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INVESTIGATION OF THE RUTTING PERFORMANCE OF PAVEMENTS IN COLORADO

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16. Abstract

A study of the rutting performance from plastic flow on 33 hot mix asphalt (HMA) pavements was performed. Air voids in the wheel path of 3.0% clearly distinguished pavements with good and bad rutting performances: air voids less than 3% rutted and air voids greater than 3% did not rut from plastic flow.

Samples were recompacted in the Texas gyratory using the high and low efforts. Samples recompacted with air voids greater than 2.0% with the high effort or 3.0% with the low effort indicated good performance with respect to rutting. The air voids after the low effort of compaction correlated best with the air voids in the wheel path for high volume roadways.

Component properties (aggregates, asphalt cements, gradation, etc.) did not reveal why the good pavements performed well and the bad pavements did poorly. Performance was directly tied to the void properties. Field verification should be performed throughout the project to provide indications of the future rutting performance of the pavements.

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I. INTRODUCTION

Achieving better performing hot mix asphalt (HMA) pavements has been a priority of the Colorado Department of Transportation (CDOT) for several decades. In 1952 and 1953, 113 major new pavements were constructed in Colorado. A majority of those pavements were performing excellently after 15 to 16 years. In 1970, a study was reported on 27 of those pavements and identified the primary distresses to be cracking due to age hardening and subgrade failure (1). Thirteen of the original 113 failed prematurely because of subgrade failures. The maximum rutting depths measured were 5 mm (0.2 in.): rutting was not a problem.

Since 1973, numerous changes occurred throughout the country which impacted the asphalt paving industry nationally and in Colorado. The changes probably were summarized best by Santucci (2), and included: emphasis on thin lift construction, increased truck loads and tire pressures, use of baghouse fines in mixes, introduction of drum mix plants, crude variability to a refinery because of the oil embargo, and viscosity grading of asphalt cements.

By 1984 rutting and raveling pavements were widespread, so the CDOT formed a task force to provide recommendations to mitigate the problems (3). The task force was composed of CDOT material, construction, design and research personnel, along with Colorado paving contractors and suppliers. Rutting was determined to be the most serious problem because raveling was more easily controlled. Pavements that exhibited rutting, as well as pavements that performed excellently seemed to occur randomly. The recommendations of the task force were implemented in 1985 after the study but were not particularly successful in solving pavement rutting problems.

A new high-stability pavement design was recommended and implemented in 1987; the results were not successful as some pavements exhibited severe moisture damage. In 1990, a moratorium was placed on high-stability pavements.

Because of the lack of success in solving the rutting problem, this study of in-place pavements, some rutted and some performing well, was initiated in 1992. The properties of excellent performing pavements and those pavements that had severe rutting depths were examined. It was hoped that the properties of the excellent performing pavements could be duplicated in a consistent manner on future projects. The purpose of this report is to provide the results of the rutting study.

The sites analyzed in this study were the identical sites tested in the French rutting tester as reported by Aschenbrener (4).

II. SITE SELECTION

Sites were selected based upon performance, temperature, and traffic. The SHRP classifications were used to categorize temperature and traffic.

Temperature. SHRP has developed recommendations for four levels of high temperature pavement conditions, three of which exist in Colorado. The high temperature pavement condition is defined as the highest monthly mean maximum temperature (HMMMT), i.e. the average of the daily high temperatures in the hottest month of the year. The temperatures used in this report were determined from data recorded at approximately 240 weather stations in Colorado and reported by the National Oceanic and Atmospheric Administration's National Climatic Data Center.

Traffic. SHRP has developed recommendations for seven traffic levels, six of which exist in Colorado. The levels are defined according to the number of equivalent 18-kip single axle loads (ESALs) applied during the design life of the pavement. The traffic levels used in this report were determined from the network level pavement management reports. The equivalent daily 18-kip load applications (EDLAs) were reported.

Performance. Rutting depths in inches are reported by the network level pavement management report. Several projects with high levels of rutting and several projects with no rutting were identified for each combination of traffic and temperature classifications. Acceptable levels of rutting were defined as less than 5 mm (0.2 in.).

Each site was then visited to determine the cause of rutting, and the actual rutting depths were measured with a 2-meter (6-foot) straight edge. Only sites exhibiting rutting from plastic flow were selected. Sites rutting because of subgrade failure, stripping or improper compaction were eliminated. Additionally, sites at intersections or with climbing lanes for trucks on steep grades were eliminated.

__Final Site Selection.__ At least one rutting and one non-rutting site from each traffic level and temperature environment in Colorado were selected and are shown in Table 1. Additional sites were selected which corresponded to a majority of Colorado's Interstate conditions. A total of 33 sites were evaluated and are listed on Table 2. The vicinity of each test site is shown on Figure 1. Pavement ages ranged from 4 to 33 years.

Table 1. Summary of Site Conditions by Site Number

	Highest Monthly Mean Maximum Temperature		
EDLA	< 80° F	80° to 90° F	90° to 100° F
< 27		19,20	25,26
27- 82	33	27,28	23,24
82- 274	31,32	5,6	21
274- 822	17,18	7,8	15,34,35
822-2740	36,37	3,4,11,12,13,14	9,10
2740-8220		29,30	

Table 2. Sites for French Rutting Tester

Site	Hwy	M.P.		Location	Rut Depth	HMMM Temp.	Traffic EDLA	Age Yrs.
3	US-85	251	(SB)	Platteville	0.0"	88	941	
4	US-85	248.3	(SB)	Platteville	1.0"	88	864	6
5	SH-66	40	(EB)	Longmont	0.0"	88	250	7
6	SH-119	50	(EB)	Niwot	0.4"	88	221	17
7	SH-52	12	(WB)	Dacona	0.1"	88	358	18
8	SH-52	19	(WB)	Fort Lupton	0.7"	88	310	12
9	US-287	430.3	(EB)	Lamar	0.1"	96	878	9
10	US-287	430.5	(EB)	Lamar	1.0"	96	878	13
11	I-25	41	(SB)	Walsenburg	0.0"	85	1027	8
12	I-25	35	(SB)	Walsenburg	0.8"	85	1027	9
13	I-70	430	(EB)	Burlington	0.1"	89	1377	6
14	I-70	445	(EB)	Burlington	0.8"	89	1336	23
15	US-50	375	(WB)	LaJunta	0.1"	94	551	15
17	US-160	271	(EB)	LaVeta Pass	0.5"	75	493	15
18	US-160	278	(WB)	LaVeta Pass	0.1"	75	465	31
19	US-389	10.3	(NB)	Branson	0.0"	84	3	-
20	US-389	10.5	(SB)	Branson	0.4"	84	3	-
21	US-50	454	(WB)	Granada	0.0"	94	270	12
23	US-160	490	(WB)	Walsh	0.1"	91	48	21
24	US-160	486	(WB)	Walsh	0.4"	91	48	21
25	SH-55	2	(NB)	Crook	0.1"	91	20	25
26	SH-55	0.3	(SB)	Crook	0.5"	91	20	25
27	SH-71	219	(NB)	Stoneham	0.0"	87	56	5
28	SH-71	214.4	(NB)	Stoneham	0.7"	87	56	33
29	I-25	237	(SB)	Denver	0.3"	87	3127	9
30	I-25	242.5	(NB)	Denver	0.6"	87	3127	9
31	US-40	225	(EB)	Fraser	0.4"	75	169	-
32	US-40	216	(WB)	Granby	0.1"	75	171	-
33	US-34	2.3	(WB)	Granby	0.5"	75	53	-
34	I-70	14.9	(WB)	Fruita	1.0"	93	780	21
35	US-50	75	(NB)	Delta	0.5"	93	399	8
36	I-70	214	(EB)	Eisenhower	0.8"	72	1137	29
37	I-70	207	(EB)	Silverthorne	0.1"	72	1137	4

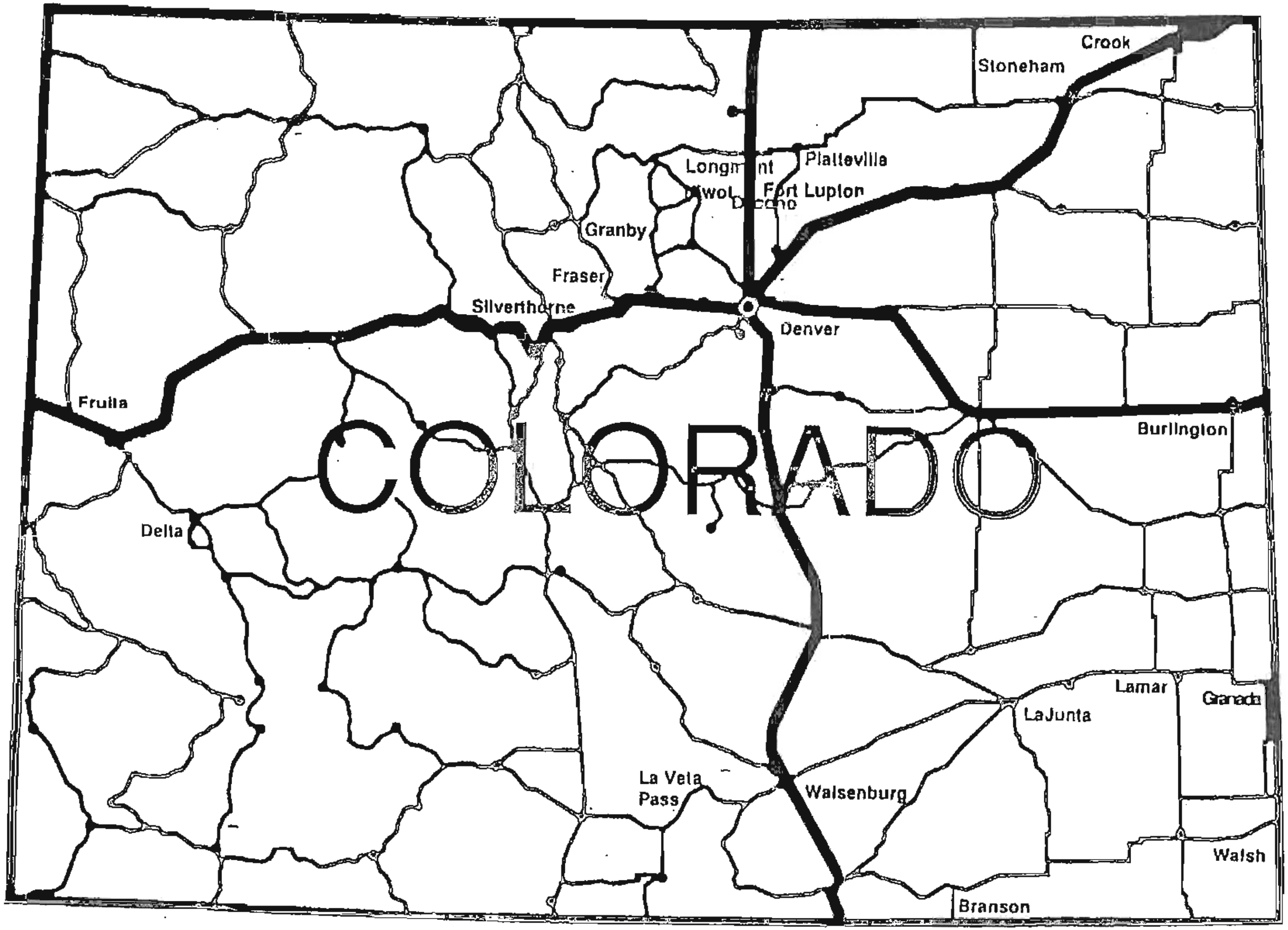


Figure 1 Test Site Locations Listed by City's Name

III. DOCUMENTATION REVIEW

A documentation review was performed to identify the most recent paving project at each of the sites. Information from most of the original mix designs and field verification testing was obtained from the districts or central project files and is shown on Table 3 (Appendix B). Results listed as "design" or "field verification" were obtained from the original project files. Field verification testing was defined as loose hot mix asphalt produced in the plant, then compacted in the laboratory.

IV. SAMPLING AND TESTING

To determine the current properties of the pavements, cores were obtained from each selected site. Five 100-mm (4-inch) diameter cores were obtained between the wheel paths; three were obtained in the wheel paths. The thickness of each lift was measured, then cores were cut into their respective lifts.

Mixture Tests. Mixture tests included the bulk and maximum specific gravities (AASHTO T 166 and AASHTO T 209, respectively). Air voids were then calculated between the wheel path and in the wheel path for each lift of all sites.

Texas Gyratory Recompaction. Samples were heated and recompacted in a Texas gyratory compactor (ASTM D 4013). Two efforts were used on the gyratory compactor: 1034 kPa (150 psi) end point stress (equivalent to a 75-blow

Marshall compactive effort, as indicated in a study by Brown (5)) and a 620 kPa (90 psi) end point stress. The air voids and Hveem stabilometer results (AASHTO T 246) also were determined for the recompacted samples.

Although the recompaction was performed many years after construction, the recompaction was considered to be roughly equivalent to a field verification test. The primary difference from a true verification test would be the compaction temperature which was selected as 121°C (250°F). This temperature was specified in ASTM D 4013 but is lower than the equiviscous compaction temperature. The asphalt had aged with time so it was much stiffer than when the design originally was performed. If higher compaction temperatures were used, the air voids reported in this study would have been lower.

Asphalt Cement Testing. Vacuum extractions (AASHTO T 164, Method E) were performed to determine the asphalt content, and the asphalt cement was recovered using the Abson method (AASHTO T 170). Penetration tests (AASHTO T 49) at 25°C (77°F) were performed to identify the properties of the asphalt cement; the samples were saved for testing with the shear rheometer.

Aggregate Testing. Testing on the aggregate included the gradation of the extracted aggregate (AASHTO T 30). Gradations of the sample extracted from each site are plotted in Appendix A. The percent coarse particles with two or more fractured faces and the National Aggregate Association particle shape and texture test for fine aggregates were determined.

V. TEST RESULTS AND DISCUSSION

Results of testing for all layers, 1 to 4 per site, are shown on Table 3 (Appendix B). One layer from each site was used in the following analyses. A layer of significance was identified based upon rutting susceptibility and layer thickness at each site. The layer of significance was the top lift for 27 of the sites, and the second lift was used for the remaining 6 sites. The second lift was used when the top lift was very thin and did not have properties representative of the lower lifts.

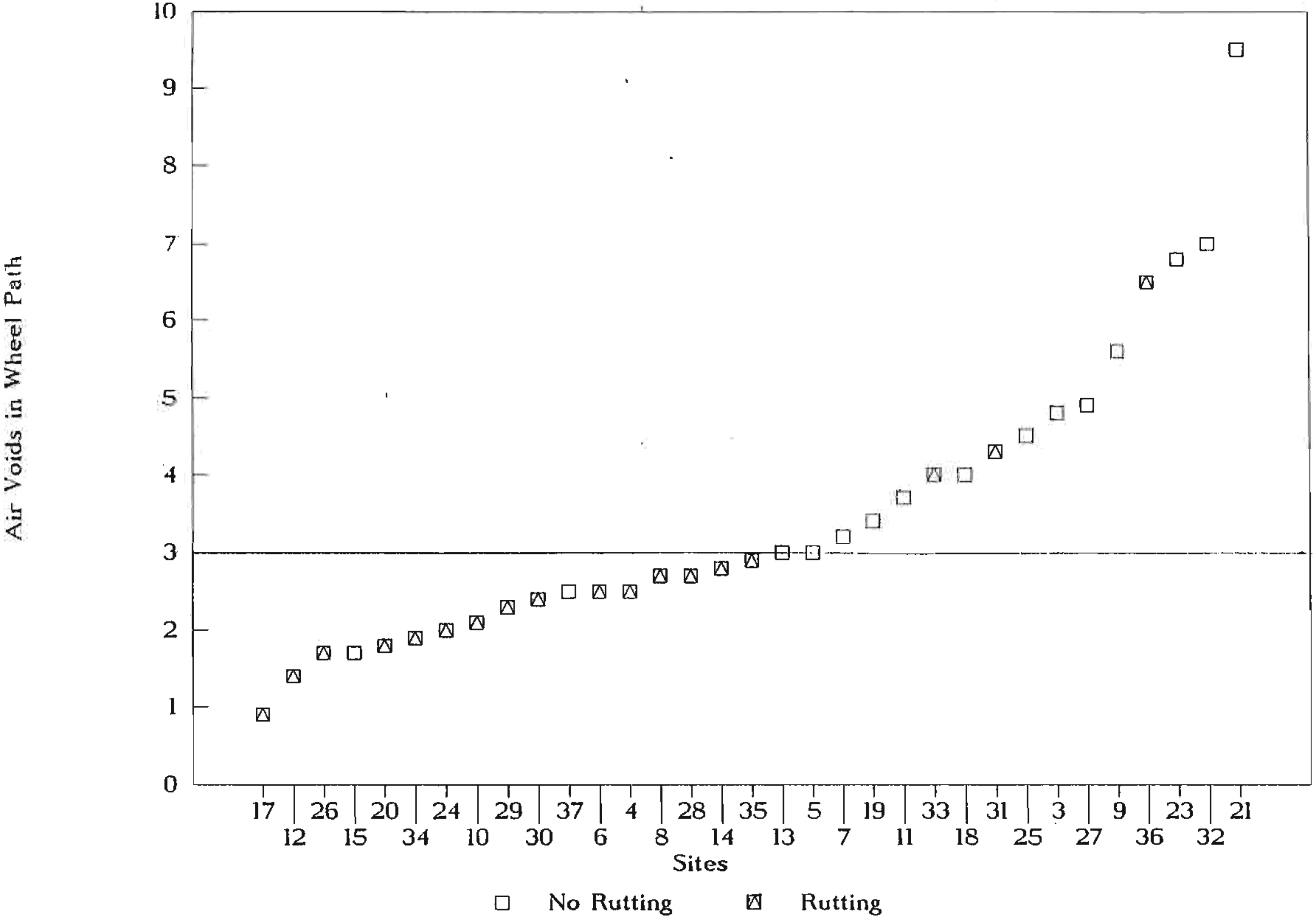
VI. PROPERTIES OF IN-PLACE PAVEMENTS

Air Voids in the Wheel Path. Air voids in the wheel path were measured and correlated to the pavement performance. Each of the sites are listed in ranked order from highest to lowest air voids in the wheel path and are plotted on Fig. 2. For all cases but four, the pavements that performed well had air voids equal to or greater than 3.0% in the wheel path, and pavements that performed poorly had air voids less than 3.0% in the wheel path. Site 36 was located in the Eisenhower Tunnel and was believed to have rutted from abrasion by tire chains. The pavement surface was very rough and pitted. Site 36 was excluded from additional analysis.

