PB99-102477

REPORT FHWA/NY/SR-89/96

Implications of Adopting a "Range Method" For New York's Marshall Mix Design

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SPECIAL REPORT 96

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

Mario M. Cuomo, Governor/Franklin E. White, Commissioner

IMPLICATIONS OF ADOPTING A "RANGE METHOD" FOR NEW YORK'S MARSHALL MIX DESIGN

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Final Report on Research Project 12-19
Conducted in Cooperation With
The U.S. Department of Transportation
Federal Highway Administration

Special Report 96
October 1989

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU
New York State Department of Transportation
State Campus, Albany, New York 12232

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2.	3. Recipient's Catalog No.
FHWA/NY/SR-89/96	PB99-102477	

4. Title and Subtitle	5. Report Date
Implications of Adopting a "Range Method" for New York's Marshall Mix Design	October 1989
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Prasanta K. Gupta Thomas F. VanBramer	Special Report 96
9. Performing Organization Name and Address	10. Work Unit No.
Engineering Research and Development Bureau New York State Department of Transportation State Campus, Albany, New York 12232	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final Report Research Project 12-19
Office of Research, Development, and Technology HRD-10 Federal Highway Administration U. S. Department of Transportation Washington, DC 20590	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Study Title: Range Method for Marshall Mix Design.

16. Abstract

Changes in interpretation of Marshall mix-design data that would simplify the Department's present method of selecting optimum asphalt content for flexible pavements were investigated. The new procedure is known as the "Range Method." Based on Marshall mix-design data analysis of 170 New York 6F and 7F mixes, it was determined that the difference of optimum asphalt content by the Range and New York methods was statistically insignificant for all but the 7F crushed stone mixes. The Range method was found to be suitable to specify acceptable production deviations from optimum asphalt contents.

17. Key Words	18. Distribution Statement
Marshall mix design method, asphaltic concrete, asphalt content.	No restriction. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

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

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I. INTRODUCTION

A. Purpose

This report is in response to a request from the Materials Bureau, that implications of adopting recommendations by Lees (1) be investigated. Lees proposed certain changes in interpretation of Marshall mix-design data that would simplify the present method of selecting optimum asphalt content, and suggested changes in the criteria to make them more responsive to the specific level of traffic anticipated. The new procedure is known as the "Range Method."

B. Background

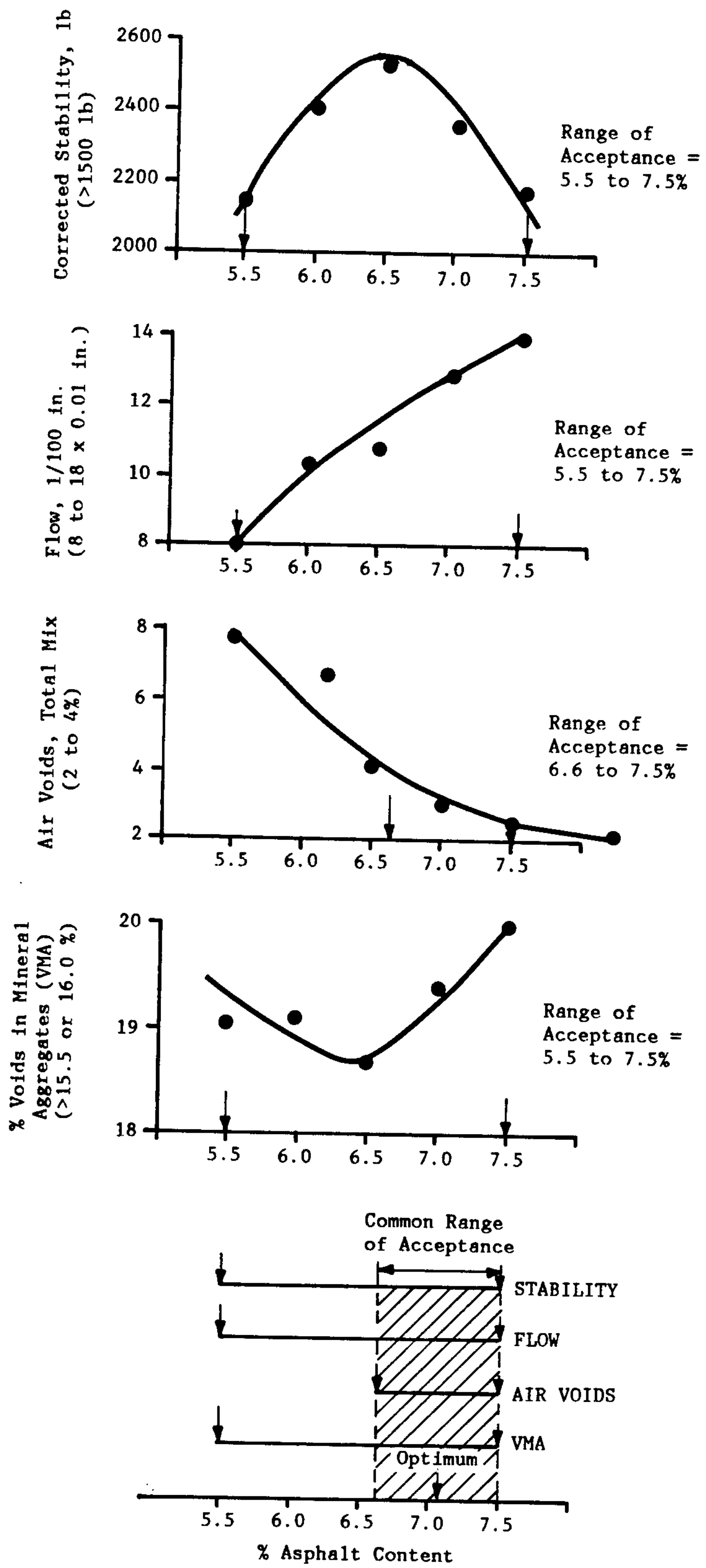
In 1981, the New York State Department of Transportation (NYSDOT) adopted the Marshall method of designing asphalt paving mixes. This requires that producers supplying state contracts prepare a complete Marshall mix design for each aggregate source-gradation combination they intend to produce for state work. Top course mixes so designed (Types 6F and 7F) must meet the following requirements:

Minimum Stability, lb	1500 (or 1200*)
Flow, 0.01 in.	8-18
Voids, percent	2.0-4.0
Minimum Voids in Mineral Aggregates (VMA), percent	15.5 (Mix 6F) 16.0 (Mix 7F)

* For bituminous mixtures using a natural sand containing in excess of 90-percent rounded quartz particles as the fine aggregate constituent.

