LOWER BITUMINOUS MIXING TEMPERATURES

REPORT 78-7
MARCH 1978

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS DIVISION

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Materials Division
Highway Department
Agency of Transportation
March 27, 1978

Reviewed By: R. F. Nicholson
R. F. Nicholson, P.E., Materials Engineer

Date: March 31, 1978

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15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

A one day study was conducted on the effects of lowering the mixing temperature of bituminous concrete on an interstate paving project. Properties of the mix which appeared to be affected to the greatest degree were particle coating and compaction. A 15° F drop in mixing temperature from the standard 275° F mixing temperature to 260° F was achieved before any apparent harm was done to the mix.

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HD 565 7/77

Prepared By: R. Snow
Date: 7/22/77
Sheet 1, of 3

Vermont Department of Highways
Materials Division - Research & Development Subdivision

RESEARCH INVESTIGATION

Work Plan No. 77-R-55

Subject Lower Bituminous Mixing Temperatures

Investigation Requested By FHWA Letter Barrows to Crisman Date June 13, 1977

Date Information Required Whenever a suitable project can be found

Purpose of Investigation In an effort to save energy (dryer fuel), reduce mix temperatures in 10° to 15° increments without sacrificing the quality characteristics of density, coating and smoothness.

Proposed Tests (Attach extra sheet if necessary) See attached sheets 2 & 3 from FHWA Notice N 5080.52 dated June 9, 1976. Project selected is Ryegate Barnet I 91-2 (27) Stage II.

Proposal Discussed With Murphy Bartlett Willey

Projected Manpower Requirements 9 man days (2 each plant & road, 5 lab Willey)

Investigation To Be Conducted By L. Willey, Materials

Proposed Starting Date Aug. 1977 Estimated Completion Date Aug. 1977

Approval/Disapproval by Materials Engineer R.H. Nichols 8/9/77

Comments by Materials Engineer Approval is given only with assumption that Contractors agree, otherwise denied and therefore necessary to select a different project.

Materials Division
Highway Department
Agency of Transportation
July 27, 1977

R.H.N. 8/9/77

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ABSTRACT

On September 8, 1977, a study of the effects of lowering the mixing temperature of bituminous concrete was performed on Interstate 91, Ryegate-Barnet I 91-2 (27) Stage II. The area studied was on the southbound lane from Station 693+25 (mile marker 115.932) to station 631+00 (mile marker 114.751).

Properties of the mix which appeared to be affected to the greatest degree were particle coating and compaction. A 15° F drop in mixing temperature, from 275° F to 260° F, was achieved before any apparent harm was done to the mix.

Although the values contained in this report are not representative of all possible paving situations, the findings are indicative of what can reasonably be expected.

INTRODUCTION

The primary objective of this study is to determine the lowest possible mixing temperature of bituminous concrete, under normal operating conditions, without sacrificing the quality of the finished pavement.

In June 1977, the F.H.W.A. office in Montpelier contacted the State of Vermont, Agency of Transportation, Materials Division, regarding the subject of "Lower Bituminous Mixing Temperatures". It was the intent to study what effect lowering the mixing temperature of bituminous concrete would have on pavement physical properties and performance.

Therefore, this study was undertaken in the interest of conserving energy (less fuel required for lower mixing temperatures) and possibly increasing pavement life (asphalt cement binder retains its life better, at lower mixing temperatures).

The project chosen for this study was on Interstate 91, Ryegate-Barnet I 91-2 (27) Stage II. Type II, 3/4" binder mix, was monitored. See Figure 1.

MATERIALS

Type II bituminous concrete, 3/4" binder mix, was used as the wearing course for Stage II construction on this project.

The coarse aggregate used was crushed stone from L. M. Pike's quarry in Ryegate, Vermont. Fine aggregate consisted of a blend of crusher dust from L. M. Pike's quarry and natural sand from Calkins of St. Johnsbury, Vermont. The asphalt cement was a 150-200 penetration grade asphalt from Gulf of Montreal, Quebec, Canada.

The "Mix Design" for the Type II mix and a "Temperature-Viscosity Chart" for the asphalt cement are contained in Appendix C.

The 150-200 penetration grade asphalt cement, being a soft grade of asphalt, requires lower mixing temperatures than the stiffer grades of asphalt. Therefore, a drop in mixing temperature of approximately 10^{o} F is possible, simply by using the softer asphalts.

PROCEDURE

The general approach of this study follows guidelines as outlined in the F.H.W.A. Notice N 5080.52, dated June 9, 1976. The intent being to lower the mixing temperature of bituminous concrete by gradual increments (10^{o} F to 15^{o} F) until such time as the physical properties of the mix are detrimentally affected.

The study was carried out September 8, 1977. Ambient project temperature was on the rise, ranging from 67^{o} F to 76^{o} F. The weather was clear, with a light breeze.

A state inspector at the plant monitored such items as raw aggregate moisture content, dried aggregate moisture content, ambient plant air temperature, temperature of the discharged mix, and ross count (particle coating) of the mix.

Project observations included monitoring ambient air temperature, haul length and time, mix lay down temperature, uncompacted mix depth, and numbers and types of pavers and rollers.

Percent air voids of the compacted mix, for each temperature interval, was determined from the plant quality control records and from tests done on special request. These tests were performed in accordance with the Marshall Method.

Compaction achieved relative to target density was determined, for each temperature interval, using a nuclear density gauge. Two sets of tests were run to determine compaction. The first set being quality control tests which are normally run as a basis for payment. The second set was run on special request as part of this study.

Pavement roughness was measured using a May's Ride Meter for the entire day's production. Roughness for each temperature interval was also determined.

RESULTS

Air Voids of Compacted Mixture as Determined by Marshall Method (Figure 2)

As the mixing temperature was lowered, the percent air voids increased slightly. However, for mixing temperatures ranging from 275° F to 240° F, there did not appear to be any difficulty in achieving the required level of air voids. i.e. 2% to 5%.

Ross Count (Figure 3)

As the mixing temperature was lowered, the stone particles remained 100 percent coated, down to a temperature of 265° F. At least 95% of the particles remained coated down to 235° F. However, for temperatures below 250° F, the sand particles in the mix did not appear to be thoroughly coated.

Compaction Achieved Relative to Target Density (Figure 4)

The quality control tests indicated that compaction failed around 270° F and continued to decline as the temperature was lowered. However, the special request tests indicated compaction failure occurred at around 260° F. Below 260° F, down to 240° F, percent compaction remained fairly constant at around 97.8%.

Surface Characteristics - Roughness (Figure 5)

Pavement roughness was 42.2 inches/mile at a mixing temperature of 275° F, but decreased to an acceptable level for lower temperatures, down to 250° F. In the section paved at 240° F, the roughness jumped to 58.9 inches/mile. This may be due in part to the fact that this section was at the end of the day's production.

CONCLUSIONS

Properties of bituminous concrete that appeared to be detrimentally affected by lowering the mixing temperature, within the temperature range studied, were particle coating and compaction.

Particle coating became critical at 240° F, with the sand portion of the mix appearing partially coated below 250° F.

Compaction achieved relative to target density, on the tests run for this study, fell below acceptance limits for temperatures below 260° F.