Other Studies. There were numerous other studies that had been performed which indicated that pavements rutting from plastic flow had air voids in the wheel path of less than 3.0% (6,7,8,9). Huber and Heiman (6) performed a study

Figure 2

Ranked Order of Air Voids in Wheel Path



using four acceptable and five unacceptable sites in Canada. All unacceptable sites had air voids of less than 2.0% in the wheel path; three of the acceptable sites had air voids greater than 3.0%. The fourth acceptable site had 1.4% air voids.

Brown and Cross (7) performed a study on 42 rutted pavements in 14 states. Air voids in the wheel path were less than 3.0% from 20 of the 28 pavements assumed to be rutted from plastic flow. Of the 28 rutted sites, 26 had air voids of less than 4.0%. All sites with levels of rutting less than or equal to 5 mm (0.2 in.) had air voids in the wheel path greater than 5.0%.

Summary. When air voids in the wheel path were less than 3.0%, there was a high probability of rutting from plastic flow. When air voids in the wheel path were greater than or equal to 3.0%, there was a high probability that the pavement would not rut from plastic flow.

VII. COMPARISON OF VOIDS IN THE WHEEL PATH AND RECOMPACTED CORES

Compactive Effort Which Modeled Wheel Path Voids. The Texas gyratory was used to recompact samples from each lift and the air voids were measured and correlated with the air voids in the wheel path. The results are shown on Fig. 3 using the 1034 kPa (150 psi) end point stress defined in ASTM D 4013 and on Fig. 4 using the 620 kPa (90 psi) end point stress. Linear regression results included all sites and were:

Figure 3 - Air Voids in Wheel Path
Versus Air Voids T.G. (High)

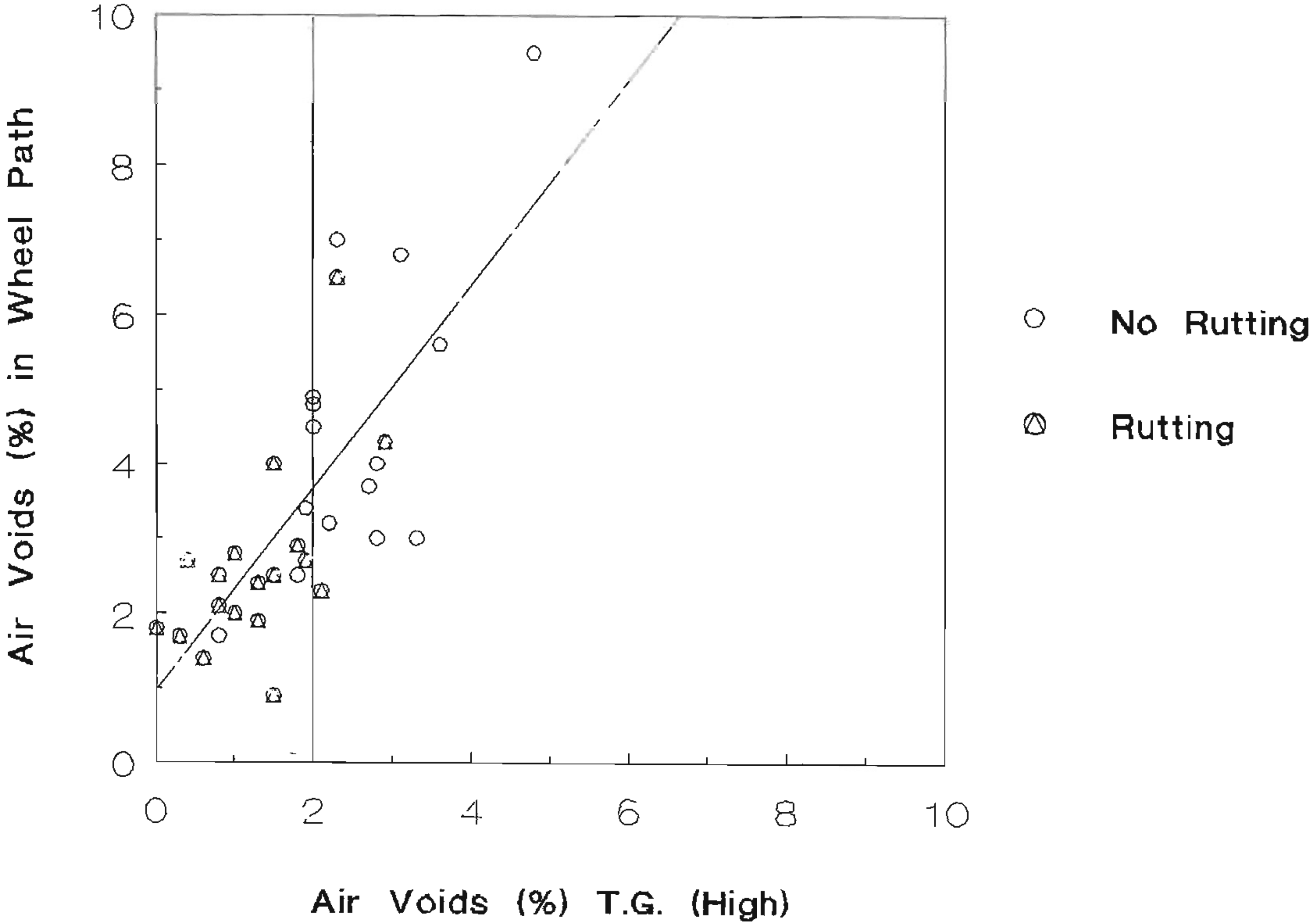
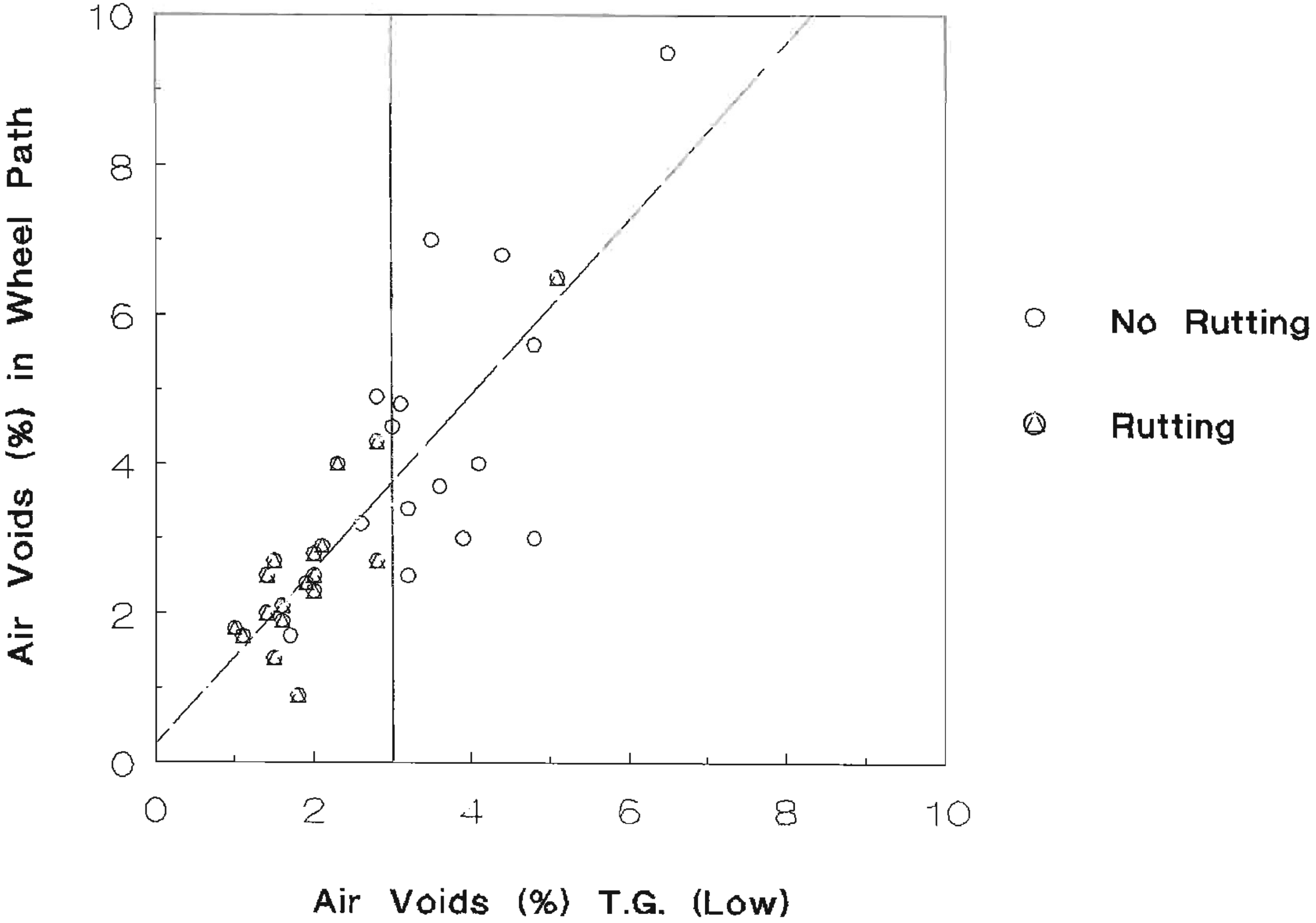


Figure 4 - Air Voids in Wheel Path
Versus Air Voids T.G. (Low)



High Effort: $Y = 1.4X + 1.0$ $r^2 = 0.57$ [Eqn. 1]
Low Effort: $Y = 1.2X + 0.3$ $r^2 = 0.67$ [Eqn. 2]

where:

Y = air voids in the wheel path (%),
X = air voids from the sample recompacted in the gyratory (%), and
r^2= the coefficient of determination.

For an ideal relationship, the slope should have been 1.0 and the intercept should have been 0.0. For each regression, there was nearly an ideal 1:1 correlation between the air voids recompacted in the Texas gyratory and the air voids in the wheel path. However, since the recompacted samples that used the high effort had an intercept of 1.0% air voids, the air voids were approximately 1.0% lower than the air voids in the wheel path. The lower compactive effort had a very small intercept, 0.3, which was much closer to the ideal intercept of 0.0.

Laboratory Compactive Effort and Traffic Loading. It was hypothesized that separating heavier and lighter traffic loadings might provide better correlation with different gyratory compactive efforts. Traffic was divided at an equivalent daily 18-kip load application (EDLA) of 400, which corresponded to 1.5 million equivalent single axle loads (ESALs) for a 10-year design. Results used to test the hypothesis are shown on Table 4.

Table 4. Correlation of Air Voids in the Wheel Path with Recompacted Air Voids for Different Traffic Loadings and Compactive Efforts

Traffic Loading	Compactive Effort	Linear Regression	r^2
Light	Low	$Y = 1.2X + 0.6$	0.68
Light	High	$Y = 1.4X + 1.3$	0.63
Heavy	Low	$Y = 1.1X - 0.1$	0.78
Heavy	High	$Y = 0.9X + 1.2$	0.36

X and Y were defined in Equations 1 and 2.

The air voids from low compactive effort excellently modeled the air voids in the wheel path for the heavy traffic since the intercept was close to zero and the slope was close to one. Regardless of traffic, the air voids from the high compactive effort were consistently more than 1.0% lower than the air voids in the wheel path.

For light traffic, the air voids from the low gyratory effort under-predicted the air voids in the wheel path by 0.6%. A compactive effort even lower than the low effort might have better modeled the air voids in the wheel path.

<u>Critical Air Voids.</u> The critical air voids were defined as the air voids on the threshold of representing a rutting-susceptible mix. When recompacted air voids were less than 2.0% using the high effort of gyratory compaction, there was a high probability of the pavement rutting; when air voids were greater than or equal to 2.0%, there was a high probability of the pavement not rutting (Fig. 3). When recompacted air voids were less than 3.0% using the low effort of gyratory compaction,

there was a high probability of the pavement rutting; when air voids were greater than or equal to 3.0%, there was a high probability of the pavement not rutting (Fig. 4). The critical air voids were not a function of traffic.

The correlation of the air voids obtained from the high compactive effort with the low effort of the Texas gyratory (Fig. 5) was:

$$Y = 1.2X + 0.6 \qquad r^2 = 0.85 \qquad \text{[Eqn. 3]}$$

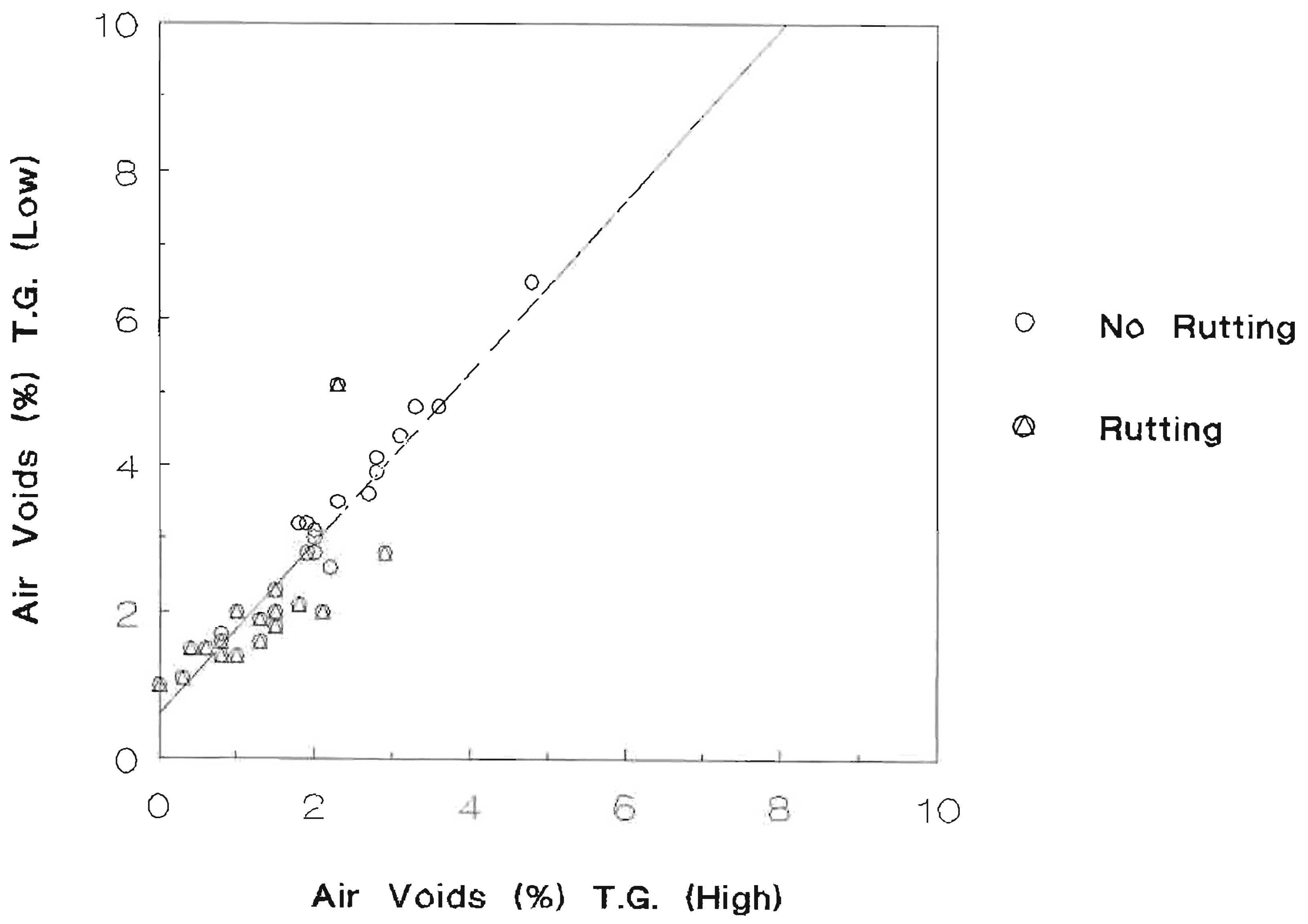
where:

Y – air voids from the sample recompacted with the low gyratory effort (%),
X = air voids from the sample recompacted with the high gyratory effort (%), and
r^2= the coefficient of determination.