Optimum asphalt cement content for the proposed gradation, from Marshall tests typically conducted with five different asphalt cement contents, is taken as the average value corresponding to the highest stability, the highest unit weight, and a void content of 3.0 percent. If the optimum asphalt content thus chosen does not produce a mix meeting all design requirements, including those for flow and VMA, the aggregate gradation is altered until compliance is attained.

Figure 1. Range method for asphalt content determination.



Although this procedure is widely used, it has disadvantages:

1. Selection of optimum asphalt content, in the first instance, does not incorporate all the design criteria, and a series of iterations thus may be required,

2. The process of curve fitting can be highly subjective, and

3. No basis is provided for selecting acceptable production deviations from optimum asphalt content.

In an alternative procedure suggested by Lees, optimum asphalt content is chosen as the midpoint of the range of asphalt contents that satisfy the design criteria. The method is illustrated in Figure 1, for a NYSDOT-approved asphalt concrete mix that was tested with percentages of asphalt varying from 5.5 to 7.5 percent. This overcomes the disadvantages inherent in the method now used by NYSDOT, and has been incorporated in some Japanese specifications.

Lees also suggests that the ratio of stability to flow, which he calls the "Marshall Quotient," be included as a mix design criterion in lieu of an upper limit on flow, and proposes different quotient levels for different categories of traffic volume and asphalt pavement thickness. Lees defines Marshall compressive strength as the ratio of stability to specimen thickness multiplied by diameter. He suggests using compressive strength in lieu of stability for thin asphalt concrete layers and permeability as mix design criteria for selection of optimum asphalt content. Specifications proposed by Lees are summarized in Appendix A.

C. Specific Objectives

By agreement with the Materials Bureau, work was undertaken to accomplish the following specific tasks:

1. Analyze and compare optimum asphalt cement contents of the established Materials Bureau five-point Marshall mix design method and the Range Method. The Marshall parameter most strongly influencing selection of optimum asphalt content by the Range Method was also to be identified.

2. Determine tolerances that can be set based on the Range Method.

3. Determine any additional effect on optimum asphalt content and tolerances by including requirements for the Marshall Quotient.

The Marshall compressive strength criterion is for thin asphalt layers placed directly on granular base courses. NYSDOT 6F and 7F surface mixes are not used in this fashion. Top course mixes in New York are placed on asphalt concrete binder and base courses constructed over granular subbases. Because of this, implications of incorporating compressive strength requirements in NYSDOT specifications were not investigated. Also, because mix permeability is not measured in New York, implications of incorporating a permeability requirement could not be analyzed.

Table 1. Distribution of approved top-course mixes by region.

Region	Mix 6F	Mix 7F	Total
1 (Albany)	9	4	13
2 (Utica)	10	17	27
3 (Syracuse)	2	6	8
4 (Rochester)	2	12	14
5 (Buffalo)	1	6	7
6 (Hornell)	2	12	14
7 (Watertown)	5	3	8
8 (Poughkeepsie)	35	26	61
9 (Binghamton)	6	7	13
10 (Hauppauge)	5	0	5
Total	77	93	170

To accomplish these tasks, 170 approved Marshall mix designs were examined representing the predominant top-course mixes (Types 6F and 7F) on file with the Department's Materials Bureau. Specific characteristics of these two mixes are given in Appendix B. Distributions of Marshall designs by mix type and NYSDOT region are given in Table 1.

II. RESULTS AND DISCUSSION

A. Optimum Asphalt Content

Optimum asphalt contents were determined by the existing procedure and the Range Method for the four mix design criteria (stability, flow, voids, and VMA) now used by NYSDOT. Distribution of differences among optimum asphalt contents (Range minus NYSDOT) for the 170 mixes is shown in Figure 2. Frequency distributions of differences between optimum asphalt contents for the mix types (6F and 7F) and materials (stone, gravel, and stone-gravel blend) are shown in Figures 3 through 8. Based on the Kolmogorov-Smirnov test, the distributions were determined to be approximately normal. In all cases mean differences in optimum asphalt contents were found to be very small.

Figure 2. Difference of optimum asphalt content (Range minus NYSDOT method).

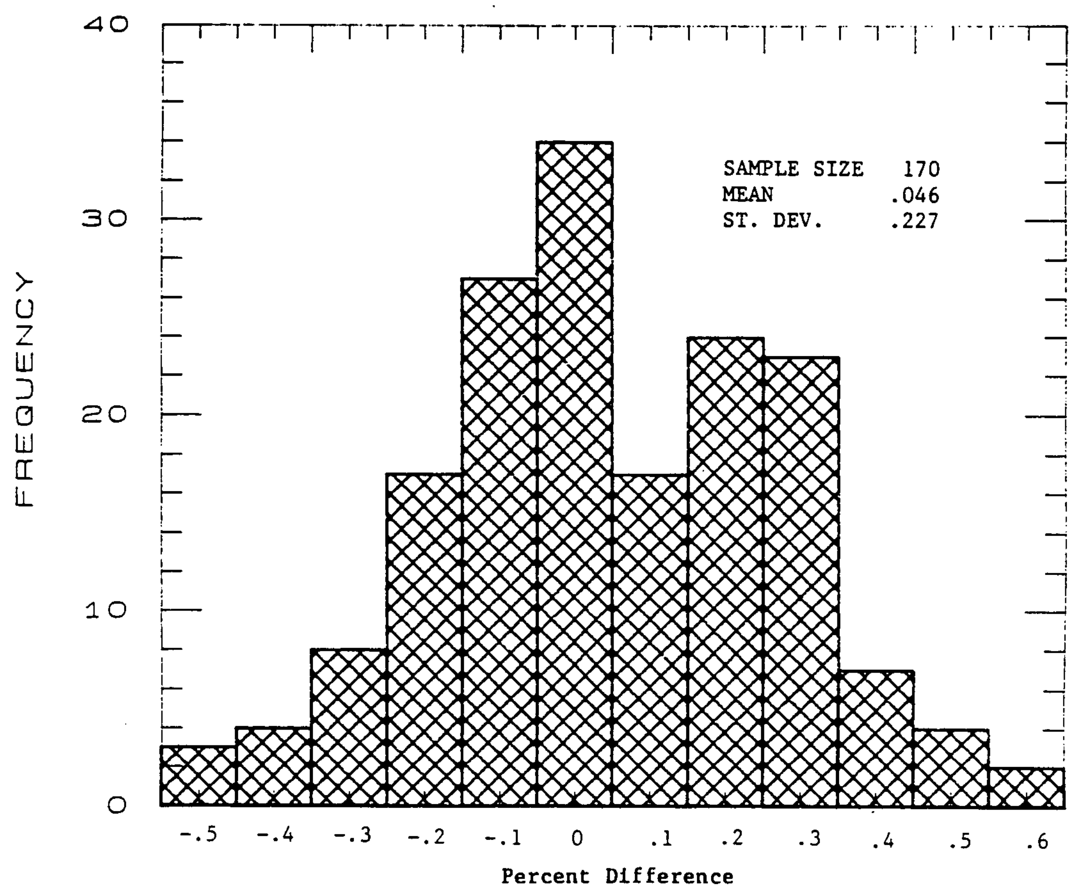


Table 2. Significance testing for asphalt cement content (Range minus NYSDOT).