Thus under the given conditions, a 15° F drop in mixing temperature, from 275° F to 260° F, was possible without harmfully affecting the finished pavement. Remedial measures such as longer mixing time and greater compactive effort might enable the mixing temperature to be lowered even further.

Values contained in this report are not representative of all possible paving situations. However, the established trends are indicative of what can reasonably be expected by lowering the mixing temperature of bituminous concrete.

Vermont Agency of Transportation
Lower Bituminous Mixing Temperatures

APPENDIX A

Field Lab Information

1. Moisture Content of Raw Aggregates:

Raw Aggregate \ Date/Time	9/8/77 11:00 AM	PM	AM	PM
3/4"	0.14 %			
1/2"	0.25 %			
3/8"	0.24 %			
Sand	3.07 %			
Dust	1.86 %			

2. Ambient Air Temperatures:

Date September 8, 1977

Time	Temperature
6 A.M.	
7	
8	
9	
10:30	62 °F
11	66 °F
12	72 °F
1 P.M.	74 °F
2	74 °F
3	
4	
5	
6	

Date _____

Time	Temperature
6 A.M.	
7	
8	
9	
10	
11	
12	
1 P.M.	
2	
3	
4	
5	
6	

Field Lab Information

3. Temperature and Moisture Content of Dried Aggregates:

Date September 8, 1977 Date _____

Bin	A.M. Time	Temp.	* % H_2O	P.M. Time	Temp.	* % H_2O	A.M. Time	Temp.	% H_2O	P.M. Time	Temp.	% H_2O
S	11:50	275	0	1:24	250	0.17						
2				2:01	260	0.20						
3												
4												

* Moisture Samples obtained from Hot Elevator Discharge Chute.

4. Temperature of Mix as Discharged From Mixer:

Date 9/8/77 Date 9/8/77 Date 9/8/77 Date 9/8/77

Time	Slip #	Temp.	Time	Slip #	Temp.	Time	Slip #	Temp.	Time	Slip #	Temp.
10:18	47042	280		47059	275	12:17	47074	270	1:47	47101	245
	47043	290		47060	275		47075	260		(Drop Temp. to 240°F)	
	47044	285		47061	265	12:41	47081	270	1:54	47103	240
10:28	47045	275		(Plant down)			47082	265		(Marshall C)	
	47046	275		47062	290	12:50	(Drop Temp. to 250 °F.)		2:01	47105	235
	47047	275		47063	250	12:54	47085	255		47106	240
10:45	47050	270		47064	265		47086	255		47107	245
	47051	275		47065	265		47087	260	2:14	47109	240
	47052	275		47066	260		(Test) 47088	260		47110	240
	47053	275		47067	265		47089	255		47111	250
	47054	280		47068	265		(Loads not covered)			47112	240
(Informed Contractor to drop Temp to 260 °F)				47069	265		47091	250		47113	240
11:02	47055	275		47070	265		47092	255		(Last load) 47114	240
	47056	275		(Marshall A) 47071	265		47093	255			
	47057	270	12:09	47072	255	1:24	(Marshall B) 47094	250			
	47058	270		47073	255	1:31	47096	255			

Field Lab Information

5. Ross Count of Mixture:

Date	Time	Slip #	Temperature	% Coated Particles
9/8/77	10:30	47047	275 °F	100
	12:47	47082	265 °F	100
	1:10	47089	255 °F	98
	2:01	47105	235 °F	95
	Visual examination of trucks showed sand portion of mix uncoated for temperatures below 250°F.			

Project Information (Ryegate-Barnet I 91-2(27) S/2)

1. Ambient Air Temperatures:

Date September 8, 1977

Time	Temperature
6 A.M.	
7	
8	
9	
10	
11	67 °F
12	72 °F
1 P.M.	74 °F
2	75 °F
3	76 °F
4	
5	
6	

Date _____

Time	Temperature
6 A.M.	
7	
8	
9	
10	
11	
12	
1 P.M.	
2	
3	
4	
5	
6	

2. Length and Time of Haul (Average):

Temperature Interval	Miles Length	Minutes Time
275 °F	0.8	5
260 °F	0.6	5
250 °F	0.4	4
240 °F	0.3	4

Project Information (Ryegate-Barnet I 91-2(27) S/2)

3. Factors Affecting Laydown and Compaction:

Paver Type(s) Mainline : (1) Blaw-Knox PF 220

Right Shoulder : (1) Blaw-Knox PF 180 H

Roller Type(s) (2) Galion - 2 Axle tandem steel drum Rollers

(1) Bros. Pneumatic tired roller.

(1) Galion - 3 Axle tandem steel drum roller.

Mix Arriving At Project

Date September 8, 1977

Time	Slip #	S.B. M.P. (Station)	(°F) Mix Temp.	Uncompacted Depth. (in.)
11:12	47055	658+00	275	2 1/8
11:20	47056	657+50	275	2 1/8
11:24	47058	657+00	270	2 1/4
11:29	47060	656+00	275	2
11:45	47062	655+50	265	2 1/8
11:51	47063	655+00	265	2 1/8
11:55	47065	654+00	265	2 1/4
12:04	47067	653+50	265	2 1/8
12:11	47069	652+50	270	2 1/8
12:15	47070	652+00	265	2 1/8
12:19	47071	651+50	265	2 1/4
12:25	47072	651+00	265	2 1/8
1:02	47084	645+50	260	2 1/8
1:08	47086	645+00	255	2 1/4
1:12	47087	644+00	255	2 1/8
1:20	47089	643+50	255	2 1/4
1:23	47090	643+00	260	2 1/4
1:28	47092	642+00	250	2 1/8
1:31	47093	641+50	250	2 1/4

Date September 8, 1977

Time	Slip #	S.B. M.P. (Station)	(°F) Mix Temp.	Unc. Depth
1:35	47095	641+00	250	2 1/8
1:41	47096	640+50	250	2 1/8
1:50	47099	639+00	245	2 1/8
1:54	47100	638+00	250	2
2:04	47103	637+00	245	2 1/8
2:11	47105	636+00	240	2 1/4
2:15	47106	635+50	245	2 1/8
2:18	47107	635+00	240	2 1/8
2:24	47109	634+00	240	2 1/4
2:42	(Last load) 47114	631+50	240	2 1/4
— End at Sta.		631+00	—	

HD180 Rev 4-77 Proj. Code ______	APPENDIX A Vermont Department of Highways Materials Division PROPERTIES OF ASPHALT MIXTURES	Sheet 7 of ___