The correlation given in Equation 3 validated the difference between the critical 2.0% and 3.0% air voids which used the high and low gyratory efforts, respectively.

<u>Sensitivity of Air Voids to Compactive Effort.</u> A design laboratory compactive effort is often used to simulate the air voids in the pavement after 2 to 3 years of service. A refusal or terminal compactive effort has been proposed to measure the ultimate air voids a pavement will have under traffic loading. The relationship of air voids obtained from the high and low gyratory compactive efforts was examined to determine if there was a relationship with the refusal concept. For sites that did not rut, the relationship between the high and low gyratory efforts was:

Figure 5 - Air Voids T.G. (Low)
Versus Air Voids T.G. (High)



$$Y = 0.8X - 0.5 \qquad r^2 = 0.95 \qquad \text{[Eqn. 4]}$$

where:

Y = air voids from the sample recompacted with the high gyratory effort (%),
X = air voids from the sample recompacted with the low gyratory effort (%), and
r^2 = the coefficient of determination.

Equation 4 indicated that mixes from good performing pavements designed at 4.0% air voids with the low compactive effort would have approximately 2.7% air voids if recompacted using the high gyratory effort. After selecting optimum asphalt content with the low gyratory effort, an additional sample at the same asphalt content compacted with the high effort should have air voids of no less than 2.7%.

Summary. Air voids of laboratory compacted samples using the Texas gyratory compactor modeled the air voids in the wheel path as a function of laboratory compactive effort. When compacted voids fell below 3.0% for the low gyratory effort and 2.0% for the high effort, the probability of rutting increased significantly. The air voids from the low gyratory effort modeled the voids in the wheel path of heavy traffic, and an effort lower than the low gyratory effort would probably have better modeled the low traffic.

VIII. PAVEMENT PERFORMANCE AND FIELD VERIFICATION DATA

Field Verification Data. Field verification testing was defined as testing of loose hot mix asphalt produced in the plant, then compacted in the laboratory. It was desired to correlate the original field verification air voids versus pavement performance. Unfortunately, the data was collected for only 23 sites and was sparse and incomplete. The samples were designed and field verified with the Colorado version of the California kneading compaction procedure (AASHTO T 247) which is an effort equivalent to the low Texas gyratory effort. The data is summarized on Table 5. Nine sites had field verification air voids over 3.0% and zero rutted. Nine sites under 3.0% air voids rutted; however, there were five sites under 3.0% air voids that did not rut.

When field verification air voids were below 3%, the pavement performance was related to Hveem stability. The five sites with field verification air voids under 3.0% that did not rut maintained a Hveem stability value greater than 40 or had very low traffic. The nine sites which had less than 3% air voids that did rut had Hveem stability values lower than 40. Acceptable Hveem stability values were a function of traffic; ie., a high Hveem stability value was required to prevent rutting on high traffic pavements and a low Hveem stability would prevent rutting on low trafficked pavements.

Table 5. Summary of Field Verification Data for This Study

		Field Verif. Air Voids	
		> 3%	< 3%
Rutting	Acceptable	9	5
	Unacceptable	0	9

<u>Recompacted Cores.</u> The cores recompacted with the Texas gyratory for this study could be considered field verification samples. It should be noted that the critical air voids for the high compactive effort was

2.0%, and the critical air voids for the low compactive effort was 3.0%. If the low compactive effort was used and the mix was designed at 4.0% air voids, then a drop of 1.0% air voids in the project-produced material would be at the rutting threshold. However, if the high compactive effort was used, then a drop of 2.0% air voids from the design value in the project produced material would be required to reach the rutting threshold. The high compactive effort provides a larger "buffer" against rutting. It must be noted that the optimum asphalt content should also be balanced with considerations for moisture susceptibility.

1986 Colorado Study (3). In a performance study of 75 Colorado pavements in 1986 (3), the field verification data was reported when available. These projects were designed and field verified with a laboratory compactive effort equivalent to the low gyratory effort. In reanalyzing the data for this study, only 41 sites were included because 34 sites had insufficient data, were too new, or were sand mixes. Comparison of field verification data is shown on Table 6.

When field verification air voids were greater than 3%, there was a high probability that the pavement performed well. The only site to have field verification air voids greater than 3% with unacceptable levels of rutting had very severe longitudinal and alligator cracking. It is possible that the rutting was caused by a subgrade failure and a brittle HMA pavement.

Table 6. Summary of Field Verification Data for 1986 Study (3)

		Field Verif. Air Voids	
		> 3%	< 3%
Rutting	Acceptable	21	11
	Unacceptable	1	8

When air voids were less than 3%, nine of the 11 acceptable sites had Hveem stability values greater than or equal to 35. Seven of the eight unacceptable sites had Hveem stability values less than 35. When field verification air voids were less than 3%, the Hveem stability as a function of traffic provided a good indication of pavement performance. A flat Hveem stability vs. air voids curve is very desirable.

D'Angelo and Ferragut Study (10). It is common for samples compacted in the laboratory that were produced from an HMA plant to have lower laboratory compacted air voids than the samples prepared in the laboratory. In 17 projects reported by D'Angelo and Ferragut (10), 13 projects had project-produced material with lower air voids than the design. Eight projects, 47%, had reductions in air voids greater than 1.0%, indicating a mix very susceptible to rutting if the optimum asphalt content was selected at 4.0% air voids and there was a low laboratory compactive effort. Five projects, 29%, had reductions in air voids greater than 2.0%, indicating a mix very susceptible to rutting if the design was at 4.0% air voids and there was a high or low laboratory compactive effort.

__Summary.__ It is critical to control the mix in the field because of the potential drop in air voids. When field verification air voids were greater than 3% using the low gyratory effort or equivalent, there was a high probability that the pavement would not rut. When using the high gyratory effort, air voids greater than 2% were necessary to minimize the chance of rutting. When air voids were below the threshold values, the Hveem stability provided a good indication of pavement performance.

Because of inherent variability of the laboratory compacted air voids between the mix design and construction, field verification should be performed and the adjustments made accordingly. The high effort should be used for heavy traffic and the low effort should be used for light traffic. Since high traffic roads are more likely to rut, the high traffic roads should have a higher factor of safety. Moisture susceptibility testing is also critical.

IX. RELATIONSHIPS OF PAVEMENT RUTTING AND HVEEM STABILITY

__Hveem Stability and Pavement Performance.__ Although air voids in the pavement closely related to rutting performance, and air voids of recompacted samples closely related to air voids in the pavement, it was considered critical to have an indication of the strength of the hot mix asphalt. The strength property used to evaluate the material tested in this study was the Hveem stability.

The use of Hveem stability as a "go, no-go" specification did have some correlation. The values of Hveem stability in ranked order and their relationship to the pavement performance are shown on Figs. 6 and 7. Fig. 6 has results of the Hveem stabilometer utilizing the high compactive effort and Fig. 7 with the low compactive effort.

The generally accepted criteria for Hveem stability varies with traffic loading as recommended by the Federal Highway Administration's Technical Advisory (FHWA TA) (11). The relationship of the FHWA stability criteria and the criteria indicated by Figs. 6 and 7 are summarized on Table 7. It should be noted that the guidance set forth in the FHWA TA was used to assist in selecting of stability criteria, since the stability data was limited and scattered.

Traffic levels defined by the FHWA were based upon cumulative ESALs. High traffic was defined as greater than 1 million ESALs and low traffic was less than 10,000 ESALs. The traffic was defined for this study with EDLA. Heavy traffic was greater than an EDLA of 400, and light traffic was less than an EDLA of 50.

Table 7. Recommended "Go, No-Go" Criteria for Hveem Stability

	Heavy Traffic	Medium Traffic	Light Traffic
FHWA-TA (7)	37	35	30
TGH	37	30	28
TGL	40	35	31

TGL - Low compactive effort on the Texas gyratory
TGH - High compactive effort on the Texas gyratory

Figure 6

RANKED ORDER OF HVEEM STABILITY T.G. (HIGH)

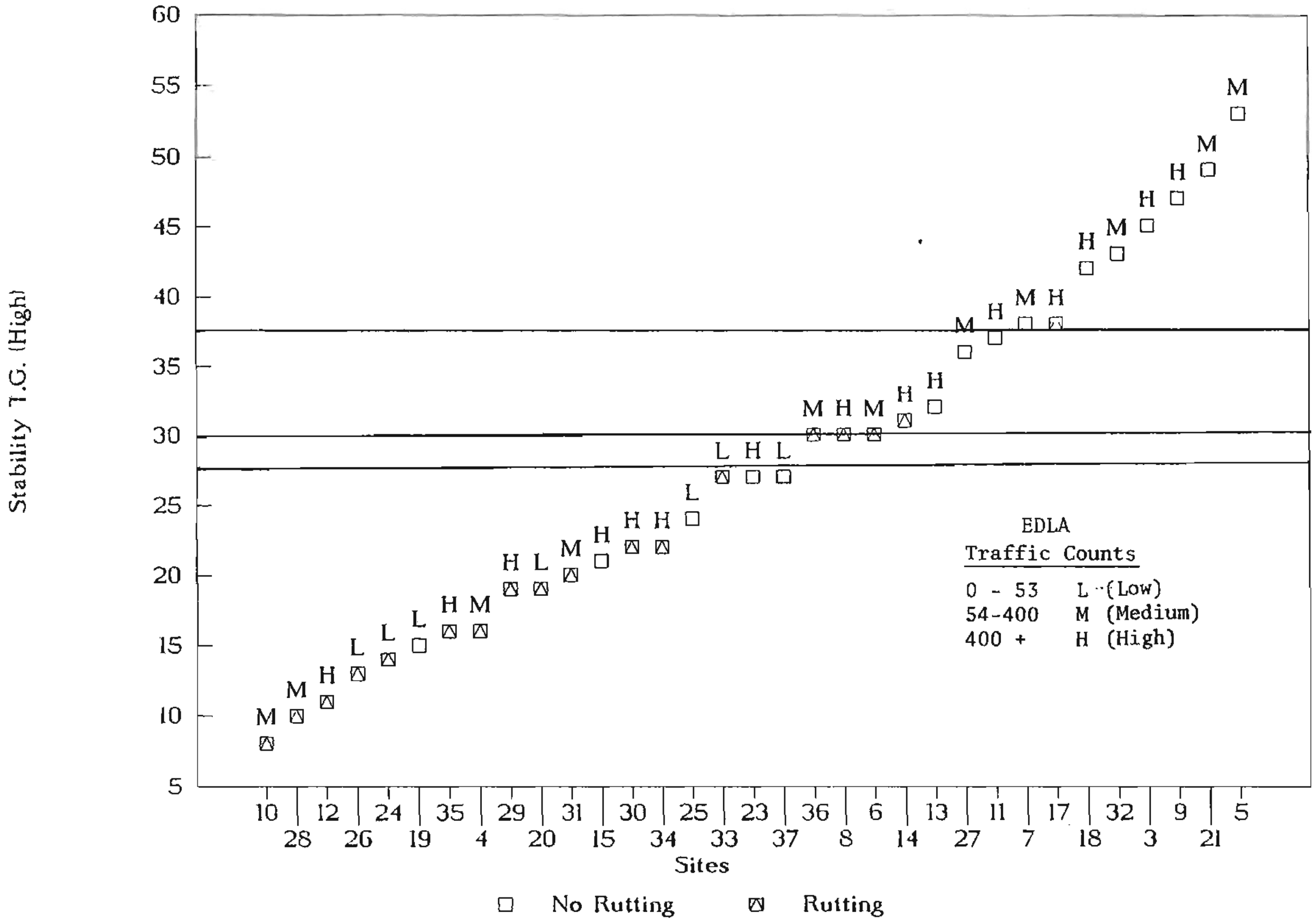
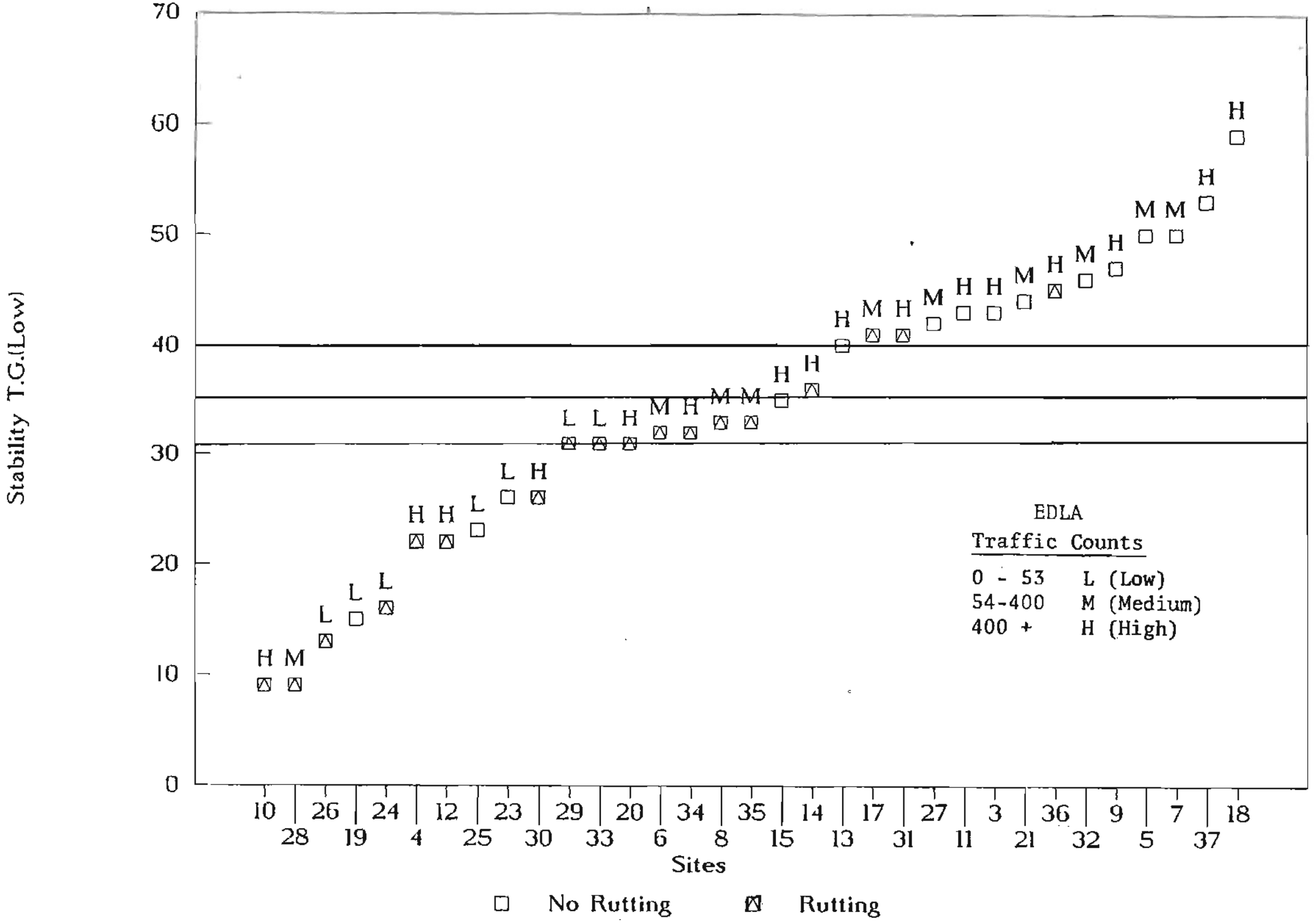


Figure 7

RANKED ORDER OF HVEEM STABILITY T.G. (LOW)



Based on Figs. 6 and 7, there was a correlation between Hveem stability and pavement performance. Additionally, there was a correlation for using different stability values for different levels of traffic loadings.

