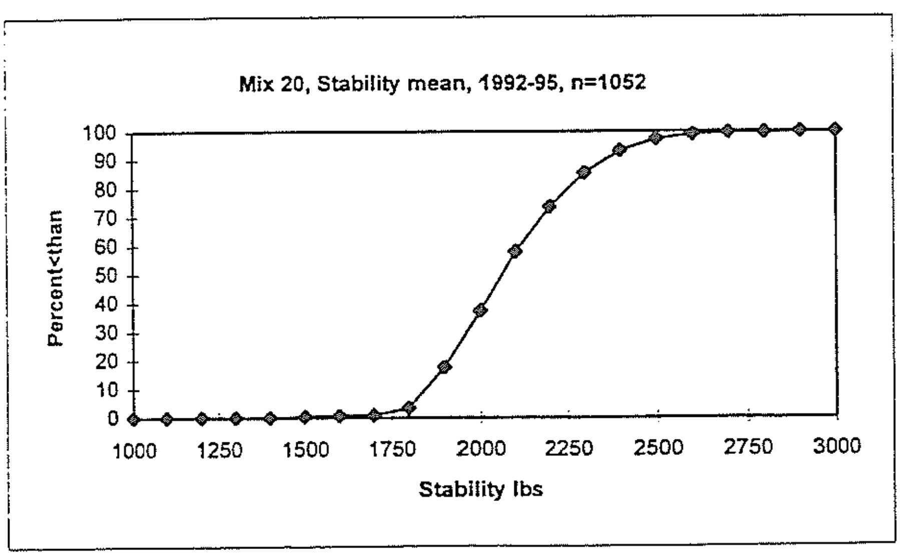

Mix 9, stability devn, 1988-95, n=1095
Percent<than
Stability devn lbs
0
100
200
300
400
10
20
30
40
50
60
70
80
90



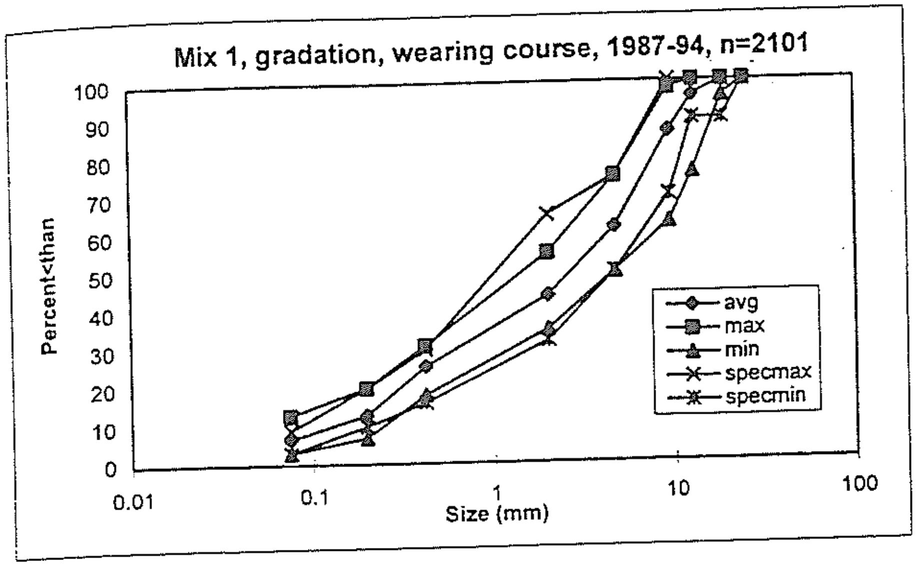
Mix 20, Stability mean, 1988-95, n=1704
Percent<than
100
90
80
70
60
50
40
30
20
10
0
1000
1250
1500
1750
2000
2250
2500
2750
3000
Stability lbs