RECEIVED 1977 HIGHWAY TEST LAB

Job Name: Ryegate - Barnet Job No. ______

Source of Material: Pit ... Ryegate

Source of AC: BP Montreal AC Grade: 150-200

Item No. 406.25 Type of Mix: 406.02 (b) II Year: 1977

Sp.Gr. +8: 2808 Sp.Gr. -8: 2763 Sp. Gr. Ac: 1.018 Ring No. 1204

Line	Formula	Description	1	2	3	4	5	6	7	8	9	0
A		Lab No. D77-	0878	→			→	0887	→			→
B		Field Specimen No.	RB 43b	RB 44B	RB 45B	RB 46B	RB 47B	RB 48B	RB 49B	RB 50B	RB 51b	RB 52b
C		Test Date (mo./day)	9-8	9-8	9-8	9-8	9-8	9-9	9-9	9-9	9-9	9-9
D1	100	% Passing 1"	100	100.0	100.0	100.0	100.0	100	100	100	100	100
D2	98	" 3/4"	96.7	95.5	95.7	97.2	98.7	96.8	98.9	96.8	98.1	98.2
D3	80	" 1/2"	75.7	72.6	76.3	83.1	76.9	76.2	80.7	75.8	73.4	71.8
D4	68	" 3/8"	64.2	61.2	65.1	70.3	66.3	65.8	70.3	67.2	60.2	57.3
D5	48	" #4	44.8	44.4	46.9	48.6	45.1	46.8	48.1	47.2	43.5	43.0
D6	38	" #8	37.9	37.1	38.3	40.4	36.0	38.9	39.0	37.9	36.3	36.9
D7	30	" #16	32.6	32.0	32.6	34.2	30.1	33.6	33.7	32.3	31.9	31.3
D8	24	" #30	25.3	24.5	24.8	25.4	21.9	26.8	27.2	26.0	25.0	22.9
D9	15	" #50	15.9	15.3	15.7	15.7	13.4	17.1	17.4	17.6	15.2	13.7
D10	4	" #200	4.0	3.2	4.1	3.8	3.2	4.3	4.0	4.5	3.4	3.0
E	5.20	Bitumen % (AC)	5.06	4.98	5.22	5.53	5.19	5.35	5.27	5.28	4.94	5.03
F	100(R-P)/R	% Voids - Mix	3.3	4.60	5.04	2.83	3.32	2.08	4.00	3.44	3.77	3.8
G	S/(S+F)	" - Filled	78.89	72.3	71.2	82.6	79.2	86.3	76.0	78.8	76.1	76.3
H	P x 62.4	Unit Wgt., lbs/ft³	154.8	152.9	151.6	154.3	154.4	156.0	153.1	154.0	154.3	154.1
I		Stab. - conv., lb.	1450	1197	1348	1467	1552	1500	1450	1432	1319	1462
J		Marshall Flow Value	8	9	7	10	10	10	9	8	10	10
		Time / Slip # / Temp (°F)	6:12 / 46969 / 275	8:07 / 47003 / 280	9:32 / 47028 / 280	12:09 / 47072 / 260	1:04 / 47088 / 260	lbw				
K		Sample Thickness, in.	2 1/2	2 5/8	2 3/8	2 1/2	2 9/16	2 1/2	2 1/2	2 5/8	2 3/8	2 3/4
L		Wgt. in Air, grams	1250	1296	1224	1313	1297	1290	1271	1345	1207	1361
M		Wgt. in Water, grams	746	767	720	782	773	774	753	800	719	810
N	L - M	Volume, cubic cm.	504	529	504	531	524	516	518	545	488	551
P	L / N	Sp. Gr. - Bulk	2.480	2.450	2.429	2.473	2.475	2.500	2.454	2.468	2.473	2.470
R	See below	Sp. Gr. - Theor.	2.565	2.568	2.558	2.545	2.560	2.553	2.556	2.556	2.570	2.567
S	PxE/SpGrAC	AC by Volume %	12.33	11.99	12.46	13.43	12.62	13.14	12.70	12.80	12.00	12.20
T		Stab. - measured, lb	93	83	80	94	103	96	93	98	78	110
U		Accepted or Rejected										

Theoretical Specific Gravity Formula:

$$100 \div \left(\frac{\%AC}{Sp.\ Gr.\ AC} + \frac{\% + 8(100\% - \%AC)}{Sp.\ Gr.\ +8} + \frac{\% - 8(100\% - \%AC)}{Sp.\ Gr.\ -8} \right)$$

Inspector(s): Stevens, Beyer

ED180 Rev 1M 8-77	APPENDIX A Vermont Department of Highways Materials Division PROPERTIES OF ASPHALT MIXTURES	Sheet 1 of 1
Proj. Code		

Job Name "Low Bituminous Mixing Temperatures" Job No. Ryegate - Barnet

Source of Material Pike Ind. Inc. Ryegate, Vt.

Source of AC BP Montreal, Canada AC Grade 150-200

Item No. 406.25 Type of Mix II Year 1977

Sp.Gr. +8 2.808 Sp.Gr. -8 2.763 Sp. Gr. Ac 1.018 Ring No. 1554-A

Line	Formula	Description	1	2	3	4	5	6	7	8	9	0
A		~~Lab No.~~ 077 -	12:05	1:24	2:01	← Time						
B		Field Specimen No.	A	B	C							
C		Test Date (mo./day)	9/21	9/21	9/21							
D1		% Passing 1"	100	100	100							
D2		" 3/4"	100	97	100							
D3		" 1/2"	82	79	80							
D4		" 3/8"	68	68	67							
D5		" #4	49	48	49							
D6		" #8	39	40	40							
D7		" #16	33	33	35							
D8		" #30	25	25	27							
D9		" #50	15	15	17							
D10		" #200	5	4	4							
E		Bitumen % (AC)	5.50	5.39	5.28							
F	100(R-P)/R	% Voids - Mix	2.2	3.1	3.8							
G	S/(S+F)	" - Filled	86.0	80.9	77.4							
H	P x 62.4	Unit Wgt., lbs/ft^3	155.4	154.3	153.4							
I		Stab. - conv., lb.	1145	1188	992							
J		Marshall Flow Value	9	6	6							
			260°	250°	240° ← Temp							
K		Sample Thickness, in.	2 3/8	2 3/16	2 3/8							
L		Wgt. in Air, grams	1223	1098	1160							
M		Wgt. in Water, grams	732	654	688							
N	L - M	Volume, cubic cm.	491	444	472							
P	L / N	Sp. Gr. - Bulk	2.491	2.473	2.458							
R	See below	Sp. Gr. - Theor.	2.546	2.551	2.555							
S	PxE/SpGrAC	AC by Volume %	13.46	13.09	12.98							
T		Stab. - measured, lb	102	93	89							
U		Accepted or Rejected	47071	47094	47105	← Slip #						

Theoretical Specific Gravity Formula:

$$100 \div \left(\frac{\%AC}{\text{Sp. Gr. AC}} + \frac{\% + 8(100\%-\%AC)}{\text{Sp. Gr. +8}} + \frac{\% - 8(100\%-\%AC)}{\text{Sp. Gr. -8}} \right)$$