Hveem Stability and Actual Pavement Rutting Depth. Direct correlation of Hveem stability with both actual rutting depth and air voids in the wheel path was very poor. The use of Hveem stability could not be used to predict actual pavement rutting depths. The coefficients of determination and the probability of a relationship were very low, even when different levels of traffic were considered as shown on Table 8. Traffic levels used on Table 8 were defined identically to those used on Table 4.

Table 8. Coefficients of Determination, r^2, for Hveem Stability Versus Air Voids in the Wheel Path and Rutting Depth

Hveem Stability Versus:	All Traffic		High Traffic		Low Traffic	
	TGL	TGH	TGL	TGH	TGL	TGH
Air Voids In the Wheel Path	0.17	0.22	0.26	0.32	0.22	0.20
Rutting Depth	0.24	0.31	0.47	0.41	0.23	0.27

TGL - Low compactive effort on the Texas gyratory
TGH - High compactive effort on the Texas gyratory

Hveem Stability and Laboratory Compactive Effort. It should be noticed that the stability was a function of the compactive effort; the higher the compactive effort, the lower the stability for identical samples. Based on data used for this study, the relationship was:

$$Y = 0.9X + 9.8 \qquad r^2 = 0.68 \qquad [\text{Eqn. } 5]$$

where:

Y = Hveem stability using the low gyratory compactive effort,
X = Hveem stability using the high gyratory compactive effort (ASTM D 4013), and
r^2= the coefficient of determination.

It may appear that the FHWA recommendation and the values from this study were different as shown on Table 7. The FHWA recommendation used the same laboratory compactive efforts for each level of traffic loading. When laboratory compactive efforts were used that matched the traffic levels, the recommended Hveem stabilometer results would have been the same.

Sensitivity of Stability to Compactive Effort. The relationship of Hveem stability obtained from the high and low gyratory compactive effort for sites that did not rut was:

$$Y = 1.3X - 18.2 \qquad r^2 = 0.51 \qquad [\text{Eqn. } 6]$$

where:

Y = Hveem stability using the high gyratory compactive effort,
X = Hveem stability using the low gyratory compactive effort (ASTM D 4013), and
r^2= the coefficient of determination.

Equation 6 indicated that mixes from good performing pavements designed with a Hveem stability of 37 using the low compactive effort would have a stability of approximately 30 if recompacted using the high gyratory effort. After selecting optimum asphalt content with the low gyratory effort, an additional sample at the same asphalt content compacted with the high effort should have a stability of no less than 30.

Summary. There does need to be some measure of the strength of the HMA. There was no correlation with actual pavement rutting depth and Hveem stability; however, using Hveem stability as a "go, no-go" specification did seem appropriate. Specified Hveem stability values should vary with different traffic loadings.

X. AGGREGATE AND ASPHALT CEMENT RESULTS

Gradation. The gradations determined for each of the lifts of significance are plotted with the Texas reference gradation line in the Appendix. The Texas reference gradation line was developed by Mr. James Scherocman, Consultant, and Dr. Thomas Kennedy, University of Texas at Austin. The reference line was drawn from the first sieve retaining material to the percent passing the No. 200 sieve, P200.

Gradations that plotted above or below the Texas reference gradation line were defined as fine or coarse, respectively. The gradations of the extracted samples from each site are plotted in Appendix A. Gradations plotting along the reference line were defined as straight. There was no correlation between rutting performance and the location of the gradation with respect to the maximum density line. However, seven of the 11 sites with straight gradations did rut. Hot mix asphalt with a gradation that followed the maximum density line had more of a tendency to rut.

When a mix had a hump on the No. 30 sieve or more than 30% passed the No. 30 sieve, the mix was characterized as tender (12). Nine gradations had the tender characteristics but only three rutted. Four tender mixes were placed on high traffic sites, and two rutted. There was not a good correlation with performance and percent of aggregate passing the No. 30 sieve.

It was often considered that high quantities of coarse material provided a better chance to resist rutting. Coarse material was measured by the percent retained on the No. 4 sieve, P4. For all sites and only high or low traffic sites, there was poor correlation between amount of coarse material and rutting performance. There were sites with high traffic which had over 75% P4 and performed well.

<u>Aggregate Quality.</u> The coarse aggregates with two or more fractured faces and the angularity of the fine aggregates were measured. For coarse particles with less than 80% fractured faces, there were no sites that performed well. However, there were 14 out of 27 sites with more than 80% fractured faces that did not rut. There was not good correlation with the angularity of the fine aggregate and rutting performance.

<u>Asphalt Cement.</u> Asphalt contents were compared with performance, along with the relationship to optimum; and no relationship was discovered. There were sites with no rutting and very high asphalt contents and sites with

rutting with low asphalt contents. Asphalt cement testing included the penetration at 25°C (77°F). The shear rheometer testing will be performed. Results of penetration testing showed no correlation to actual pavement rutting depths.

Summary. Gradation, aggregate quality and asphalt cement quality all were believed to be of primary importance to creating a quality hot mix asphalt pavement. If there were less than 80% fractured faces, there was a tendency towards rutting. If a gradation followed a straight line, there was more of a tendency toward rutting.

Unfortunately, there was little correlation obtained between the component aggregate and asphalt cement properties and actual pavement performance. Placing hot mix asphalt in the field that recompacted to a lower air void level than the mix design was a more dominating factor in the rutting performance of these mixes than the component properties of the mix. Therefore, field verification should be performed and the necessary adjustments made to the mix.

XI. THE FOUR BEST PAVEMENTS

The four sites with the highest traffic and excellent rutting resistance could be considered model pavements, from a rutting perspective, which all pavements in the future should resemble. Although these pavements did not rut, several did have a high percentage of cracking (thermal and age hardening). As shown on Table 9, these sites did have common characteristics.

Table 9. Common Characteristics of the Four Best Pavements

Site	Age Yrs.	AC%	Stability		Air Voids(%)		P4	Grad. Type
			Design	Field	Design	Field		
3		5.4	38	37	4.0	3.6	67	Fine
9	9	5.2	40	39	4.0	3.8	60	Coarse
11	8	6.1	43	48	4.0	3.3	58	Fine
13	6	5.0	36	37	3.4	3.4	55	Fine

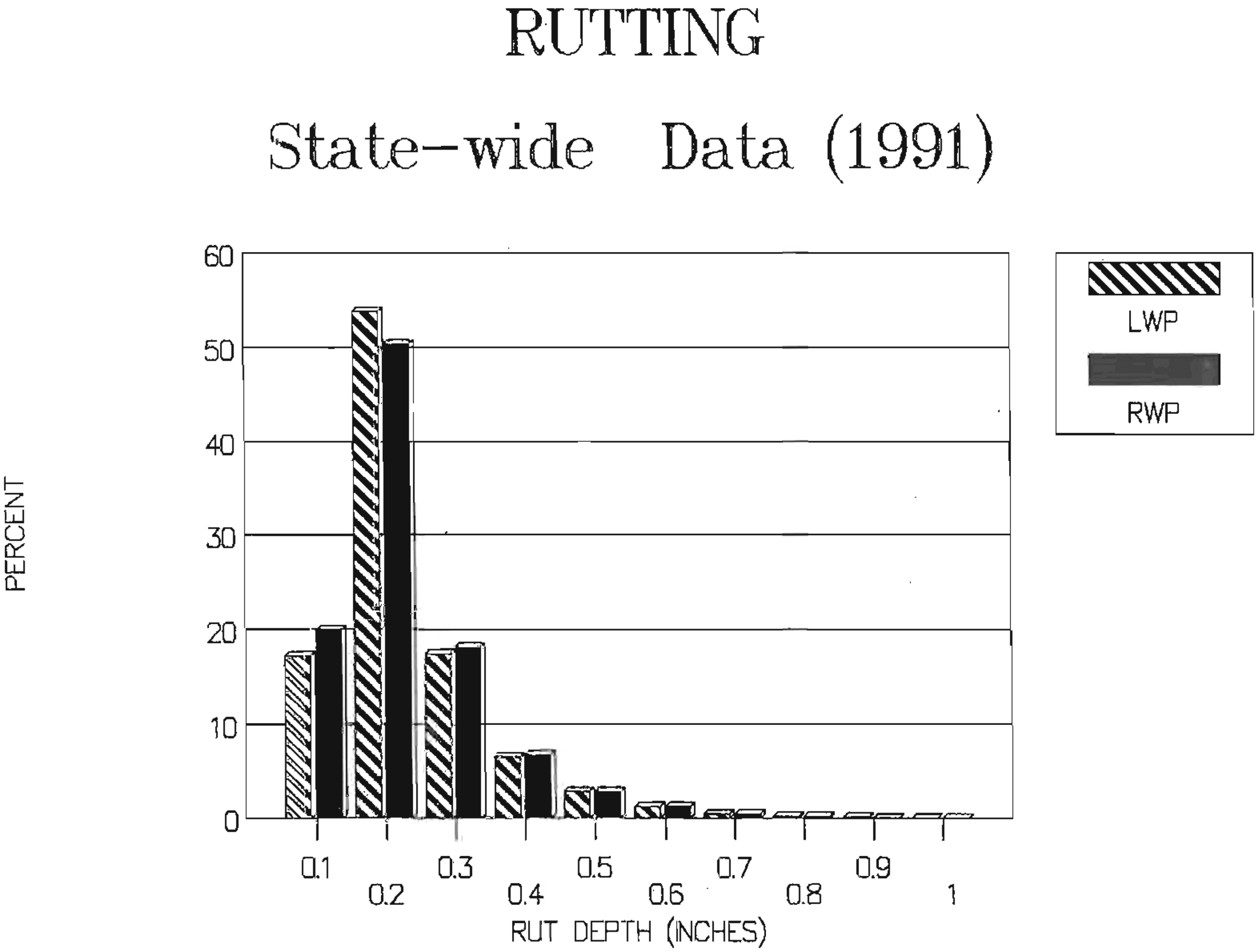
It is most noticeable that both the field verification stability and air voids closely matched the design values. The best sites did contain fine gradations (Sites 3, 11, 13) with high P4 (Site 3), a "tender" mix (Site 13), and even a high asphalt content (Site 11).

XII. COMMENTARY

The overall condition of rutting in Colorado is shown on Fig. 8. Since rutting depths of less than 5 mm (0.2 in.) are considered acceptable, rutting is not a consistent problem in Colorado. Unfortunately, when rutting does occur, there is a tendency to sensationalize rutting to exist as a statewide problem rather than the few isolated projects that really have the problem.

The primary reason for rutting in the cases investigated was that the material produced for the project did not meet the mix design requirements. The first step to eliminate rutting is to perform field verification of the project-produced mix. Even if elaborate tests, such as the SHRP or European equipment, are incorporated into the design process, the equipment will do little good if the project-produced material varies significantly from the mix design.

FIGURE 8
A SUMMARY OF RUTTING DEPTHS FOR 1991



There were numerous sites not selected; unfortunately, a few that were selected had rutted from subgrade failure. Great care must be exercised to design proper pavement thickness and to prepare a subgrade. Subgrade failure often is considered to be a hot mix asphalt failure; the two failures involve completely different mechanisms and materials.

Finally, Colorado has special cold weather loading conditions from abrasion of studded tires and tire chains; this should be examined. An effort should be made to develop a special mix for this unique distress that involves raveling and stripping.

XIII. CONCLUSIONS

1) Air voids in the wheel path correlated with the permanent deformation performance of the pavement. When air voids in the wheel path were less than 3.0%, there was a high probability of rutting from plastic flow. When air voids in the wheel path were greater than or equal to 3.0%, there was a high probability that the pavement would not rut from plastic flow.

2) Air voids from the samples recompacted in the Texas gyratory using the low effort had excellent correlation with the air voids in the wheel path. Also, the correlation was close to ideal since the slope was approximately one and the intercept was approximately zero.

3) The critical air voids that defined the threshold of rutting was 2.0% for the high compactive effort and 3.0% for the low compactive effort. When below the critical voids, there is a high probability of the pavement rutting; and when above the critical voids, there is a high probability of the pavement not rutting.

4) Stability is critical for adequate shear strength in the hot mix asphalt. There was a slight correlation between Hveem stability and the pavement's rutting performance, but the correlation was poor between Hveem stability and the actual rutting depths of a pavement. The Hveem stability requirements should be varied for different levels of traffic loading.

5) To obtain acceptable rutting performance of an HMA pavement, fractured faces of coarse particles and gradation are important. The more fractured faces of the coarse aggregate and the further the gradation from the maximum density line, the lower the probability of rutting.

6) Rutting for the sites analyzed in this study was directly related to the low recompacted air voids, not the component properties of the materials used in the hot mix asphalt.

** Field verification and corresponding adjustment of the hot mix asphalt are the primary recommended preventative actions to be taken to preclude premature rutting due to plastic flow.

** Field verification should include air voids as a minimum. Other properties should be those defined by D'Angelo and Ferragut (10) that also provide consideration to properties relating to durability.

XIV. RECOMMENDATIONS

These recommendations for design and field verification of hot mix asphalt were developed from the results of this study and the FHWA TA T 5040.27 (11). Field verification is the single greatest improvement that can be made.

The CDOT is currently in the second year of a five year plan to provide adequate field verification of HMA using the voids acceptance plan identified by D'Angelo and Ferragut (10). The recommendations are listed as "current" and "future" to account for the full implementation of the voids acceptance specifications.

It should be noted that all recommendations assume proper consideration of the durability characteristics of HMA. Specifications relating to modified Lottman testing (AASHTO T 283) and a minimum voids in the mineral aggregate are currently used by the CDOT.

Current Recommendations. For high traffic, an EDLA greater than 400, the gyratory compactive effort with an end point stress of 1034 kPa (150 psi) should be used. The specified Hveem stability should be a minimum of 37. If air voids of the field verification sample fall below 3.0%, adjustments to the hot mix asphalt should be made. Air voids should never fall below 2.0%.

For medium traffic, an EDLA less than 400, the low gyratory compactive effort (end point stress of 620 kPa (90 psi)) should be used. The specified Hveem stability should be a minimum of 35. Field verification should be performed, and the air voids should never fall below 3.0%.

Future Recommendations. The future recommendations should be implemented when strict enforcement of the void properties can be maintained throughout the duration of a project. It is anticipated that strict enforcement will be achievable after the full implementation of the five year plan to accept HMA with void properties.

For high traffic sites with a strict enforcement of the air voids through field verification, the low gyratory compactive effort (end point stress of 620 kPa (90 psi)) should be used. If specifications do not allow the acceptance of an HMA produced with a laboratory compacted air voids less than 3.0%, then the low gyratory compactive effort would be acceptable. A minimum Hveem stability value of 40 should be specified. The lower effort will allow higher asphalt contents to provide better durability of HMA while the void acceptance plan will ensure resistance to rutting.

For medium traffic sites with a strict enforcement of the air voids through field verification, a slightly lower effort than the low gyratory compactive effort should be used. A study should be performed to identify that compactive effort.

A special light traffic or high altitude design should be considered when the EDLA is less than 50.