Mix	Aggregate Type	N[a]	$\bar{X}$[b]	σ[c]	t[d]	Significance Level	Significant at 0.05 Level
6F	Gravel	9	0.03	0.22	0.458	0.659	No
	Stone	55	0.02	0.24	0.557	0.580	No
	Gravel & Stone	13	-0.07	0.21	-1.190	0.257	No
7F	Gravel	22	0.0	0.19	0.000	1.000	No
	Stone	55	0.13	0.22	4.262	8.2E-5	Yes
	Gravel & Stone	16	0.03	0.20	0.496	0.627	No

[a]Sample size.
[b]Mean difference in asphalt cement content.
[c]Standard deviation.
[d]Computed "t" statistic.

Although these differences were small, it was important to determine whether they were significantly different from zero for the mix types and material classifications, because this has financial implications for the Department. Higher asphalt contents will increase construction costs. Results for the significance tests are given in Table 2. (All statistical analyses and results presented in this report were performed with STATGRAPHICS Version 1 software installed in an IBM AT microcomputer.) All significance testing was done with a two-sample t-test analysis. Table 2 indicates that optimum asphalt contents obtained by the Range Method will be significantly higher only for 7F mixes using crushed stone aggregates. No significant increases are indicated for 6F mixes for any aggregate type.

It would have been useful to determine the impact of using the Range Method in each NYSDOT administrative region. This would have required knowing total quantities of asphalt concrete used in each region, classified according to mix (6F vs 7F) and aggregate type (crushed gravels vs crushed stones). Unfortunately, this information was not available. The only data available were total quantities of materials used in each region, classified by mix types alone. This is shown in Table 3, but the information could not be used to determine the impact on the regions of using the Range Method.

Because the Range Method did indicate changes in optimum asphalt contents, it was important to determine what Marshall parameter most strongly influenced selection of optimum asphalt contents. By examining each of the 170 mix designs, it was determined that air voids had the greatest influence. The optimum asphalt content obtained with the Range Method coincided with the asphalt content at 3-percent air [midpoint of the allowable range of 2 to 4 percent (Fig. 1)] for 157 mixes. Of the remaining 13 mixes, VMA had the greatest influence on 11 and flow on 2.

B. Acceptable Production Deviations

The NYSDOT method used to select optimum asphalt content does not provide a procedure for determining production tolerances around the optimum asphalt

Figure 3. Difference of optimum asphalt content for stone 6F mixes (Range minus NYSDOT method).

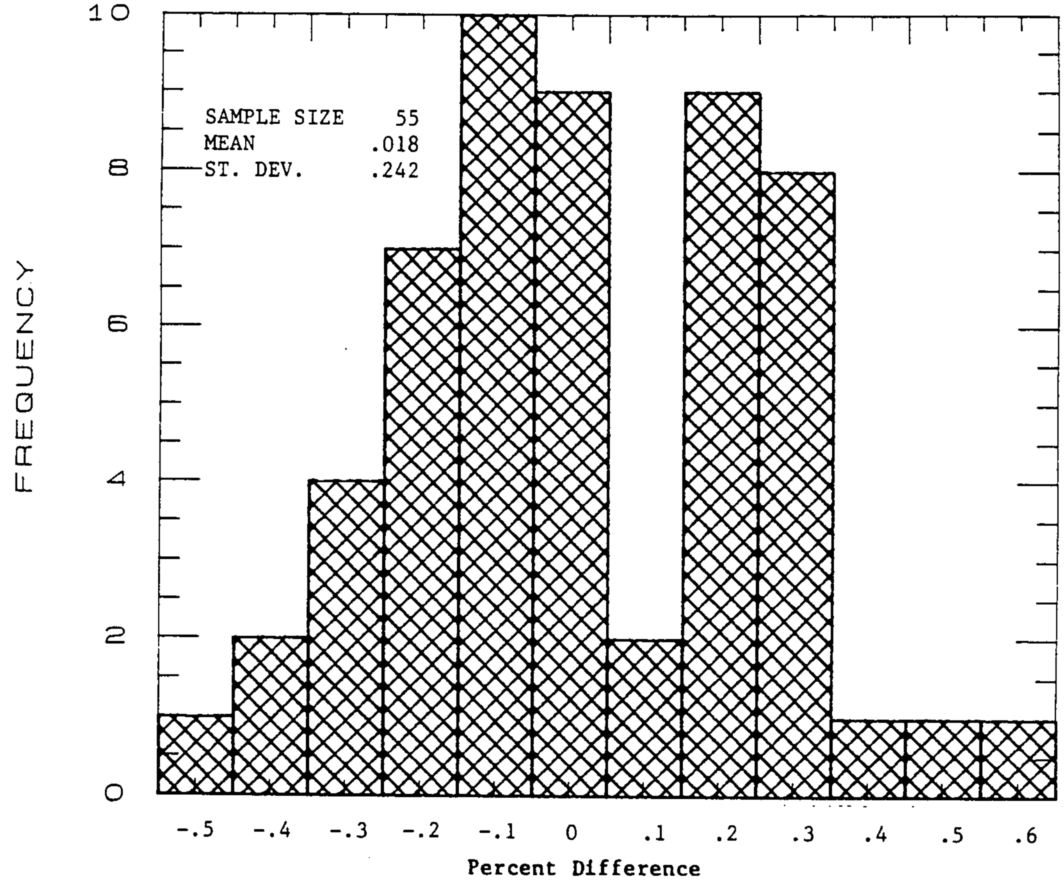


Figure 4. Difference of optimum asphalt content for gravel 6F mixes (Range minus NYSDOT method).