Inspector(s): E. Blodgett

W 9-8-77 APPENDIX A SHEET 5 OF 7

CHKD. BY DATE Compaction - SB JOB NO. I 91-2(27) 11

Ryegate - Bacnet

T.S. = 147.2

Test	Station	Off.	Count	Ratio	Den. (Chart)	% Compact	Comments
1	692+00	℄	617	317	148	100.5	Begin Paving 693+25
2	690+00	℄	619	318	148	100.5	
3	688+00	Lt. 2'	625	321	147	99.8	
4	686+00	Lt. 2'	609	313	150	101.9	
5	684+00	Rt. 2'	655	337	142	96.4	
6	682+00	Rt. 2'	646	332	143	97.1	
7	680+00	℄	648	333	143	97.1	
8	678+00	℄	648	333	143	97.1	
9	676+00	Lt. 3'	620	319	148	100.5	
10	674+00	Lt. 3'	629	323	146	99.1	
11	672+00	Rt. 3'	680	350	136.5	92.7	
12	670+00	Rt. 3'	620	318	148	100.5	
13	668+00	℄	643	330	143.5	97.4	
14	666+00	℄	654	336	142	96.4	
15	664+00	Lt. 4'	683	351	136	92.3	
16	662+00	Lt. 4'	639	328	144.5	97.8	SB Rest Area
17	660+00	Rt. 4'	626	322	146.5	99.5	
18	658+00	Rt. 4'	645	332	143	97.1	Start Lower Temp. 265°
19	656+00	℄	618	318	148	100.5	In Field @ 655+00
20	654+00	℄	661	340	140.5	95.4	End A.M.
21	652+00	℄	645	332	143	97.1	Begin P.M.
22	650+00	℄	645	332	143	97.1	
23	648+00	Lt. 2'	654	336	142	96.4	
24	646+00	Lt. 2'	660	339	141	95.7	
25	644+00	Rt. 2'	667	343	139	94.4	
26	642+00	Rt. 2'	670	345	138.5	94.0	Temp to 250°
27	640+00	℄	627	322	146.5	99.5	
28	638+00	℄	694	357	134.5	91.3	
29	636+00	℄	710	365	132	89.6	Temp to 240°
30	634+00	℄	662	340	140.5	95.4	
31	632+00	℄	659	339	141	95.7	End Paving 631+00
32							
33							
34							
35							
36							
37							
38							
39							
40							

A.M.
1947
1957
1946
1933
1953
9726
÷5 = 1945.2

275° ±
98.0%

275°
98.8%

260°
96.1%

P.M.
1955 250°
1918 94.9%
1965
1934 240°
1951 96.0%
9723
÷5 = 1944.6

RECEIVED SEP 15 1977 HIGHWAY MAT. LAB.

Sum of % Compaction 3005.8 ÷ 31

Record Standard Counts on the back of this sheet. For additional tests, use additional sheet.

Pay Factor 1.0 Average % Compaction 96.96%

Stations 631+00 - 655+00 will not be Q.C. because of material division tempeture test run this date

Form 3

APPENDIX A

TO: LARRY WILLEY, MATERIALS DIVISION

FROM: WALKER, CONSTRUCTION

DATE: 9-12-77

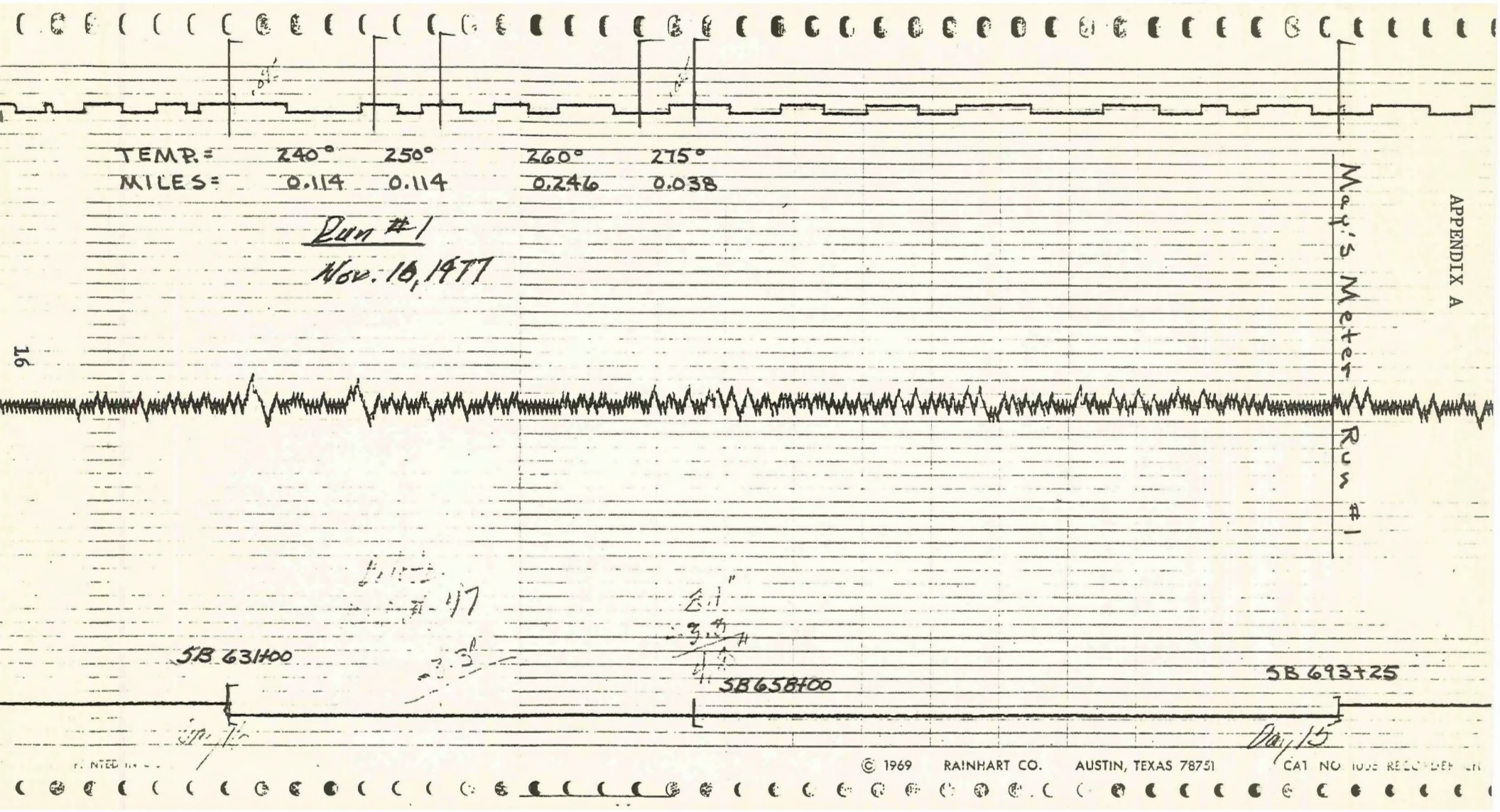
SUBJECT: RVEGATE – BARNET
I 91-2(27) II
SOUTH BOUND LANE