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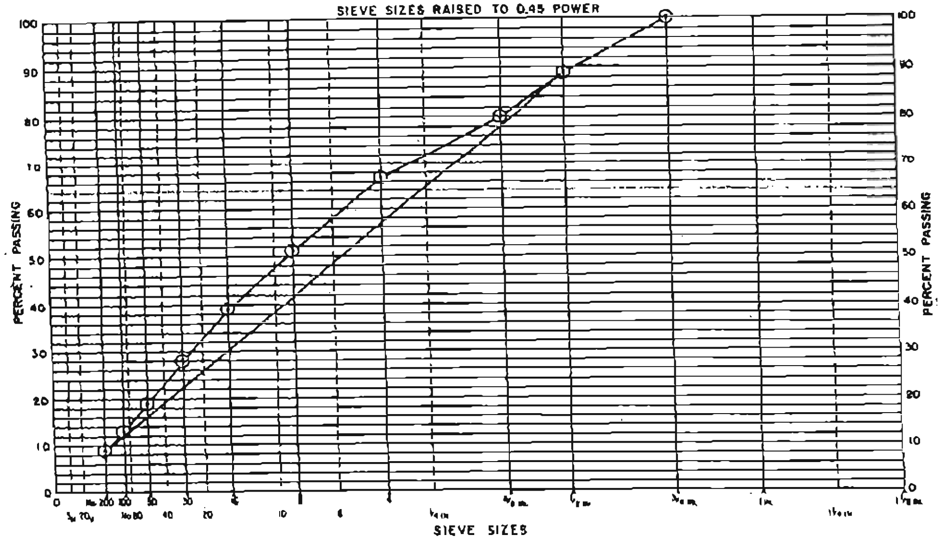
APPENDIX A

Gradations of Hot Mix Asphalt Pavements from All Sites

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



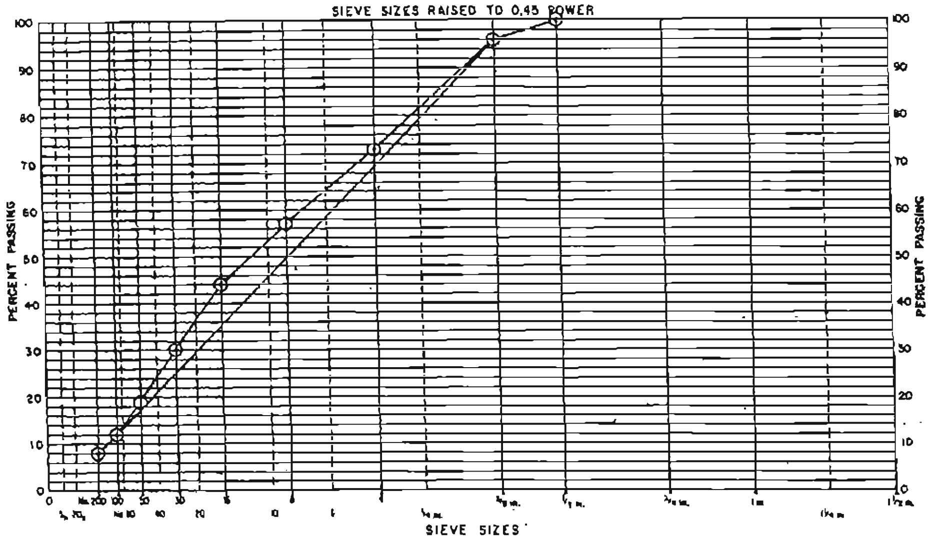
REMARKS:

Site 3

Platteville

Rut Depth: 0.0"

CDOH Form #1087



REMARKS:

Site 5

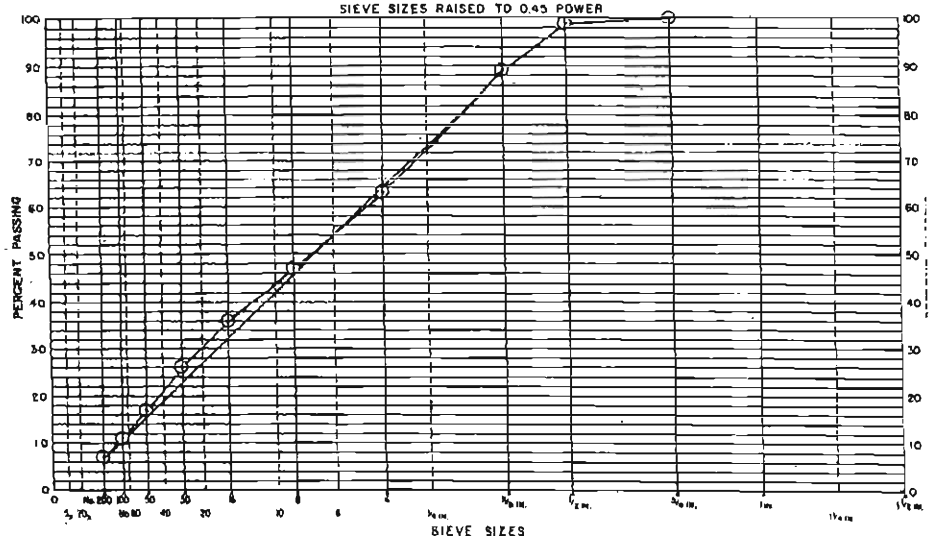
Longmont

Rut Depth: 0.0"

CDOH Form #1087

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



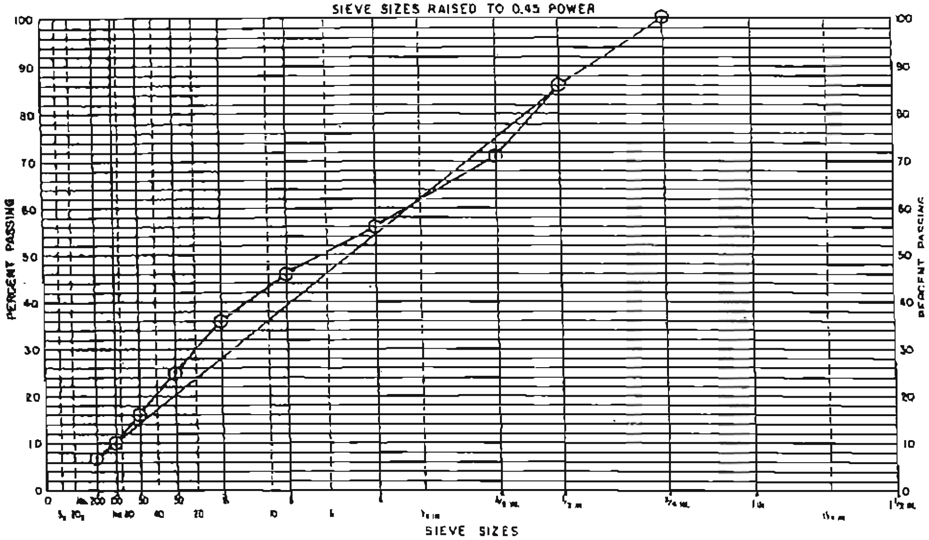
REMARKS:

Site 4

Platteville

Rut Depth: 1.0"

CDOH Form #1087



REMARKS:

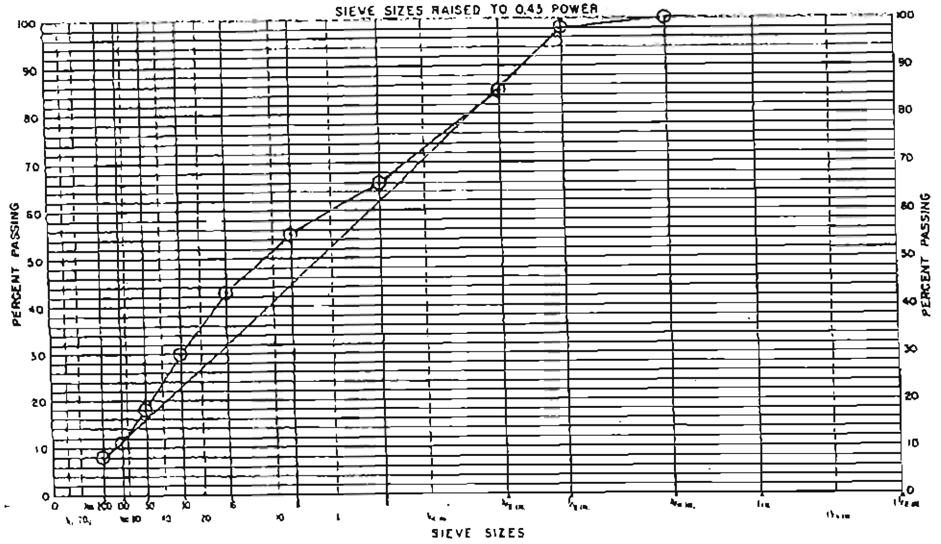
Site 6

Niwot

Rut Depth: 0.4"

CDOH Form #1087

COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART

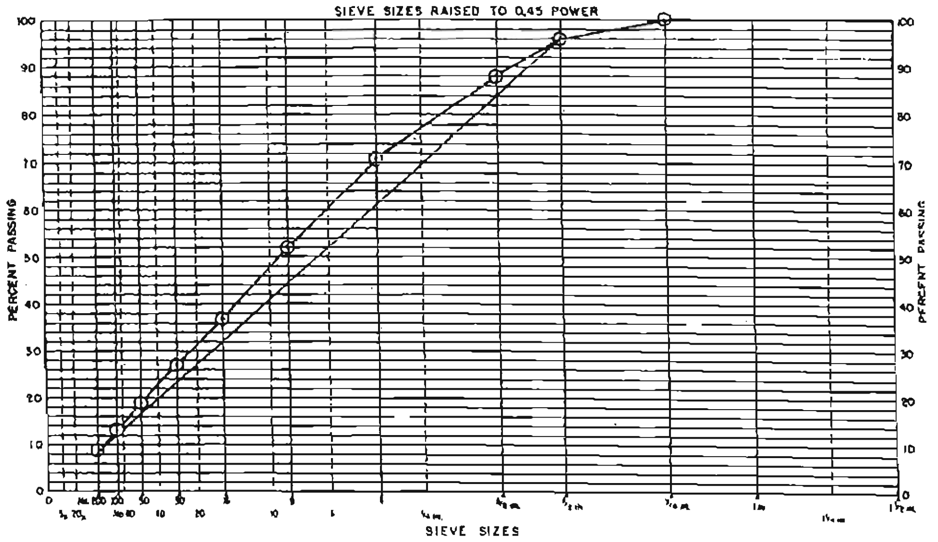


REMARKS:
Site 7
Dacona

Rut Depth: 0.1"

CDOH Form #1007 7/87

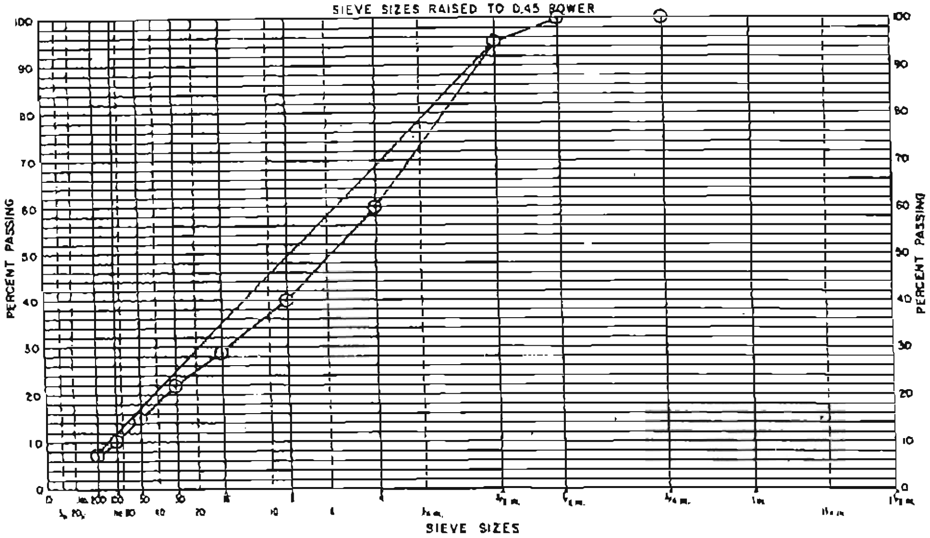
COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART



REMARKS:
Site 8
Fort Lupton

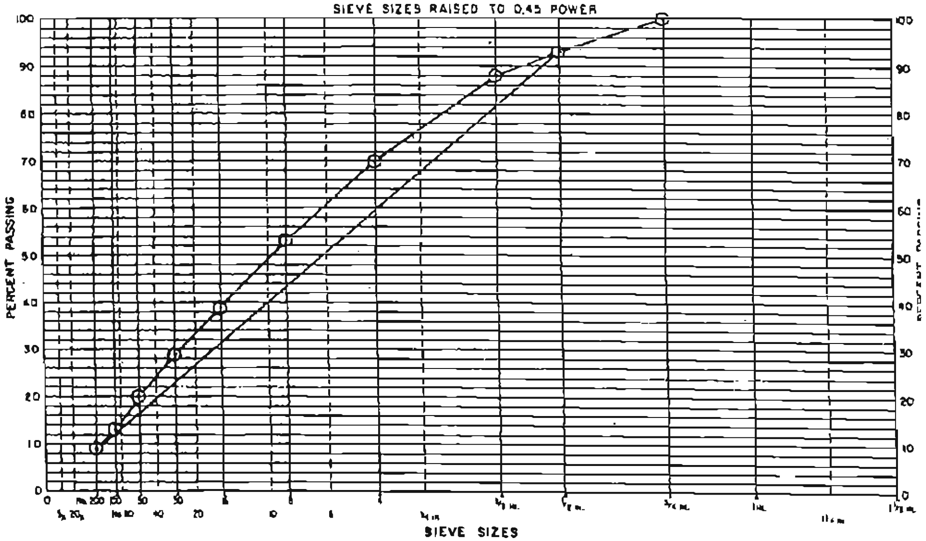
Rut Depth: 0.7"

CDOH Form #1007



REMARKS:
Site 9
Lamar

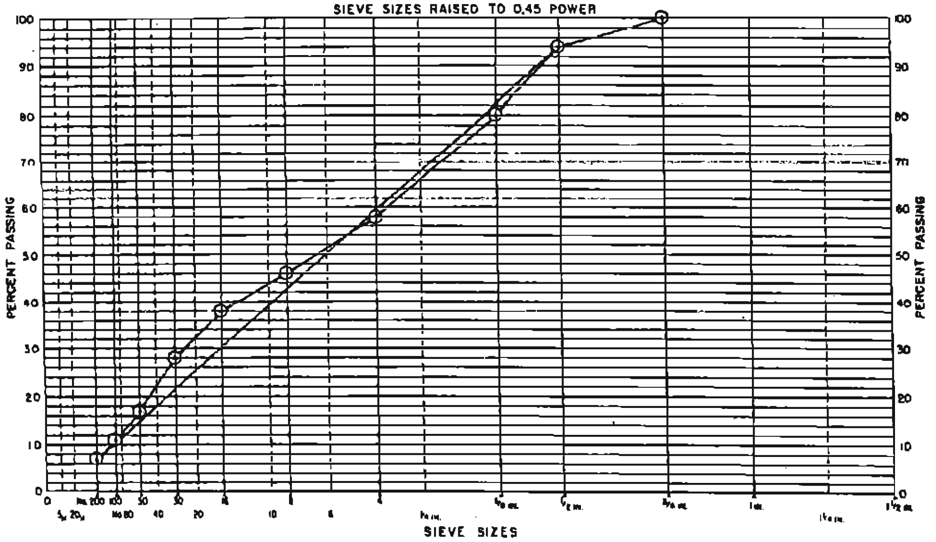
Rut Depth: 0.1"



REMARKS:
Site 10
Lamar

Rut Depth: [illegible]

COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART

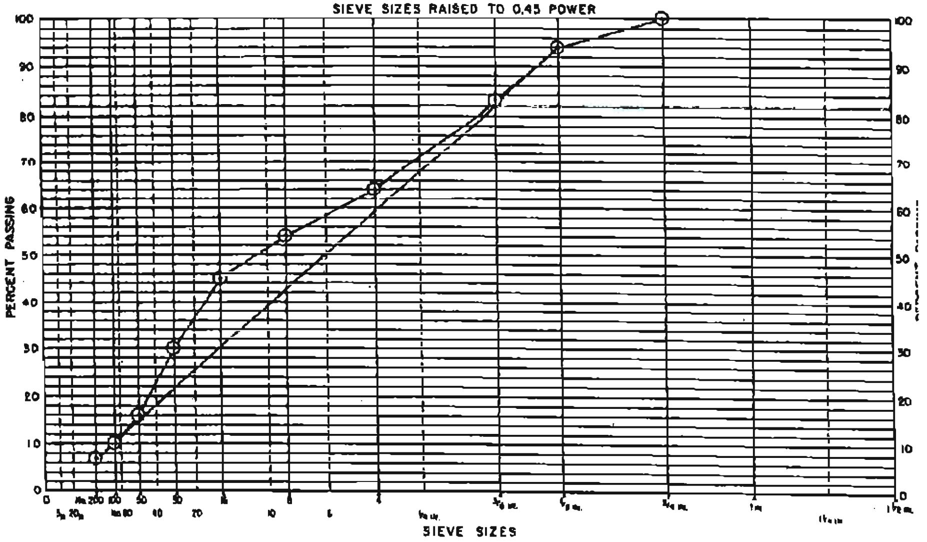


REMARKS:
Site 11
Walsenburg

Rut Depth: 0.0"

CDOH Form #1007

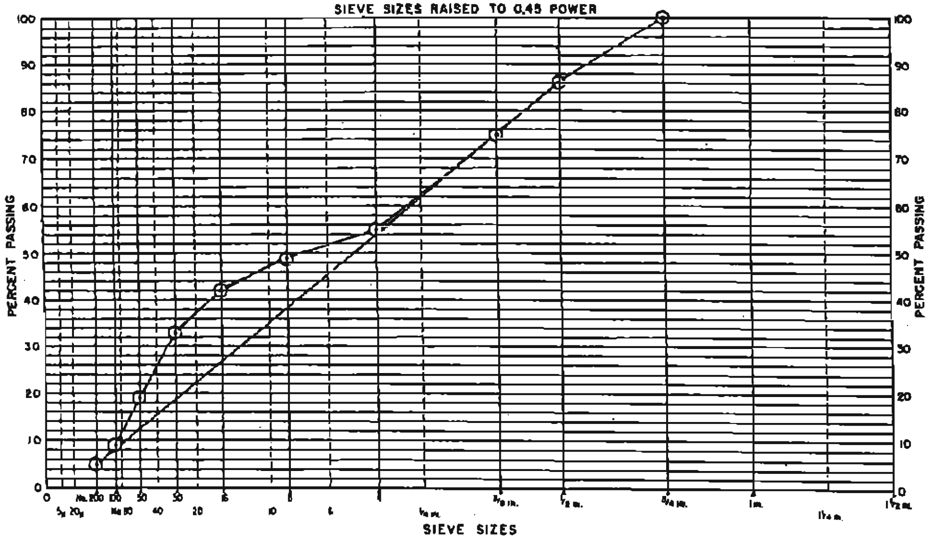
COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART