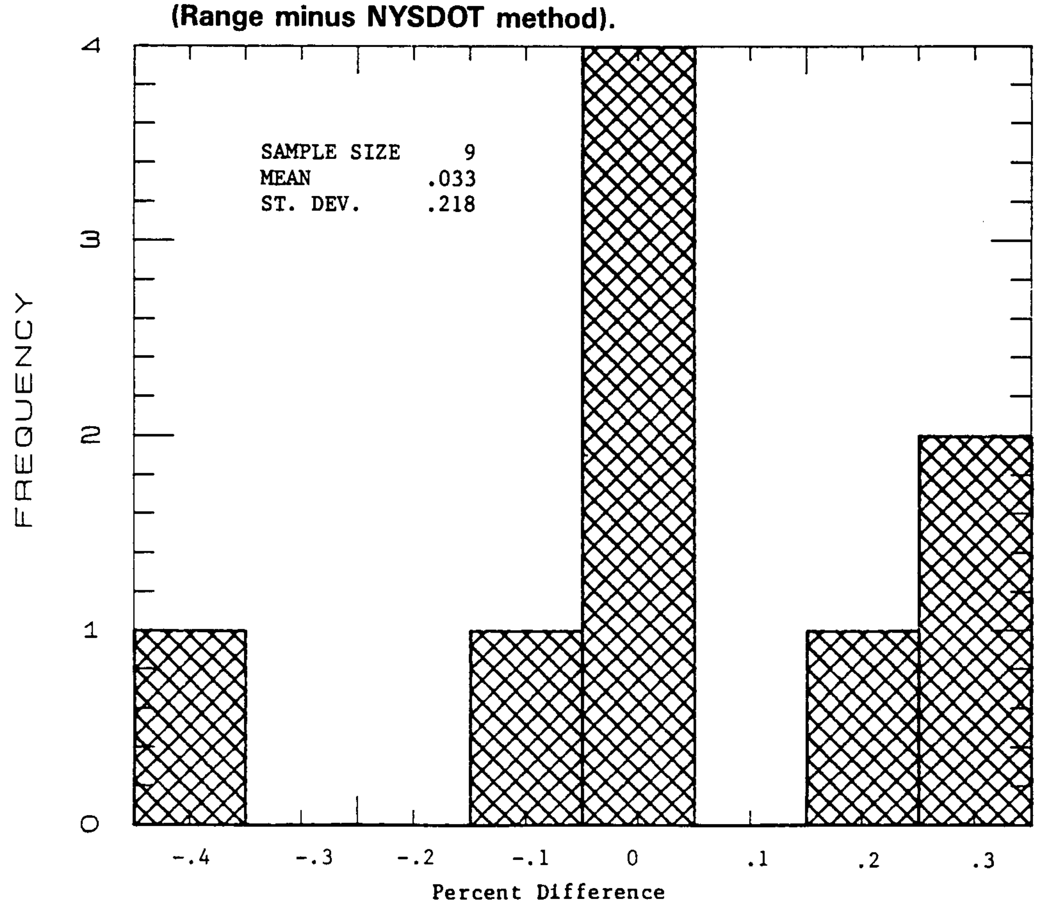


Figure 5. **Difference of optimum asphalt content for blended 6F mixes (Range minus NYSDOT method).**

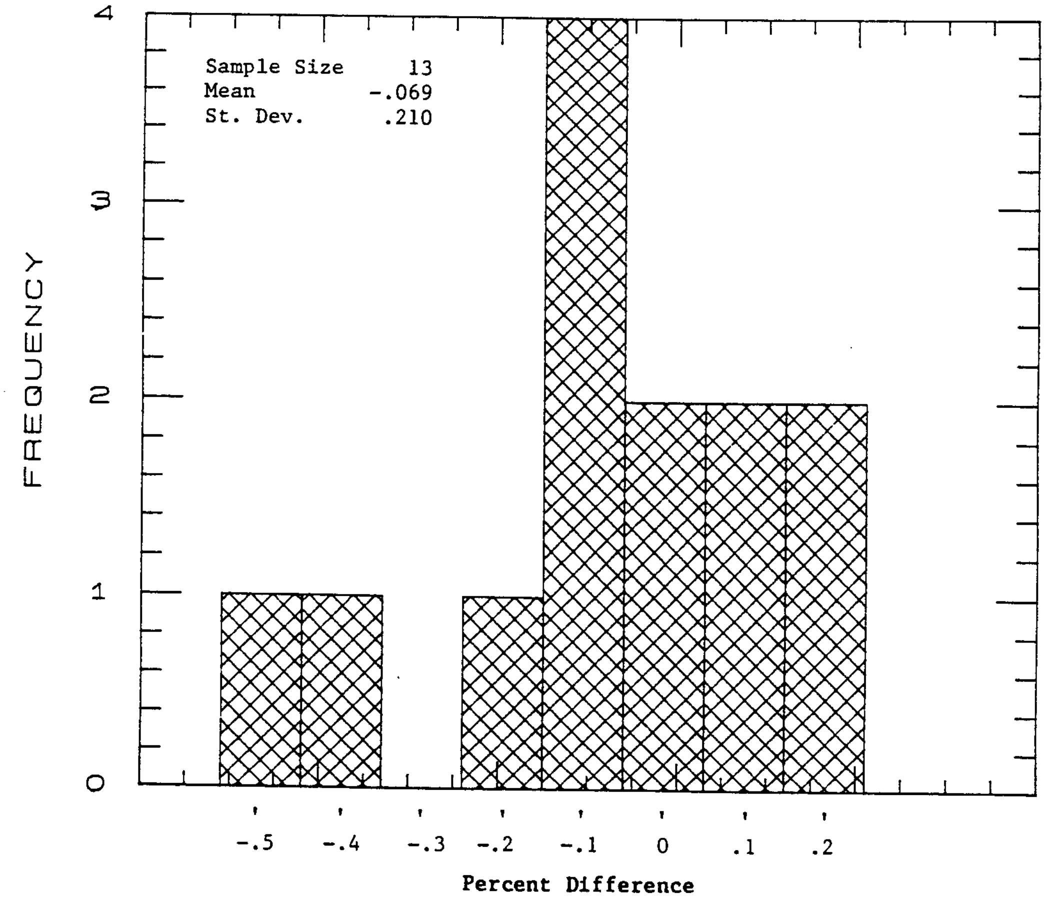


Figure 6. **Difference of optimum asphalt content for stone 7F mixes (Range minus NYSDOT method).**