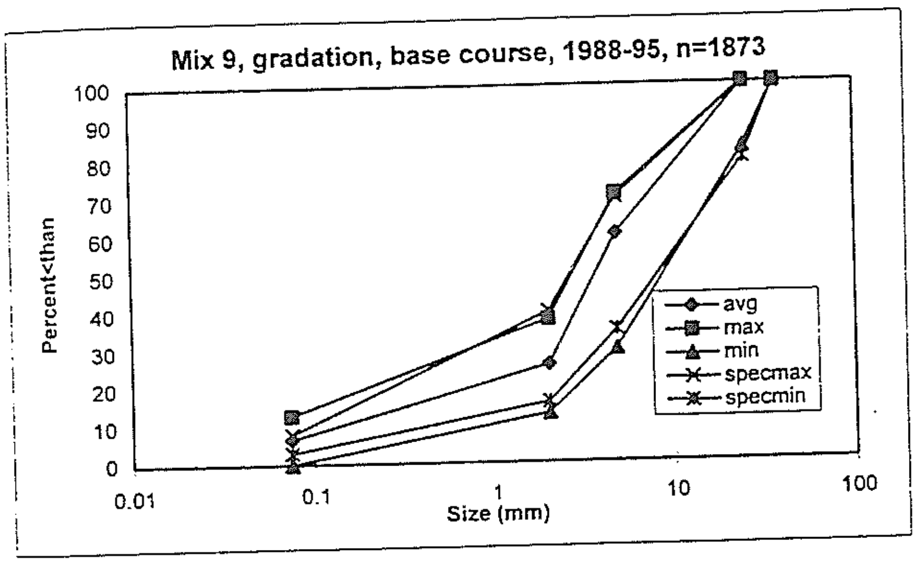


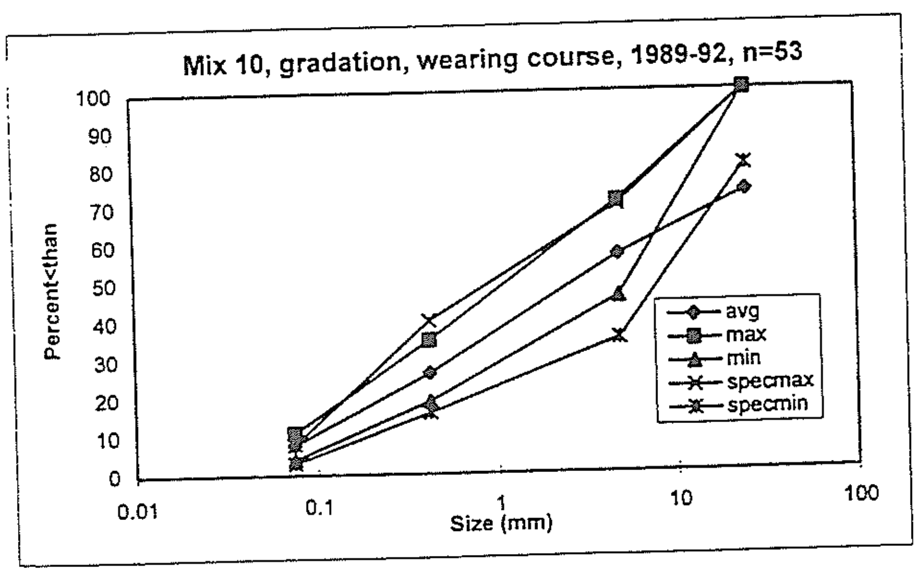
Mix 20, Stability mean, 1988-91, n=652
Percent<than
100
90
80
70
60
50
40
30
20
10
0
1000
1250
1500
1750
2000
2250
2500
2750
3000
Stability lbs



Mix 20, Stability mean, 1992-95, n=1052
Percent<than
100
90
80
70
60
50
40
30
20
10
0
1000
1250
1500
1750
2000
2250
2500
2750
3000
Stability lbs


Mix 1, gradation, wearing course, 1987-94, n=2101
Percent<than
Size (mm)
avg
max
min
specmax
specmin
0.01
0.1
1
10
100
0
10
20
30
40
50
60
70
80
90
100


Mix 9, gradation, base course, 1988-95, n=1873
Percent<than
Size (mm)
avg
max
min
specmax
specmin
0.01
0.1
1
10
100
0
10
20
30
40
50
60
70
80
90
100


Mix 10, gradation, wearing course, 1989-92, n=53
Percent<than
Size (mm)
avg
max
min
specmax
specmin
0.01
0.1
1
10
100
0
10
20
30
40
50
60
70
80
90
100

Appendix B

Derivation of Operating Characteristics

This public document is published at a total cost of $2023.31. One hundred eighty-five copies of this public document were published in this first printing at a cost of $1413.31. The total cost of all printings of this document including reprints is $2023.31. This document was published by Louisiana State University, Graphic Services, 3555 River Road, Baton Rouge, Louisiana 70802, to report and publish research findings of the Louisiana Transportation Research Center as required by R.S.48:105. This material was printed in accordance with standards for printing by state agencies established pursuant to R.S.43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.