REMARKS:
Site 12
Walsenburg

Rut Depth: 0.8"

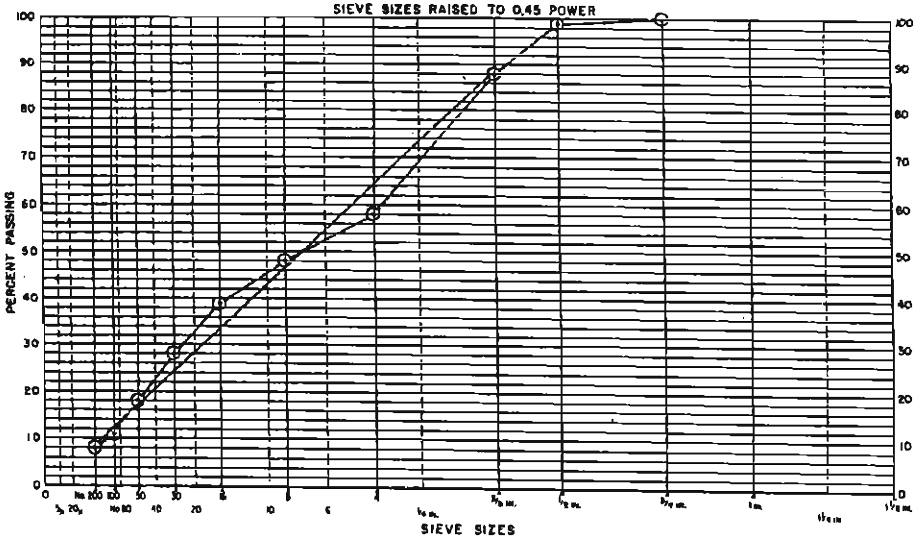
CDOH Form #1007



REMARKS:
Site 13
Burlington

Rut Depth: 0.1"

CDOH Form #1007



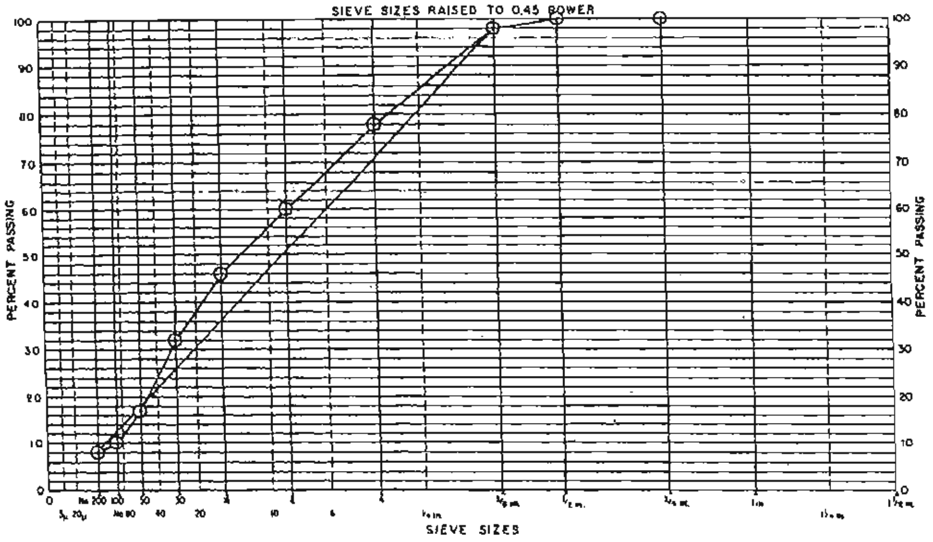
REMARKS:
Site 14
Burlington

Rut Depth: 0.8"

CDOH Form #1007
7/87

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



REMARKS:

Site 15

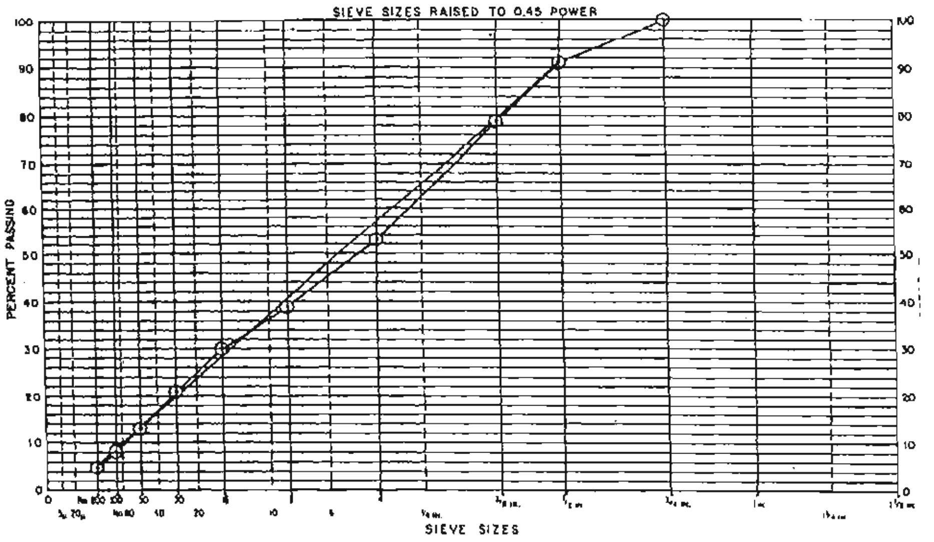
La Junta

Rut Depth: 0.1"

CDOH Form #1007

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



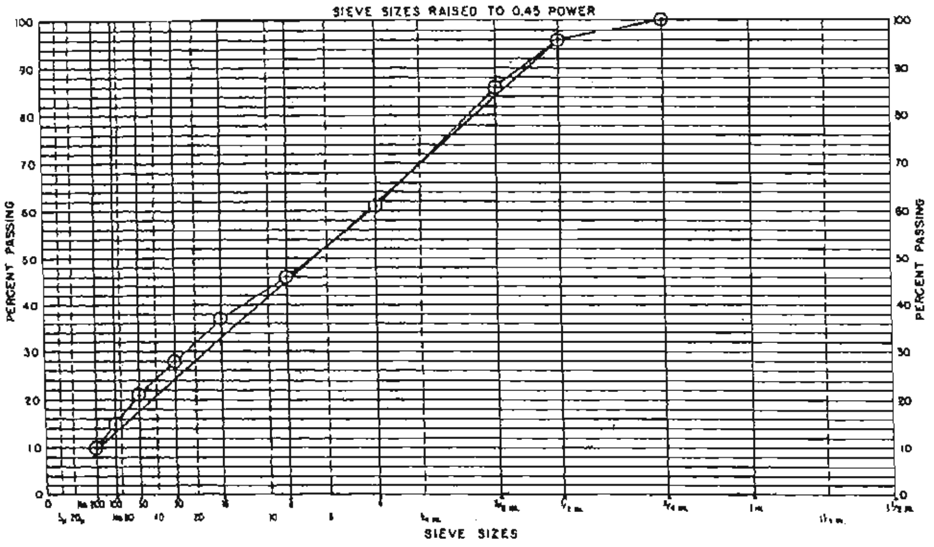
REMARKS:

Site 17

LaVeta Pass

Rut Depth: 0.5"

CDOH Form #1007

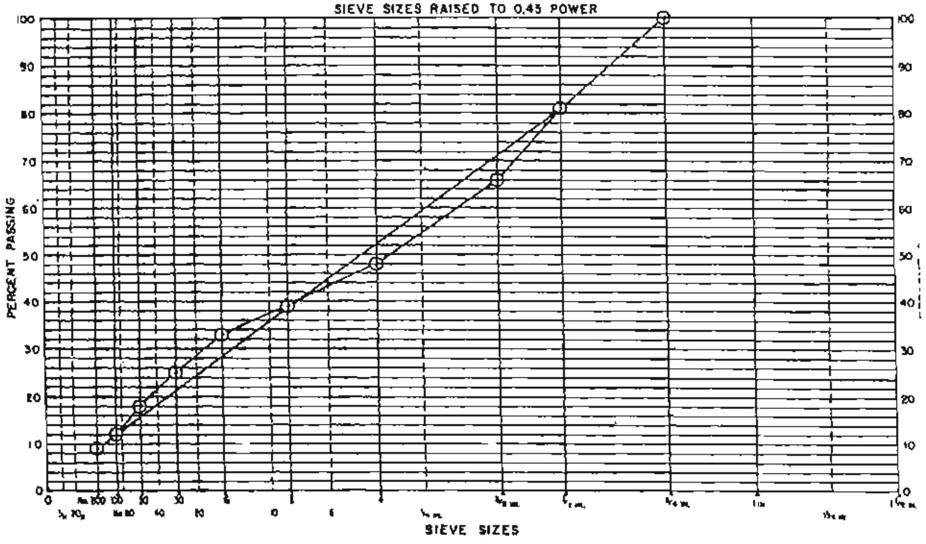


REMARKS:

Site 18

LaVeta Pass

Rut Depth: 0.1"



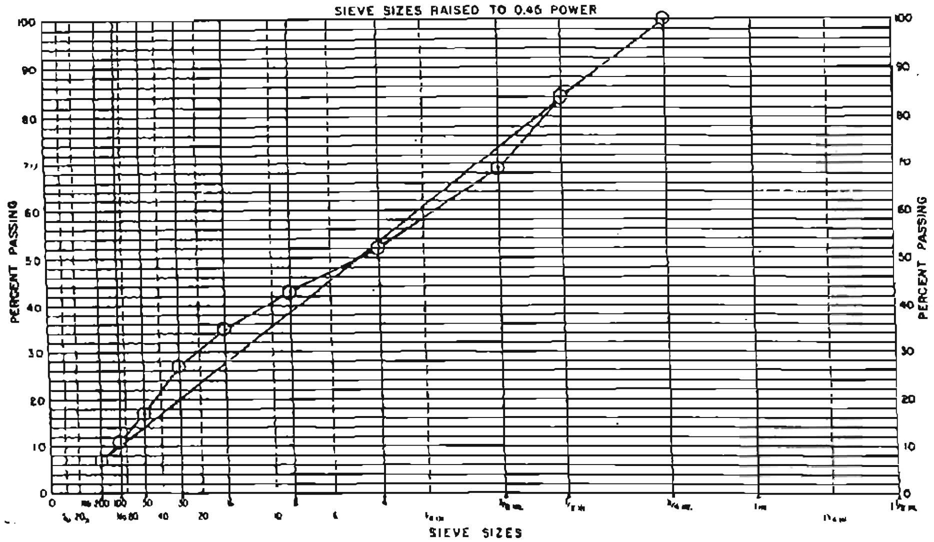
REMARKS:

Site 19

Branson

[illegible]

COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART



REMARKS:

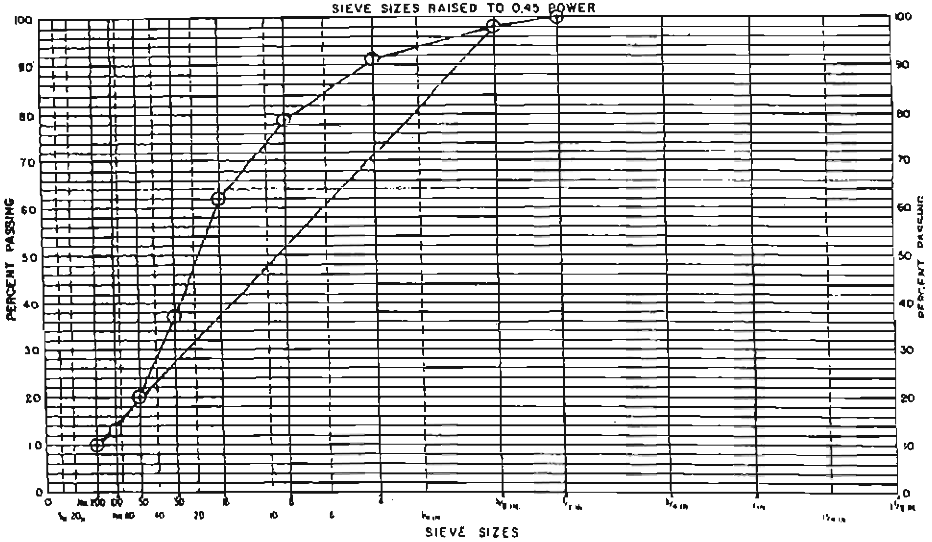
Site 20

Branson

Rut Depth: 0.4"

CDOH Form #1007

COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART



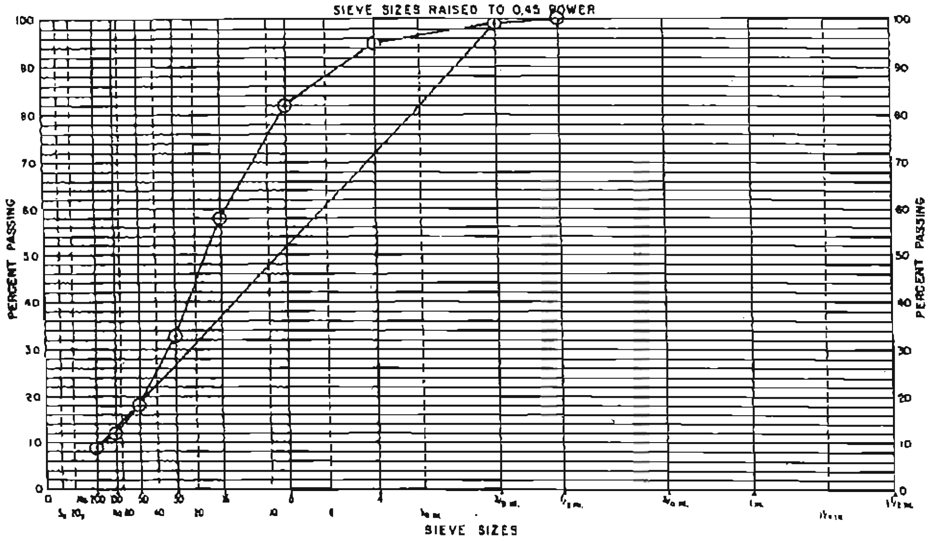
REMARKS:

Site 21

Granada

Rut Depth: 0.0"

CDOH Form #1007



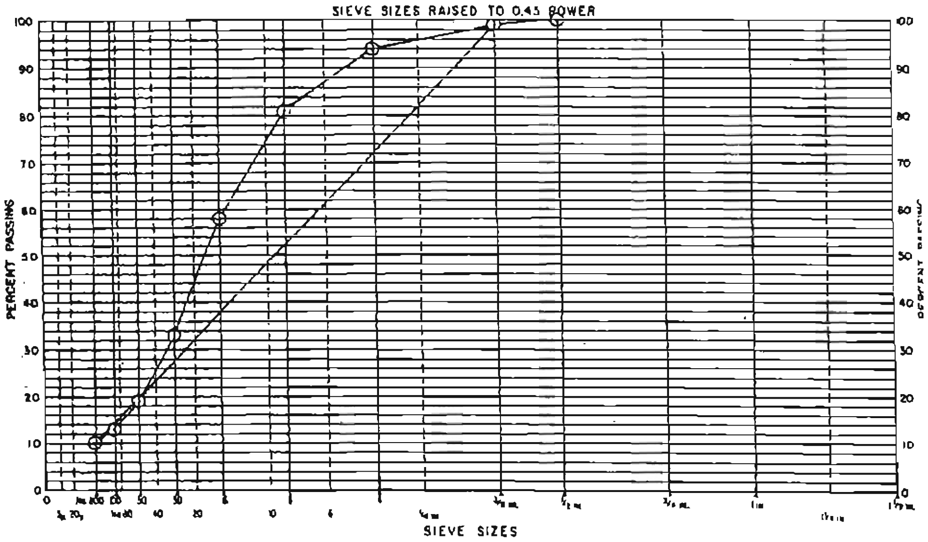
REMARKS:

Site 23

Walsh

Rut Depth: 0.1"

CDOH Form #1007



REMARKS:

Site 24

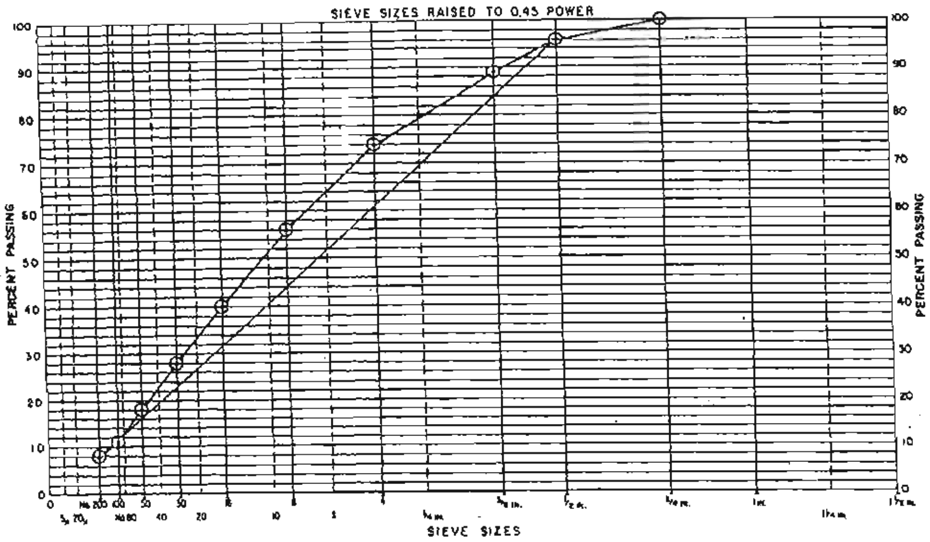
Walsh

Rut Depth: 0.4"

CDOH Form #1007

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



REMARKS:

Site 25

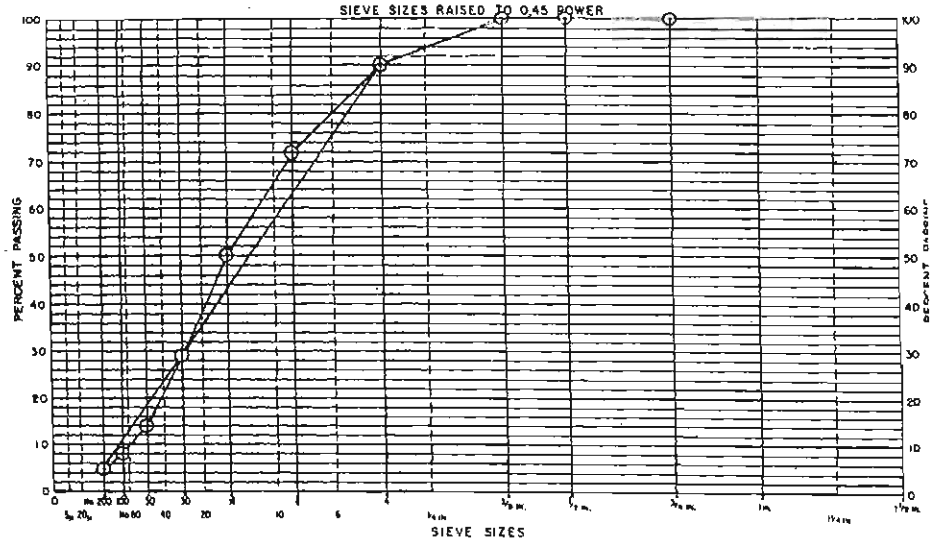
Crook

Rut Depth: 0.1"

CDOH Form #5007

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



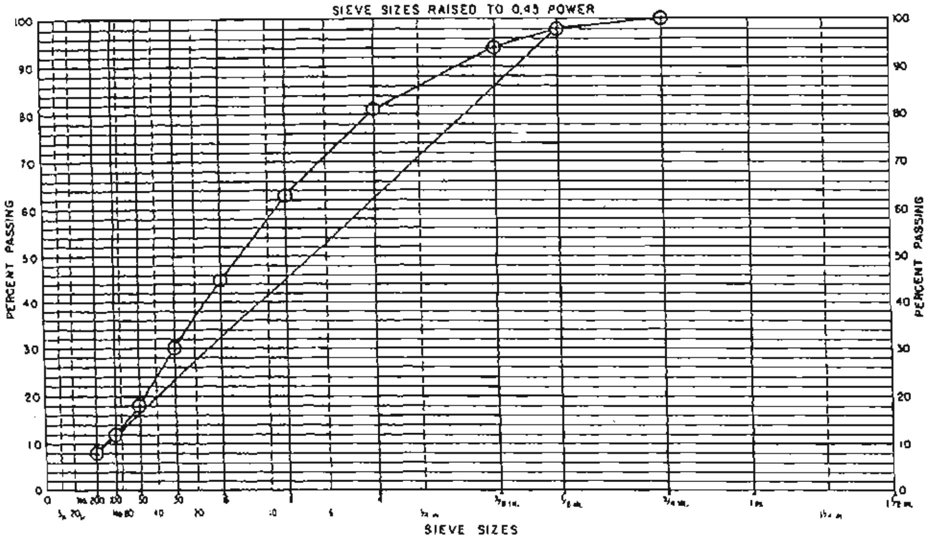
REMARKS:

Site 26

Crook

Rut Depth: 0.5"

CDOH Form #5007

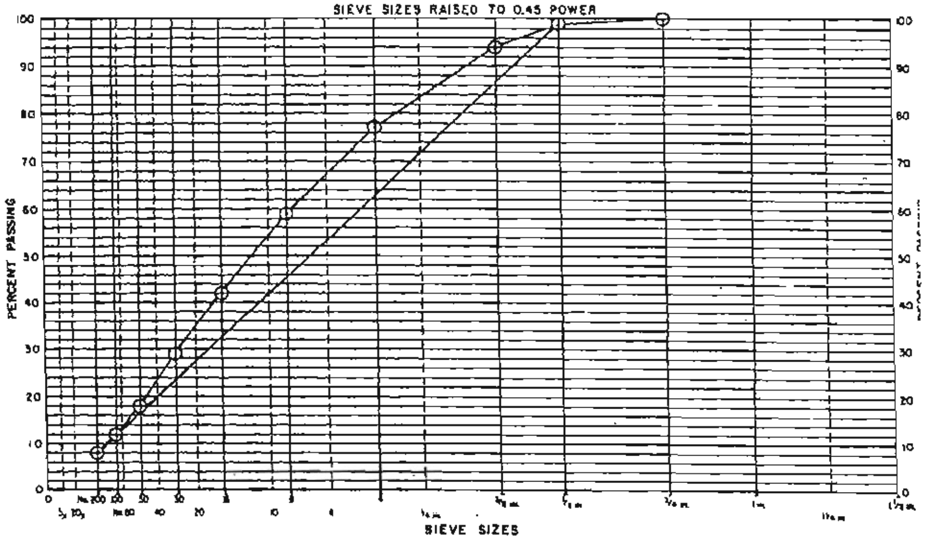


REMARKS:

Site 27

Stoneham

Rut Depth: 0.0"



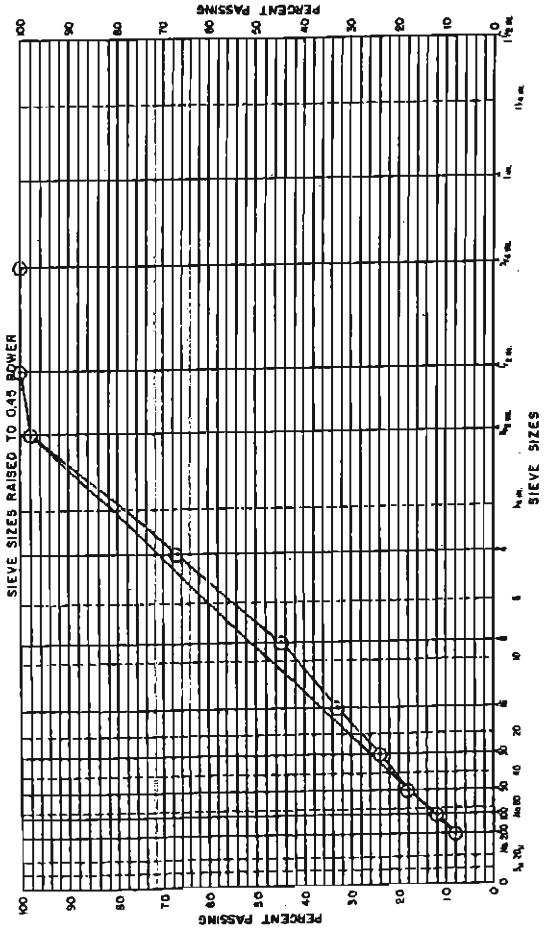
REMARKS:

Site 28

Stoneham

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



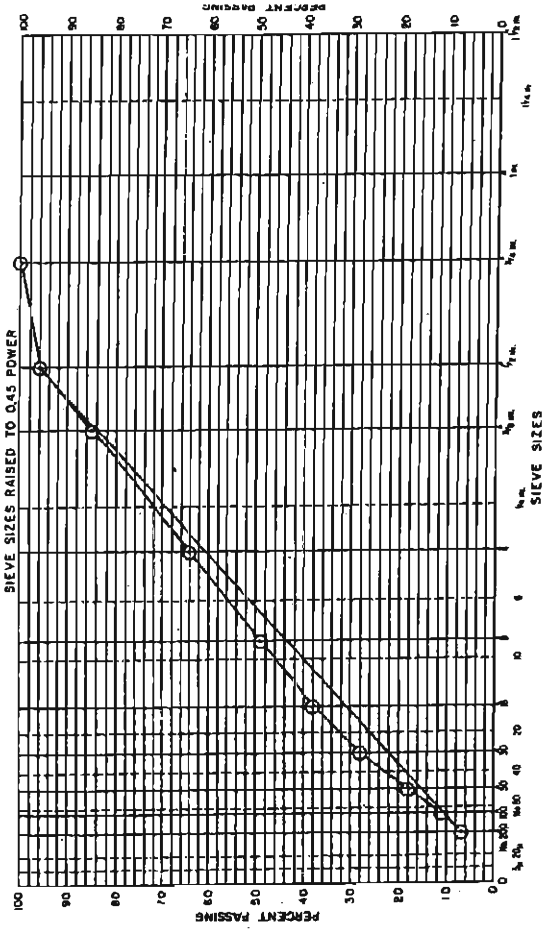
REMARKS:
Site 29
Denver

Rut Depth: 0.3"

CDOH Form #1807

COLORADO DEPARTMENT OF HIGHWAYS

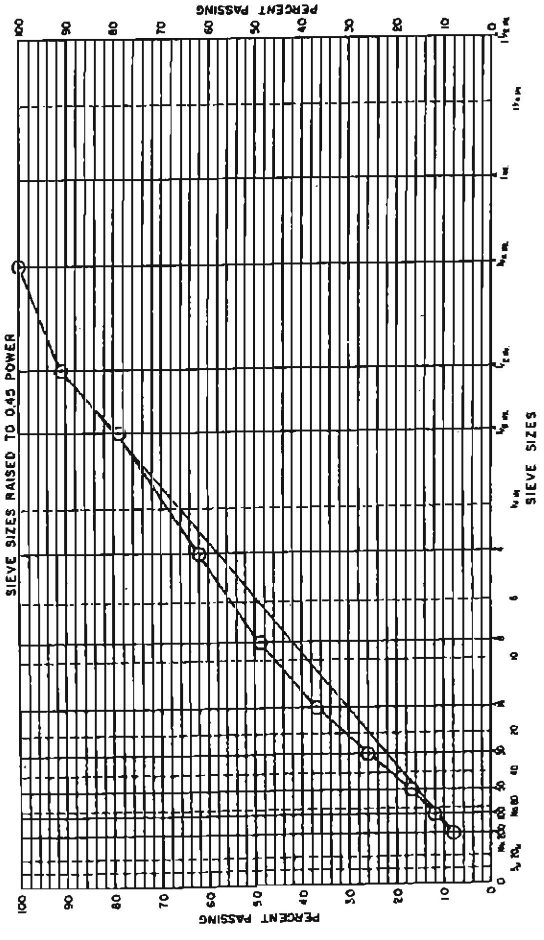
GRADATION CHART



REMARKS:
Site 30
Denver

Rut Depth: 0.6"

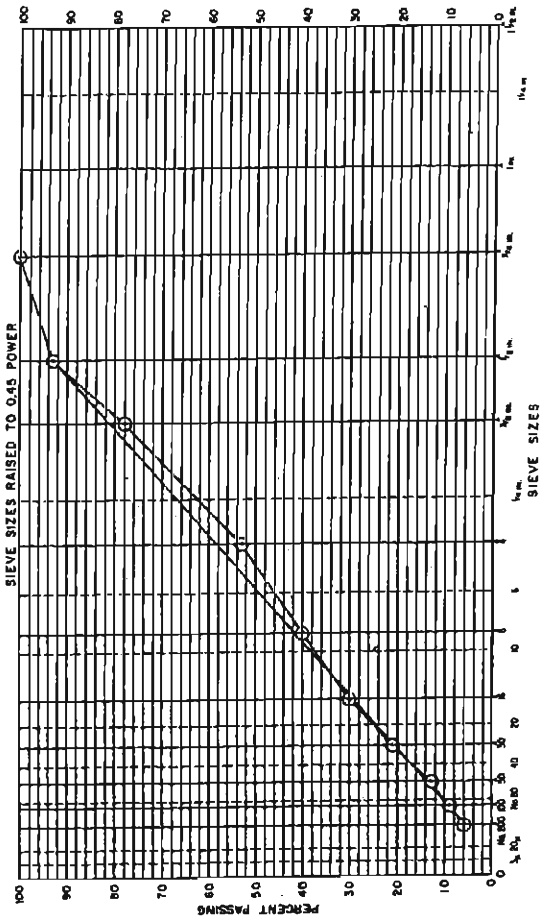
CDOH Form #1807



REMARKS:
Site 31
Fraser

Rut Depth: 0.4"

CDOH Form #1807

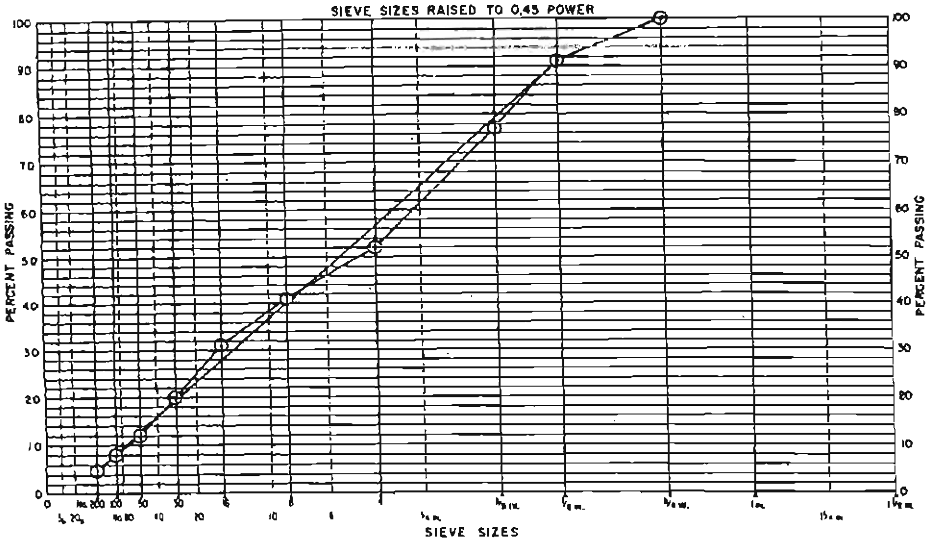


REMARKS:
Site 32
Granby

Rut Depth: 0.1"

CDOH Form #1807

COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART

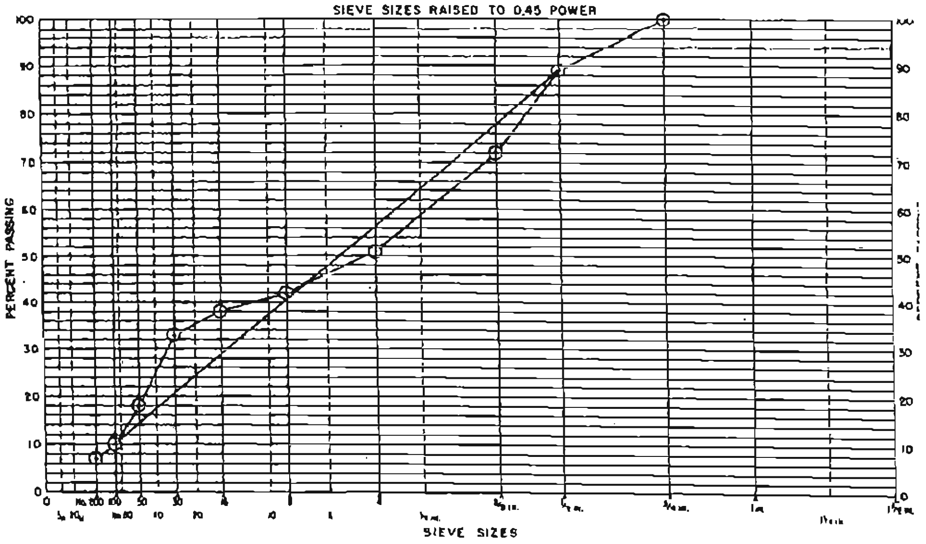


REMARKS:
Site 33
Granby

Rut Depth: 0.5"