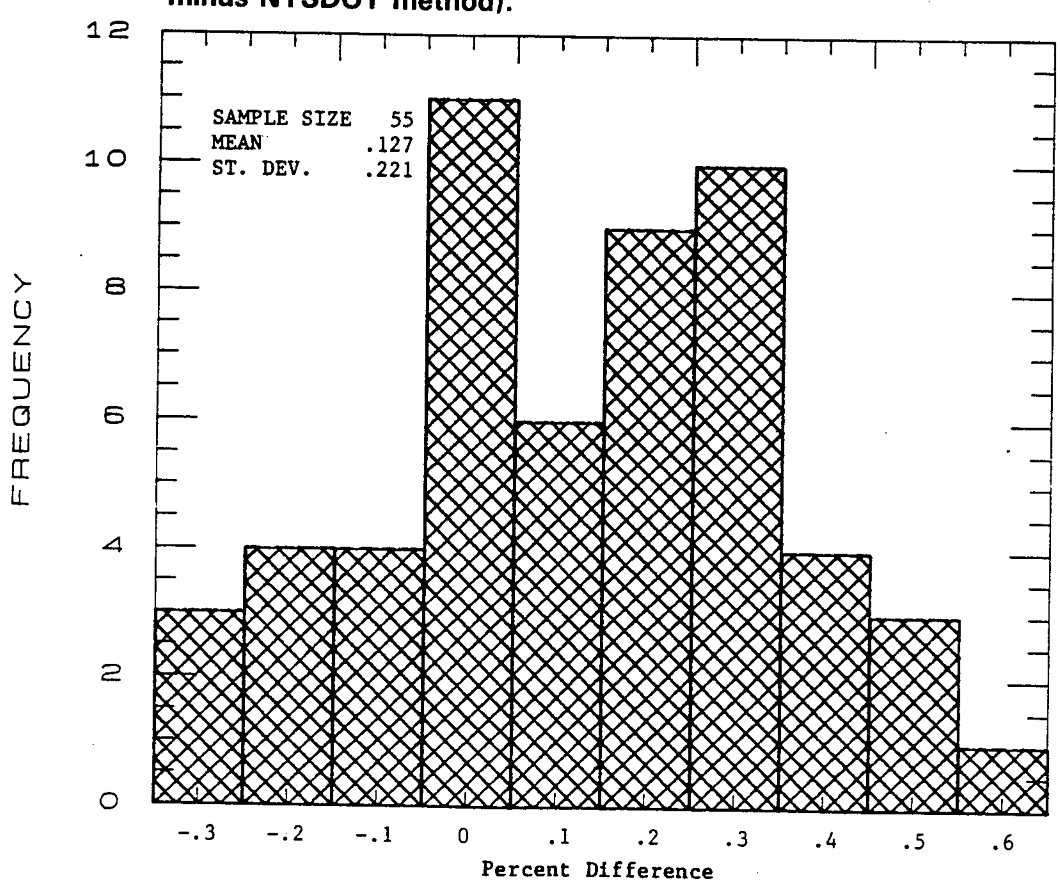


Figure 7. Difference of optimum asphalt content for gravel 7F mixes (Range minus NYSDOT method).

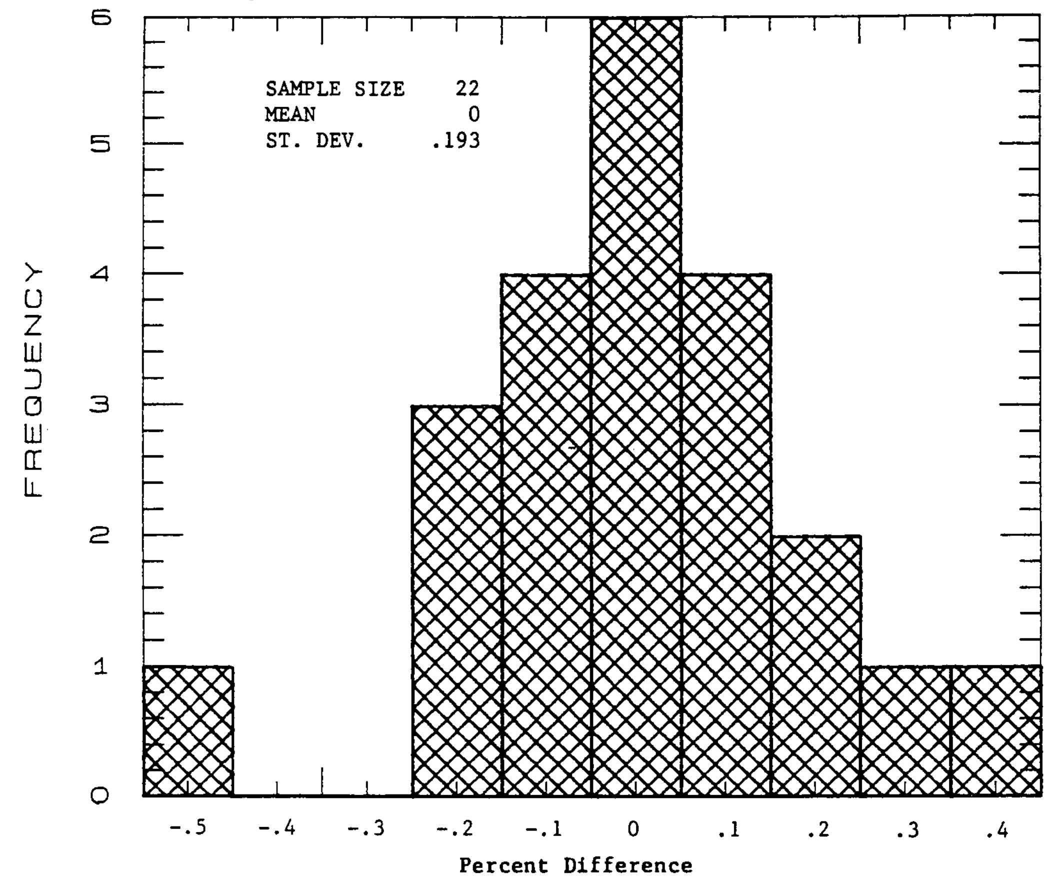


Figure 8. Difference of optimum asphalt content for blended 7F mixes (Range minus NYSDOT method).