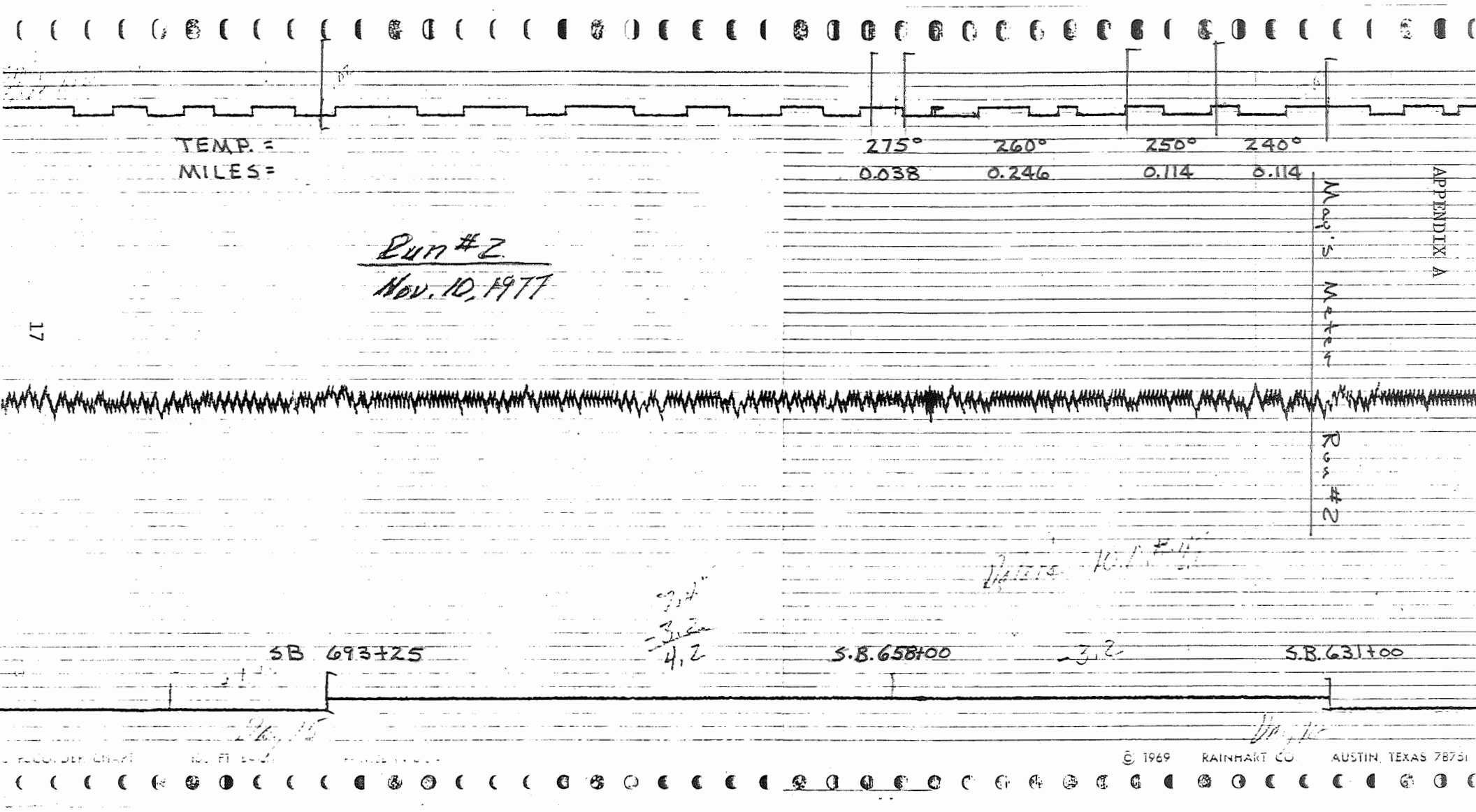
RECEIVED
SEP 15 1977
HIGHWAY
TEST. LAB

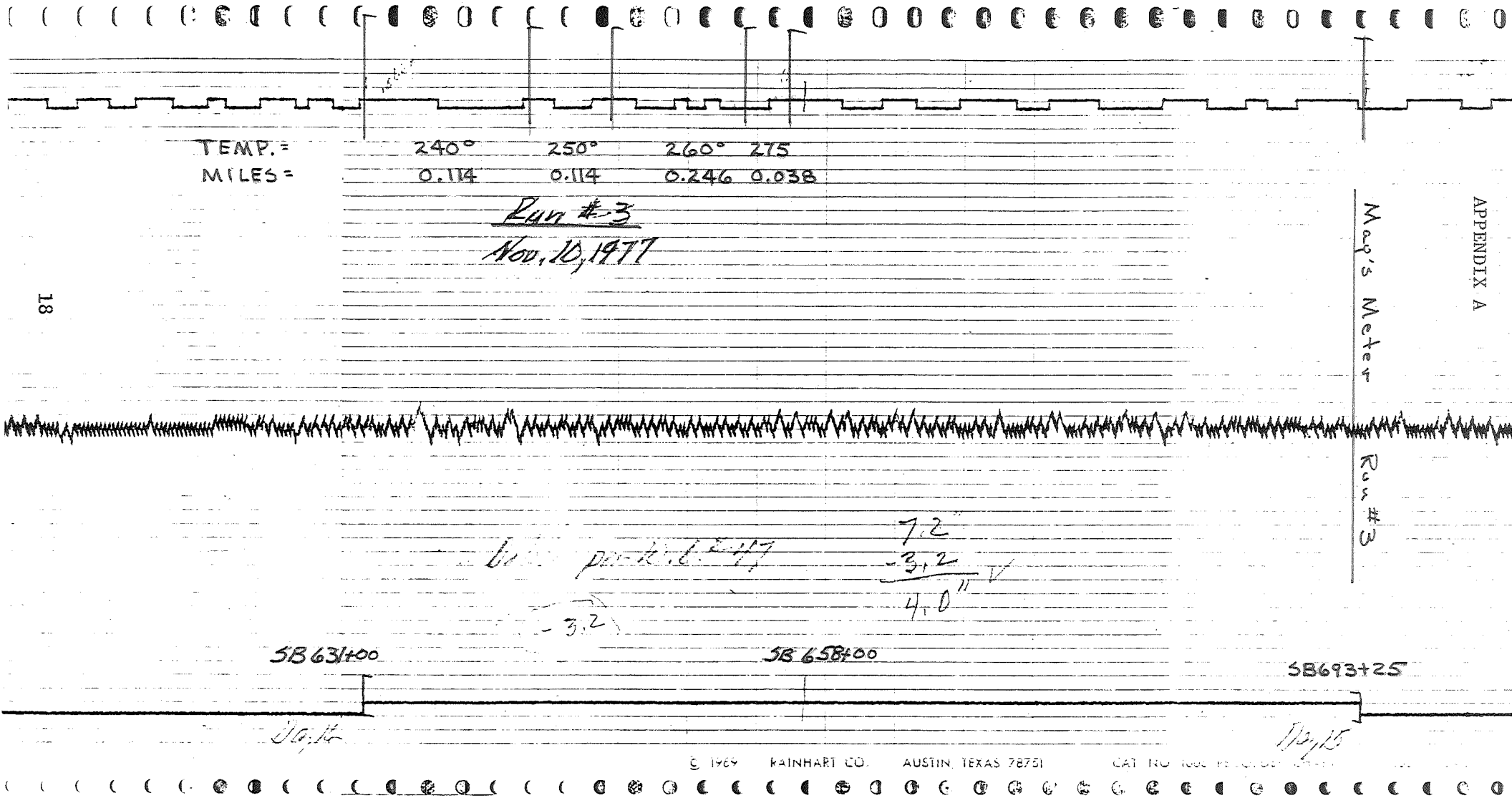
Per your request the following information was obtained, using the probe, at the stations you listed, after the 3 axle roller had finished:

	STATION	OFFSET	COUNT	RATIO	DEN. (CHART)	% COMPACT	REMARKS
	658+00	℄	621	315	149	101.2	START LOWER TEMP. 265°
	658+00	Lt. 8'	632	320	147.5	100.2	
275°	658+00	Rt. 6'	639	324	145.5	98.8	
	656+00	℄	618	313	150	101.9	(275° - 100.1%)
	656+00	Lt. 4'	629	319	148	100.5	
	656+00	Rt. 8'	648	328	144.5	98.1	✓
	654+00	℄	640	324	145.5	98.8	
	654+00	Lt. 2'	645	327	145	98.5	
260°	652+00	℄	650	329	144	97.8	(260° - 98.1%)
	652+00	Rt. 6'	658	333	143	97.1	
	644+00	℄	649	329	144	97.8	
	644+00	Lt. 3'	641	325	145	98.5	✓ TEMP. TO 250° AT 642+00 ±
250°	641+00	℄	655	332	143	97.1	(250° - 97.8%)
	641+00	Rt. 3'	644	326	145	98.5	✓
240°	635+00	℄	652	330	143.5	97.4	TEMP TO 240° AT 636+00 ±
	635+00	Lt. 6'	651	330	143.5	97.4	(240° - 97.8%)
	632+00	℄	643	326	145	98.5	✓

STANDARD COUNT = 1974 TEST STRIP = 147.2
15


TEMP.= 240° 250° 260° 275°
MILES= 0.114 0.114 0.246 0.038
Run #1
Nov. 16, 1977
May's Meter Run #1
SB 631400
SB 658400
SB 693425
Day 15
© 1969 RAINHART CO. AUSTIN, TEXAS 78751


TEMP. =
MILES =
275°
260°
250°
240°
0.038
0.246
0.114
0.114
Run #2
Nov. 10, 1977
Map's Meter
Run #2
APPENDIX A
17
SB 693+25
S.B. 658+00
S.B. 631+00
© 1969 RAINHART CO AUSTIN, TEXAS 78751



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Air Voids

Slip #	(°F) Temp.	QC/SR	% Air Voids	Station	(°F) Temp. Interval	Ave. % Air Voids
46969	275	QC	3.3		275±	4.3
47003	280	QC	4.6			
47028	280	QC	5.0			
47071	265	SR	2.2	651+50	260	2.8
47072	260	QC	2.8	651+00		
47088	260	QC	3.3	644+00		
47094	250	SR	3.1	641+00	250	3.1
47105	240	SR	3.8	636+00	240	3.8

Compaction

(°F) Temp. Interval	Station	QC/SR	Ave. % Compaction	Composite Ave. % Compaction
275±	692+00 - 658+00	QC	98.0	98.0
275	658+00 - 656+00	QC	98.8	99.5
		SR	100.1	
260	656+00 - 643+00	QC	96.1	97.1
		SR	98.1	
250	643+00 - 637+00	QC	94.9	96.4
		SR	97.8	
240	637+00 - 631+00	QC	93.6	95.7
		SR	97.8	

QC: Tests performed under quality control program.
SR: Tests done on special request.

Roughness

(°F) Temp.	Station From	Station To	(Miles) Length	May's Meter Reading Run 1	Run 2	Run 3	Ave.	(x6.4) Factor	(÷ Length) Inches/Mile-Roughness
240	631+00	637+00	0.114	1.06	0.84	1.20	1.05	6.72	58.9
250	637+00	643+00	0.114	0.48	0.66	0.60	0.58	3.71	32.5
260	643+00	656+00	0.246	1.46	1.64	0.96	1.35	8.64	35.1
275	656+00	658+00	0.038	0.40	0.26	0.32	0.33	2.11	55.5
275*	658+00	693+25	0.668	4.72	4.08	4.18	4.33	27.71	41.5
275**	656+00	693+25	0.705	5.12	4.34	4.50	4.65	29.76	42.2
Composite	631+00	693+25	1.179	8.12	7.50	7.28	7.63	48.83	41.4

*This section not monitored during paving.

**Includes sections paved at 275° F, monitored and not monitored during paving.

APPENDIX C

STATE OF VERMONT

No. 422

Design of Bituminous Concrete Mixtures

Town RYEGATE - BARNET Project No. I-91-2(27) ST. II

Gentlemen:

In accordance with the specification requirements for the above project I submit the following job mix formula:

Pavement Type II Produced By: PIKE IND. INC. Plant Location RYEGATE VT 803

Stockpile Gradations — % Passing

Size	% Used	1¾	1½	1	¾	½	⅜	4	8	16	30	50	200	
SAND	30					100	96	90	82	70	64	29	5	
DUST	15						100	98	76	52	36	26	13	
3/8	22					100	94	29	8					
1/2	5				100	98	25	4						
3/4	28			100	92	28	4							
Resultant	100			100	98	80	67	47	38	29	24	13	3.5	

Hot Bin Gradation — % Passing

Bin	% Used	1¾	1½	1	¾	½	⅜	4	8	16	30	50	200	
S	43							100	84	67	53	30	8.1	
2	25						100	30	6					
3	5					100	26	4						
4	27				100	22	3							
5														
Resultant	100			100	~~98~~	~~100~~ 79	69	50	38	29	23	13	3.5	

Batch Weights	Bin S	Bin No. 2	Bin No. 3	Bin No. 4	Bin No. 5	AC	Total
	4076	2370	474	2560		520	10,000

		1¾	1½	1	¾	½	⅜	4	8	16	30	50	200	AC
Job Mix Formula				100	98	80	68	48	38	30	24	15	4	5.2
Job Aim		/	/	/	/	/	/	/	/	/	/	/	/	/
Specification Limits		/	/	100/100	95/100	76/88	62/82	44/62	30/48	20/38	13/30	8/22	2/5	5/7

Source of Materials

Aggregates	Asphalt
Coarse: PIKE - RYEGATE VT.	AC-5:
	150-200 - GULF - CANADA
Fine: DUST - PIKE - RYEGATE VT.	AC-10:
SAND - CALKINS - ST. JOHNSBURY VT.	
	Other:

Mixing Times — Dry: 4 Wet: 36 Total: 40 Temperature: 275±20

Submitted by: Charles C. Holcomb (signature) Date: 8/22/77

Company PIKE IND. INC. Title VICE PRES.

FOR STATE OF VERMONT USE ONLY

Approved ✓ Rejected .....

Comments: This mix design supercedes #415 to reflect the new aggregate texture.

Signature [illegible] Title Bit. Concrete Engr.

Date 8/22/77

RECEIVED AUG 22 1977 HIGHWAY TEST. LAB.