CDOH Form #1007

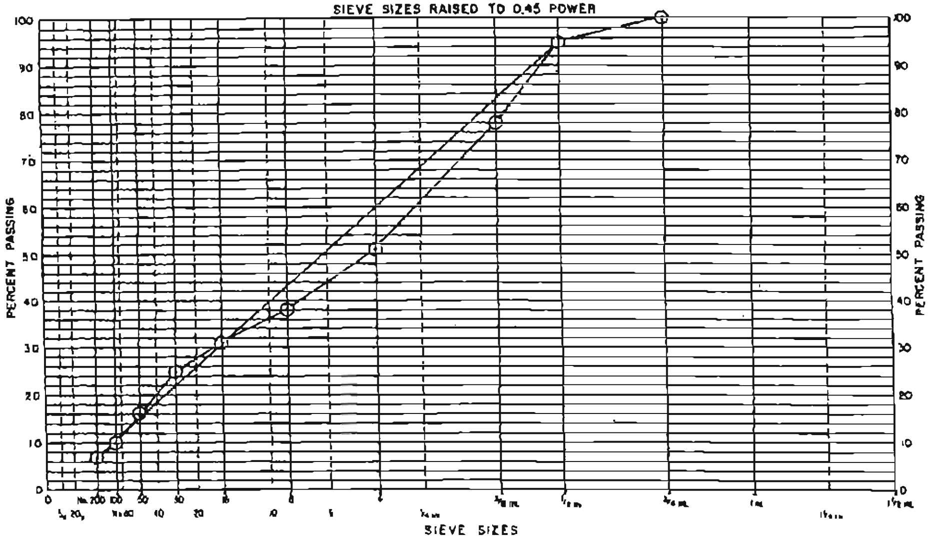
COLORADO DEPARTMENT OF HIGHWAYS
GRADATION CHART



REMARKS:
Site 34
Fruita

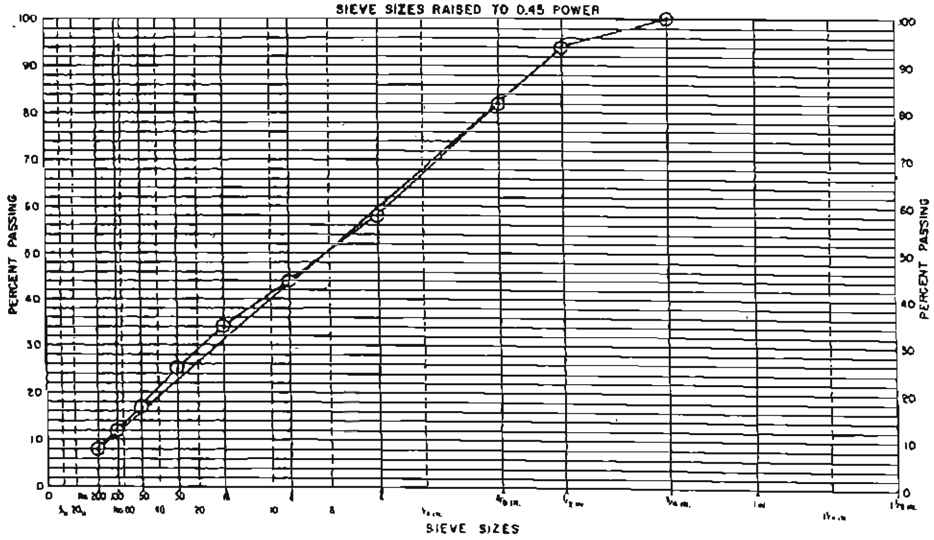
Rut Depth: 1.0"

CDOH Form #1007



REMARKS:
Site 35
Delta

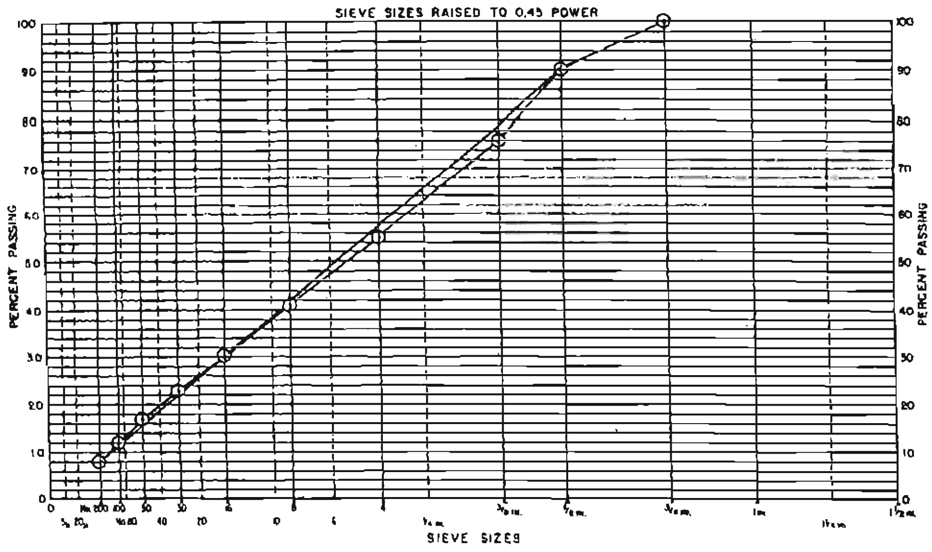
Rut Depth: 0.5"



REMARKS:
Site 36
Eisenhower

Rut Depth: 0.8"

GRADATION CHART



REMARKS:

Site 37

Silverthorne

Rut Depth: 0.1"

COOM Form #1007

APPENDIX B

Table 3 -- Properties of Pavement Studied

TABLE 3. PROPERTIES OF PAVEMENTS STUDIED

SITE	RUT IN.	LIFT NO.	THICK. IN.	AIR VOIDS (%)						STABILITY				A.C.(%)		PEN. dmm	+4 F.F. %	-4 ANG. SEC.	P200 (%)	
				BWP	IWP	TG HIGH	TG LOW	DESIGN	FIELD VER	TG HIGH	TG LOW	DESIGN	FIELD VER	DESIGN	ACTUAL				DESIGN	ACTUAL
3	0.0	1*	1.0	6.4	4.8	2.0	3.1	4.0	3.6	45	43	38	37	5.9	5.38	46	89	5.9	6.3	8.7
		2	1.0	4.8	4.5	2.0	2.7			39	49									
		3	1.0	2.7	4.3	2.0	2.6			31	35									
		4	1.5	3.5	3.5	2.6	3.2			30	30									
4	1.0	1*	2.5	3.6	2.5	1.5	2.0	3.8	2.9	16	22	39	37	6.4	6.13	56	89	6.0	7.4	7.3
		2	1.0	4.0	4.6	2.1	2.9			31	33									
		3	3.0	4.3	5.0	2.8	4.1			33	28									
5	0.0	1*	1.0	8.1	3.0	3.3	4.8	5.0	3.5	53	50	37	35	6.4	5.49	18	95	5.9	6.6	8.2
		2	1.0	3.8	3.5	2.6	2.9			26	47									
		3	2.0	5.9	5.0	4.2	5.4			52	42									
6	0.4	1	0.8	5.9	4.0	2.6	3.3			36	43									
		2*	2.5	2.3	2.5	0.8	1.4	4.4	-	30	32	44	-	6.0	5.75	56	95	5.6	6.0	6.7
		3	2.3	6.5	4.8	3.1	4.0			53	37									
7	0.1	1	1.1	4.0	1.9	1.8	1.7			27	38									
		2*	0.9	5.1	3.2	2.2	2.6	3.4	4.6	38	50	41	35	5.8	5.59	21	93	5.7	6.6	6.8
		3	1.0	7.0	3.0	2.0	1.9			20	24									
		4	3.0	5.4	3.8	1.2	2.2			27	34									
8	0.7	1	1.1	3.4	2.3	2.2	2.4			46	40									
		2*	2.9	4.4	2.7	1.9	2.8	-	2.7	30	33	-	35	5.7	4.27	81	73	5.2	8.0	9.1
9	0.1	1*	1.5	7.3	5.6	3.6	4.8	-	3.8	47	47	-	39	5.2	5.17	19	82	6.0	5.4	6.3
		2	1.5	10.2	4.4	2.0	2.7			37	38									
		3	2.5	7.0	7.3	3.4	4.8			42	47									

TABLE 3. (Cont.)

SITE	RUT IN.	LIFT NO.	THICK. IN.	AIR VOIDS (%)						STABILITY				A.C. (%)		PEN. dmm	+4 F.F. %	-4 ANG. SEC.	P200 (%)	
				BWP	IWP	TG HIGH	TG LOW	DESIGN	FIELD VER	TG HIGH	TG LOW	DESIGN	FIELD VER	DESIGN	ACTUAL				DESIGN	ACTUAL
10	1.0	1*	1.0	3.3	2.1	0.8	1.6	-	2.2	8	9	-	12	5.5	6.03	22	80	5.8	8.0	7.3
		2	2.0	3.1	3.7	1.8	2.9			25	29									
		3	8.0	4.3	4.3	2.2	3.5			36	32									
11	0.0	1*	1.8	4.6	3.7	2.7	3.6	4.0	3.3	37	43	43	48	6.2	6.11	22	83	5.9	8.0	7.7
		2	1.4	7.0	6.1	2.3	2.7			41	39									
		3	0.8	8.8	9.1															
12	0.8	1*	3.5	2.9	1.4	0.6	1.5	4.0	1.7	11	22	38	33	6.5	6.73	52	77	6.0	8.1	6.7
13	0.1	1*	1.5	6.2	3.0	2.8	3.9	3.4	3.4	32	40	36	37	5.0	4.97	22	96	5.1	6.4	5.0
		2	1.5	6.5	5.0	2.9	4.1			37	39									
		3	1.5	10.9	7.2	2.9	4.0			55	47									
14	0.8	1*	1.0	3.1	2.8	1.0	2.0	4.0	1.5	31	36	38	34	5.1	4.70	46	98	5.4	7.0	7.9
		2	2.0	3.6	2.1	2.3	4.1			46	44									
		3	2.0	5.1	3.8	2.2	2.8			39	47									
15	0.1	1*	1.8	1.9	1.7	0.8	1.7	-	2.4	21	35	-	40	6.0	6.59	39	80	5.4	8.0	6.8
		2	2.3	5.2	5.6	4.4	5.6			38	34									
17	0.5	1*	2.0	1.7	0.9	1.5	1.8	3.2	2.3	38	41	46	44	6.2	5.52	90	88	5.9	6.0	5.4
		2	3.3	4.5	4.2	2.4	4.1			21	28									
18	0.1	1*	2.0	4.3	4.0	2.8	4.1	3.0	2.2	42	59	45	47	6.1	5.47	39	90	6.0	7.5	10.3
		2	2.5	5.6	5.5	3.0	4.3			36	50									
19	0.0	1	0.8	15.2	11.4	2.5	4.0			48	51									
		2*	2.3	4.7	3.4	1.9	3.2	-	-	15	15	-	-	-	5.40	-	99	6.9		8.6

TABLE 3. (Cont.)

SITE	RUT IN.	LIFT NO.	THICK. IN.	AIR VOIDS (%)						STABILITY				A.C.(%)		PEN. dmm	+4 F.F. %	-4 ANG. SEC.	P200 (%)	
				BWP	IWP	TG HIGH	TG LOW	DESIGN	FIELD VER	TG HIGH	TG LOW	DESIGN	FIELD VER	DESIGN	ACTUAL				DESIGN	ACTUAL
20	0.4	1*	4.0	2.6	1.8	0.0	1.0	–	–	19	31	–	6	–	6.38	–	87	6.3		7.4
21	0.0	1	1.0	5.4	4.0	2.6	4.9			23	38									
		2*	4.5	10.3	9.5	4.8	6.5	12.0	11.6	49	44	22	22	6.5	6.22	13	88	5.3	7.0	10.3
23	0.1	1*	5.0	8.0	6.8	3.1	4.4	–	2.8	27	26	19	27	6.5	6.09	–	93	5.1	9.2	9.5
24	0.4	1*	6.0	4.0	2.0	1.0	1.4	–	–	14	16	19	–	6.5	6.91	–	97	5.3	9.2	10.0
25	0.1	1*	1.0	7.5	4.5	2.0	3.0	3.0	2.9	24	23	28	23	5.5	6.01	–	68	5.6	6.0	8.2
		2	1.5	6.2	4.0	2.5	3.3			27	30									
		3	3.5	4.8	5.3	2.4	3.7			31	32									
26	0.5	1*	2.3	2.7	1.7	0.3	1.1	3.0	–	13	13	28	–	5.5	6.56	–	36	5.4		5.2
		2	2.3	10.4	5.5	2.9	3.9			39	34									
27	0.0	1*	1.5	7.1	4.9	2.0	2.8	6.9	5.4	36	42	30	31	6.8	6.41	–	100	5.5	10.0	7.5
		2	2.0	4.1	4.3	2.4	2.5			26	37									
		3	8.0	4.5	6.7	2.0	3.3			32	35									
28	0.7	1*	1.5	2.8	2.7	0.4	1.5	–	–	10	9	–	33	6.5	6.15	–	100	5.3	10.5	8.0
		2	1.5	3.1	3.6	1.0	2.1			10	14									
		3	6.0	3.1	2.6	0.0	0.4			12	9									
29	0.3	1*	1.1	4.5	2.3	2.1	2.0	5.1	2.5	19	31	34	35	5.8	5.57	44	99	6.3	7.0	7.9
		2	1.8	7.3	5.6	2.6	3.0			33	47									
		3	2.5	5.4	3.1	1.9	2.0			36	39									
30	0.6	1	1.1	5.0	2.8	2.0	3.2			42	41									
		2*	1.8	5.9	2.4	1.3	1.9	3.7	2.7	22	26	39	39	6.0	6.11	46	74	6.1	7.0	7.4
		3	2.5	6.2	3.8	0.9	1.9			35	37									

TABLE 3. (Cont.)

SITE	RUT IN.	LIFT NO.	THICK. IN.	AIR VOIDS (%)						STABILITY				A.C.(%)		PEN. dmm	+4 F.F. %	-4 ANG. SEC.	P200 (%)	
				BWP	IWP	TG HIGH	TG LOW	DESIGN	FIELD VER	TG HIGH	TG LOW	DESIGN	FIELD VER	DESIGN	ACTUAL				DESIGN	ACTUAL
31	0.4	1*	2.0	6.3	4.3	2.9	2.8			20	41				5.97	40	95	6.2		8.3
32	0.1	1*	1.6	9.0	7.0	2.3	3.5			43	46				5.40	34	93	5.9		5.9
		2	1.0	8.4	5.5	2.0	3.9			30	48									
		3	2.4	8.2	7.2	4.0	6.1			64	55									
33	0.5	1*	1.3	4.3	4.0	1.5	2.3			27	31				6.11	-	96	6.2		4.9
		2	1.8	5.6	4.9	2.1	3.7			46	43									
34	1.0	1*	1.5	2.4	1.9	1.3	1.6	-	2.1	22	32	-	-	5.4	5.67	33	72	5.8	7.0	6.8
		2	1.0	3.2	3.3	2.3	2.6			31	43									
		3	3.0	1.6	2.4	1.2	3.1			26	38									
35	0.5	1*	2.3	2.7	2.9	1.8	2.1	2.9	-	16	33	40	-	5.5	5.76	54	91	6.1	6.6	7.0
		2	3.3	4.6	3.3	1.5	2.4			44	39									
36	0.8	1*	2.8	6.3	6.5	2.3	5.1	3.5	4.0	30	45	48	43	6.3	6.08	71	94	6.0	7.5	8.3
		2	3.0	4.3	2.5	1.2	3.1			11	29									
37	0.1	1*	1.8	3.8	2.5	1.8	3.2	4.4	2.5	27	53	37	-	5.7	5.27	64	95	6.2	9.3	8.3
		2	1.8	8.4	10.0	1.4	1.9			27	42									
		3	1.8	5.4	6.1	2.4	3.1			38	57									

TABLE 3. (Cont.)

LEGEND:

BWP - Between Wheel Path
IWP - In Wheel Path
TG High - 150 psi end point stress, using the Texas gyratory
TG Low - 90 psi end point stress, using the Texas gyratory
A.C. - Asphalt Content
Pen. - Penetration @ 77°F
+4 F.F. - Percent of coarse material having two or more fractured faces
-4 Ang. - NAA test for fine aggregate
P200 - Percent passing #200 sieve.