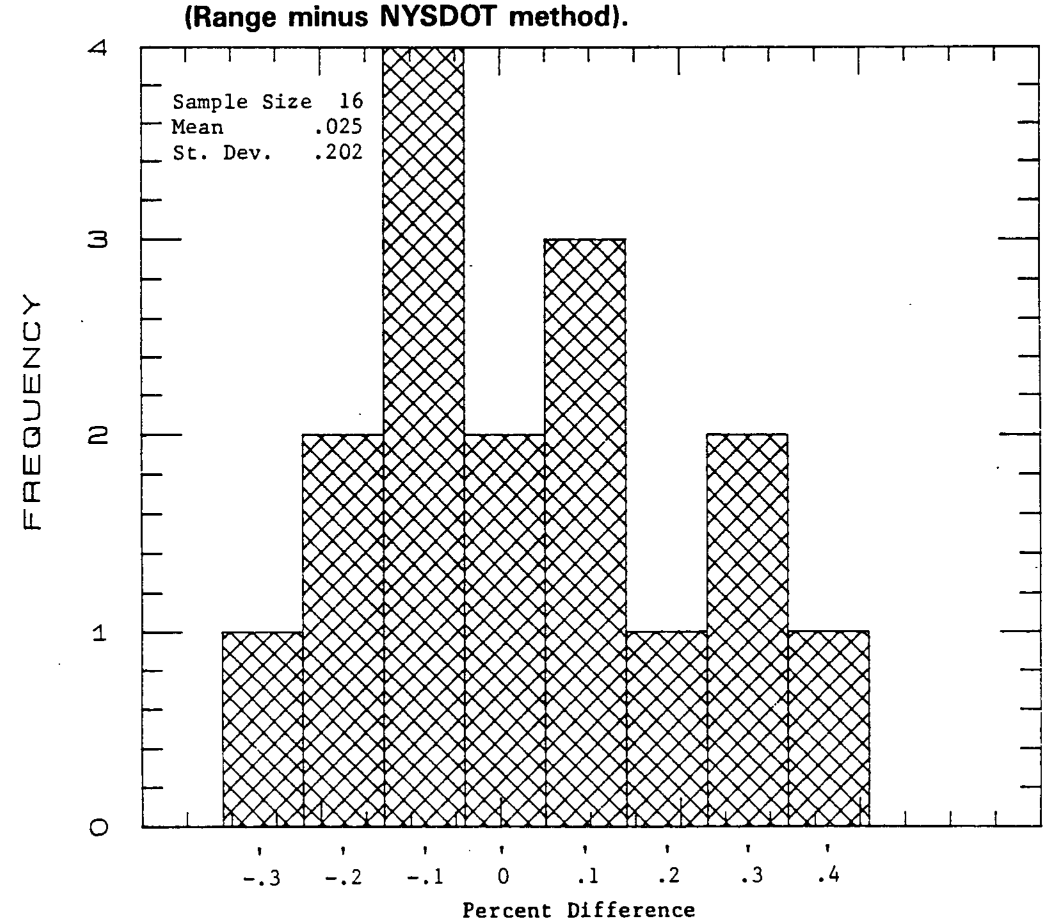


Table 3. 1987 production totals for bituminous concrete.

Region	Tons of Mix 6F	Tons of Mix 7F	Total
1	168,747	41,771	210,518
2	48,242	55,482	103,724
3	72	143,526	143,598
4	446	75,166	75,612
5	20,802	211,320	232,122
6	1,593	54,983	56,576
7	99,407	78,271	177,678
8	163,697	6,337	170,034
9	59,590	43,678	103,268
10	92,308	1,503	93,811
11	2,342	---	2,342
Totals	657,246	712,037	1,369,283

content. In the Range Method, the tolerance is taken as half the asphalt content range that satisfies all design criteria. The distribution of tolerances for the 170 mixes was determined and is shown in Figure 9. The mean tolerance was observed to be about ± 0.4 percent and the range between 0 and 0.8 percent.

C. Marshall Quotient Criterion

Based on laboratory wheel-tracking tests, Lees suggested that resistance to excessive deformation is better controlled by specifying a minimum quotient of about 14,450 lb/in. for thick (greater than 4 in.) asphalt concrete surface courses carrying many commercial vehicles (more than 6,000 per lane per day), between 6,940 to 9,250 lb/in. for intermediate traffic (1,500 to 6,000 per lane per day) for medium asphalt concrete surface course thickness (2 to 4 in.), and between 3,470 to 5,200 for thin (less than 2 in.) asphalt courses with light traffic (less than 1500 trucks per lane per day) than by specifying an upper limit on flow. Suggested specifications for Marshall quotients were incorporated in the Range Method with the other four mix design criteria, and optimum asphalt contents were determined.

The difference between asphalt contents determined from the Range Method including the quotient criterion for thick asphalt concrete surfacings, and the existing method is shown in Figure 10. Based on the Kolmogorov-Smirnov test, the distribution was determined to be about normal. The mean difference was observed to be 0.02 percent, and is less than the 0.05 percent observed without the quotient criterion (Fig. 2).

To determine whether the increase in asphalt cements was statistically significant, the data were classified according to mix type (6F or 7F) and aggregate types (gravel, stone, or blend) and checked with the t-test.

Figure 9. Range method asphalt content tolerance.

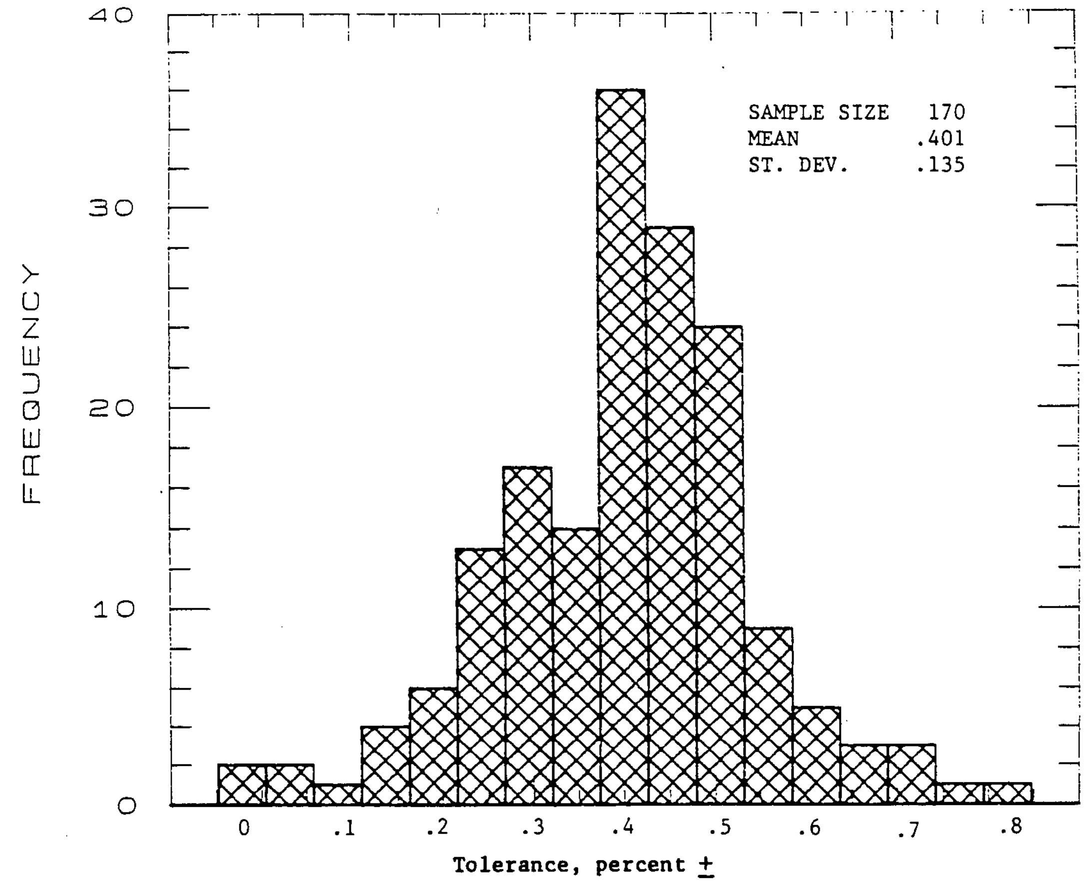


Figure 10. Difference of optimum asphalt with quotient criterion (Range minus NYSDOT method).