HD 554 500 Dup. 5-76

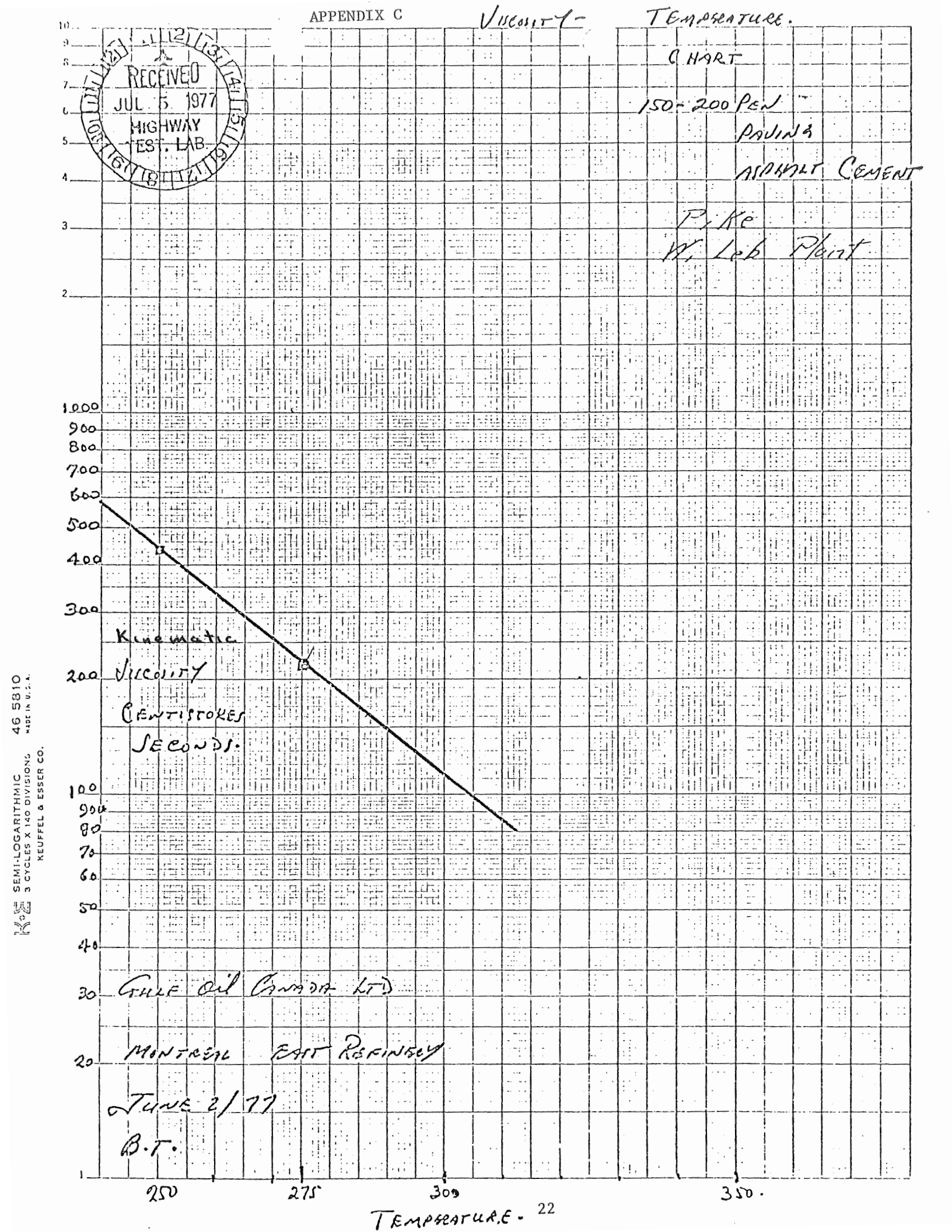
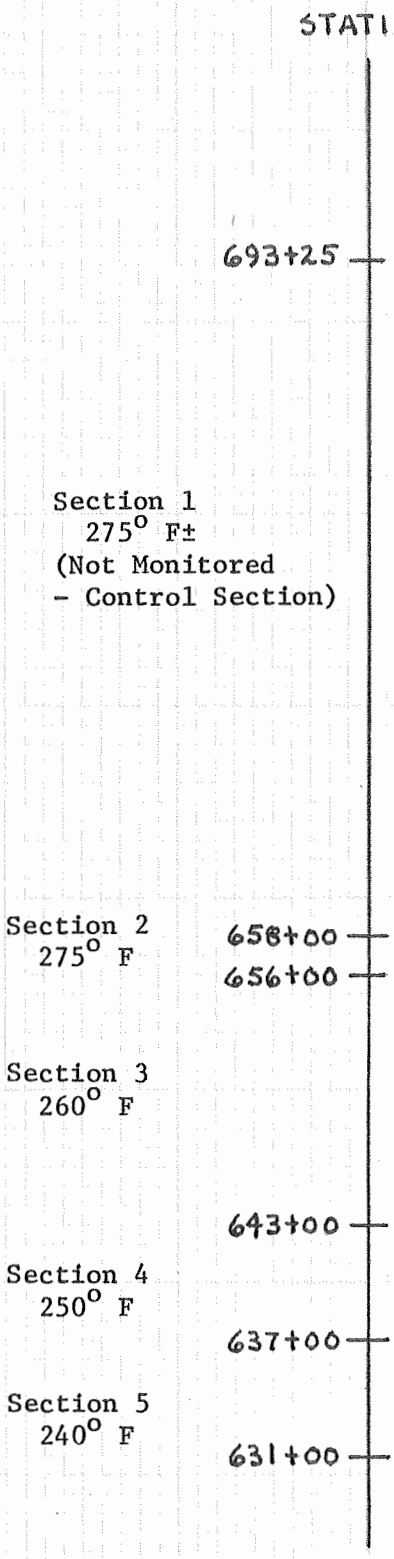

VISCOSITY - TEMPERATURE.
CHART
150-200 PEN
PAVING
ASPHALT CEMENT
PIKE
MTL LAB PLANT
RECEIVED
JUL 5 1977
HIGHWAY
EST. LAB
10
9
8
7
6
5
4
3
2
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
1
Kinematic
VISCOSITY
CENTISTOKES
SECONDS.
GULF OIL CANADA LTD
MONTREAL EAST REFINERY
JUNE 2/77
B.T.
250
275
300
350.
TEMPERATURE.
SEMI-LOGARITHMIC
3 CYCLES X 140 DIVISIONS
KEUFFEL & ESSER CO.
46 5810
MADE IN U.S.A.

FIGURE 1

STUDY LOCATION: I 91 SOUTHBOUND
RYEGATE-BARNET I 91-2 (27) S/II
PAVED SEPTEMBER 8, 1977
STA. 693+25 to STA. 631+00



	Percent Air Voids	Ross Count	Percent Compaction Q.C.	Percent Compaction S.R.	Inches/Mile Roughness
Section 1 275° F± (Not Monitored - Control Section)	4.3	100	98.0		41.5*
Section 2 275° F		100	98.8	100.1	55.5*
Section 3 260° F	2.8	100	96.1*	98.1	35.1
Section 4 250° F	3.1	98	94.9*	97.8*	32.5
Section 5 240° F	3.8	95	93.6*	97.8*	58.9*

Q.C. - Tests performed under Quality Control Program

S.R. - Tests done on Special Request.

* - Test values outside acceptance limits.