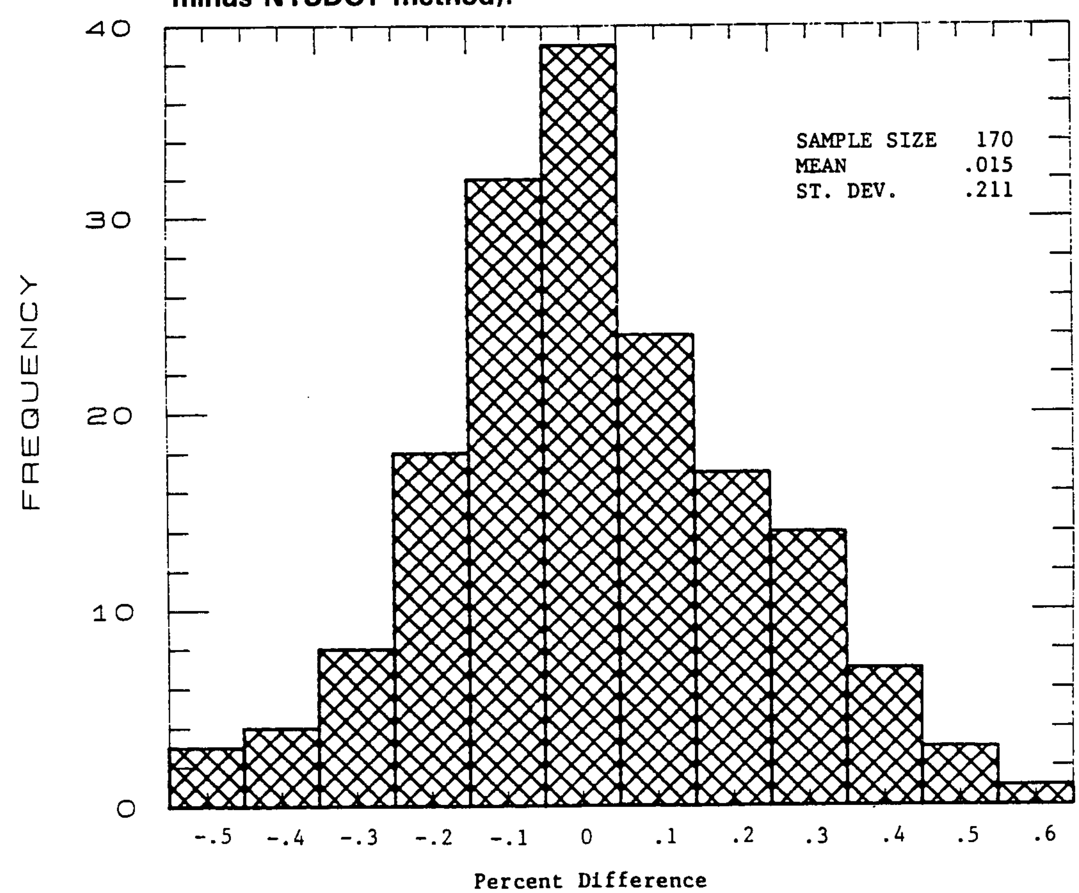
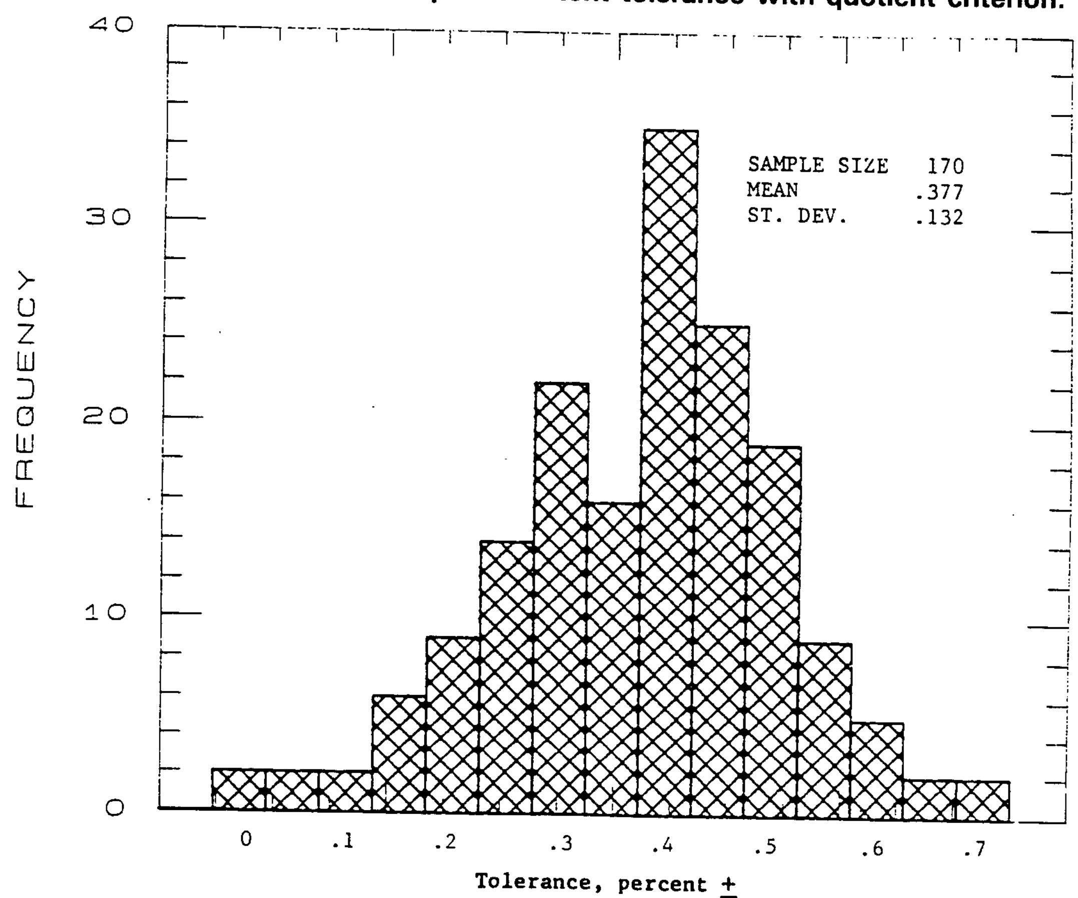


Table 4. **Significance testing for asphalt cement difference (Range minus NYSDOT) with quotient criterion.**

Mix	Aggregate Type	N	$\bar{X}$	σ	t	Significance Level	Significant At 0.05 Level
6F	Gravel	9	-0.02	0.20	-0.326	0.753	No
	Stone	55	0.02	0.21	-0.825	0.413	No
	Gravel & Stone	13	-0.07	0.21	-1.190	0.257	No
7F	Gravel	22	-0.04	0.16	-1.073	0.296	No
	Stone	55	0.10	0.21	-3.575	7.49E-4	Yes
	Gravel & Stone	16	0.03	0.20	-0.496	0.627	No

Figure 11. **Range method asphalt content tolerance with quotient criterion.**



Results are given in Table 4, which shows that asphalt content difference is significant only for 7F mixes using stone aggregates. In all other cases asphalt content differences are insignificant.

Distribution of acceptable production deviations from the optimum asphalt contents with the quotient criterion is shown in Figure 11. The mean deviation was found to be 0.4 percent and ranged from 0 to ± 0.7 percent.

Of the 170 mixes, none satisfied the quotient criterion proposed by Lees for thin and medium (as previously defined) asphalt surface courses. Quotients were much higher than the maximum limit at all asphalt contents and thus cannot be used for NYSDOT 6F and 7F mixes.

III. CONCLUSIONS AND RECOMMENDATIONS

Implications of adopting a Range Method to obtain optimum asphalt contents, instead of the existing method, were determined for 170 New York 6F and 7F mixes. Based on these analyses, the following conclusions are drawn:

1. Optimum asphalt content determined by the Range Method averaged 0.05 percent higher than the NYSDOT method, using mix design criteria of stability, flow, VMA, and air voids. The difference in optimum asphalt contents ranged between -0.5 and 0.6 percent. Although small, the asphalt content increase was found to be significant for 7F mixes using crushed stone aggregates. Asphalt content differences for 6F mixes with crushed gravels and stone and for 7F mixes with crushed gravels were found to be statistically insignificant.

2. As determined by the Range Method, mean acceptable production deviations from optimum asphalt content were found to be ±0.4 percent and ranged from 0 to ±0.8 percent. Air voids were determined to have the greatest influence on optimum asphalt contents.

3. By incorporating a quotient criterion (ratio of stability to flow) in the Range Method, optimum asphalt content was observed to be only 0.02 percent higher than obtained with the existing procedure. The increase was statistically significant only for 7F mixes with crushed stone aggregate.

4. None of the mixes satisfied the quotient criterion for medium (2 to 4 in.) and thin (<2 in.) asphalt surface courses. NYSDOT 6F and 7F mixes were found to be much stiffer than mixes designed with Lees' criteria.

5. Based on the Range Method with the quotient criterion, mean acceptable production deviations from the optimum asphalt contents were found to be ±0.4 percent and ranged from 0 to ± 0.7 percent.

Based on the findings, the following recommendations are made for NYSDOT 6F and 7F mixes:

1. NYSDOT should adopt the Range Method to determine optimum asphalt contents in the Marshall design method, with stability, flow, air voids, VMA, and Marshall Quotient with minimum value of 15,000 lb/in. as mix design criteria for NYSDOT 6F and 7F asphalt concrete mixes.

2. NYSDOT should determine acceptable production deviations from optimum asphalt contents based on the Range Method.

REFERENCE

1. Lees, G. "Asphalt Mix Design for Optimum Structural and Tyre Interaction Purposes." Proceedings, Sixth International Conference on Structural Design of Asphalt Pavements (Ann Arbor, Mich., 1987), Volume 1, pp. 404-17.

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Appendix A. Lees' Proposed Asphalt Mix Design Specifications

Specification	Commercial Vehicles per Lane per Day								
	<1500			1500-6000			>6000		
Compaction, blows									
63.5-mm Specimens	2 x 50			2 x 50			2 x 75		
Thinner Specimens	Scaled in proportion to reduced thickness								
Minimum Marshall Stability, kN	2.2			3.3			6.7		
Minimum Marshall Compressive Strength, N/mm^2	0.34			0.51			1.04		
Minimum Marshall Flow, mm	2.0			2.0			2.0		
Permeability, m/day									
Dense Mixes (maximum)	10E-4			10E-4			10E-4		
Open-Textured Mixes (minimum)	50			50			50		
Layer Thickness, in.	<2	2 to 4	>4	<2	2 to 4	>4	<2	2 to 4	>4
Minimum Marshall Quotient, kN/mm	0.6	0.9	----	0.9	1.2	----	1.4	1.9	----
	---	---	>1.2	---	---	>1.6	---	---	>2.5
	0.9	1.2	----	1.2	1.6	----	1.9	2.5	----
Minimum Marshall Compressive Strength Modulus, N/mm^2	9-14	14-19	>19	14-19	19-25	>25	22-30	30-39	>39

Appendix B. Composition of Bituminous Plant Mixtures.

Composition and typical use of NYSDOT 6F and 7F top-course mixtures, obtained from NYSDOT standard specifications were as follows:

	Mix 6F[a]		Mix 7F[b]	
Screen Size	General Limit, % Passing	Job Mix Tolerance, % ±	General Limits, % Passing	Job Mix Tolerance, % ±
1"	100	--	--	--
1/2"	95-100	--	100	--
1/4"	65-85	7	90-100	--
1/8"	36-65	7	45-70	6
No. 20	15-39	7	15-40	7
No. 40	8-27	7	8-27	7
No. 80	4-16	4	4-16	4
No. 200	2-6	2	2-6	2
Asphalt Content, %	5.8-7.0	0.4	6.0-8.0	0.4
Asphalt Cement Grade No.	AC-20 702.0500		AC-20 702.0500	
Mixing & Placing Temperature Range, F	250-325		250-325	

[a]Dense, granular texture for rural, suburban, and urban arterials.

[b]Dense, gritty texture for single-course resurfacing rural, suburban, and urban arterials.