FIGURE 2

AIR VOIDS OF COMPACTED MIXTURE
AS DETERMINED BY MARSHALL METHOD

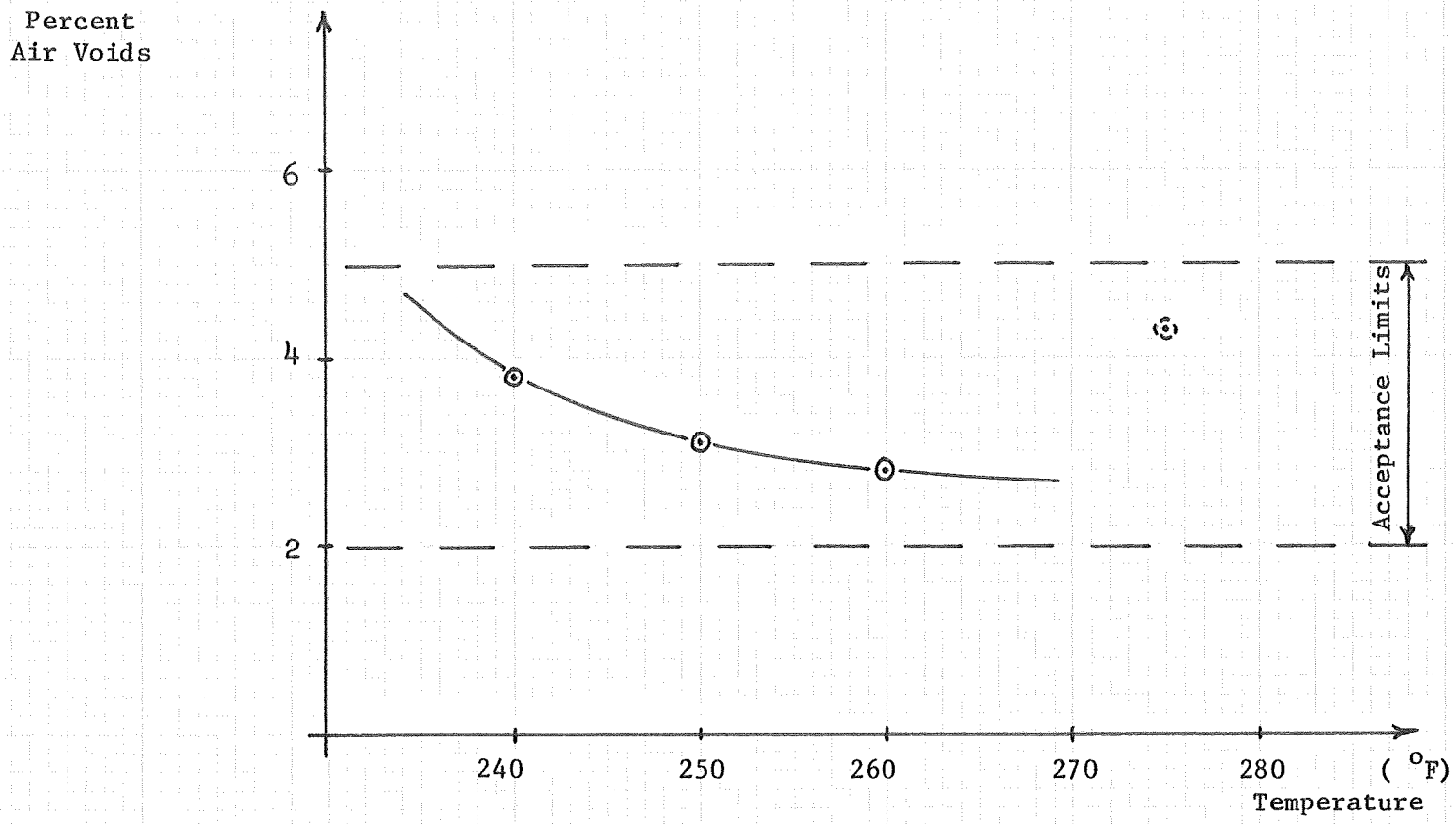


FIGURE 3

ROSS COUNT

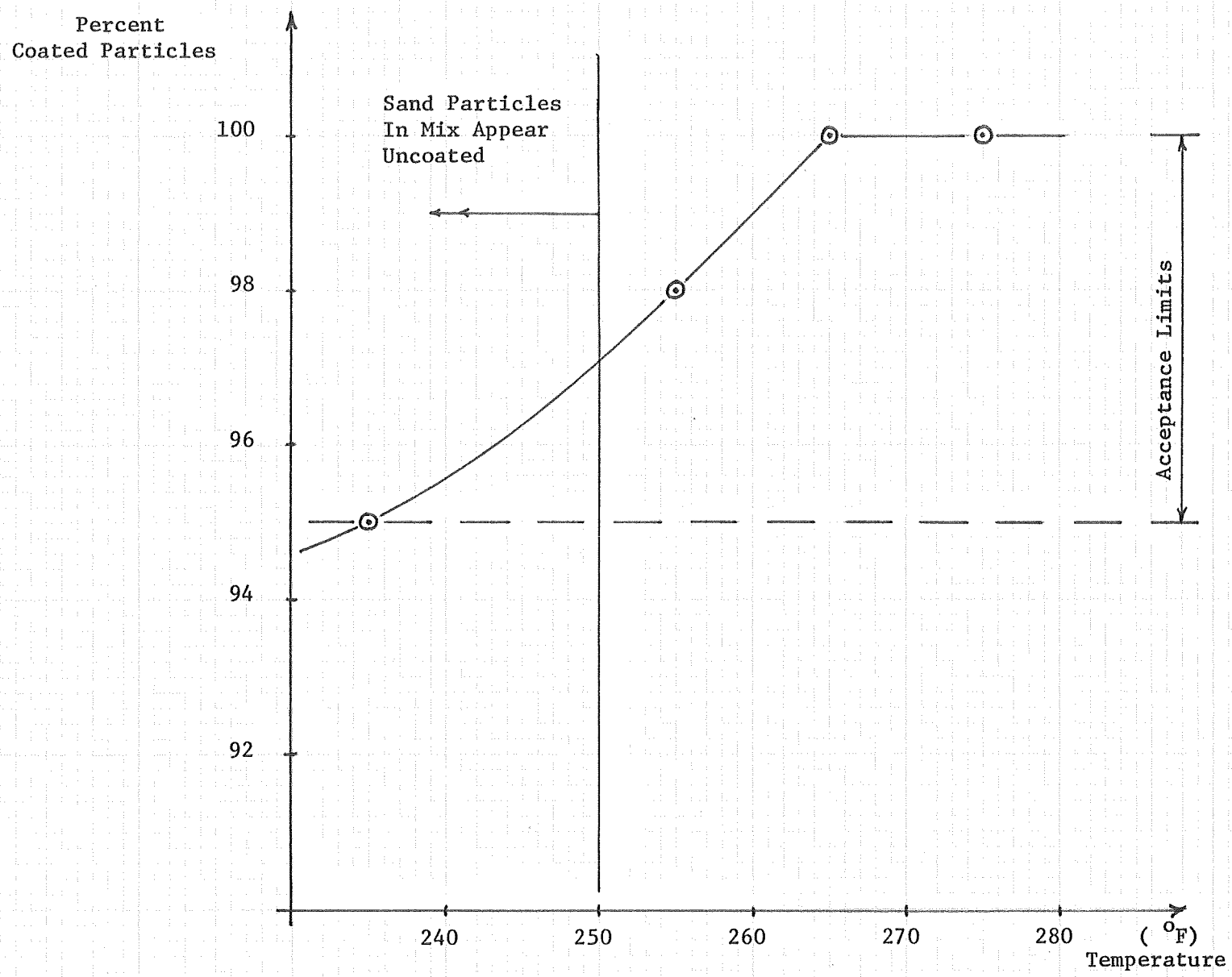


FIGURE 4

COMPACTION ACHIEVED RELATIVE TO
TARGET DENSITY

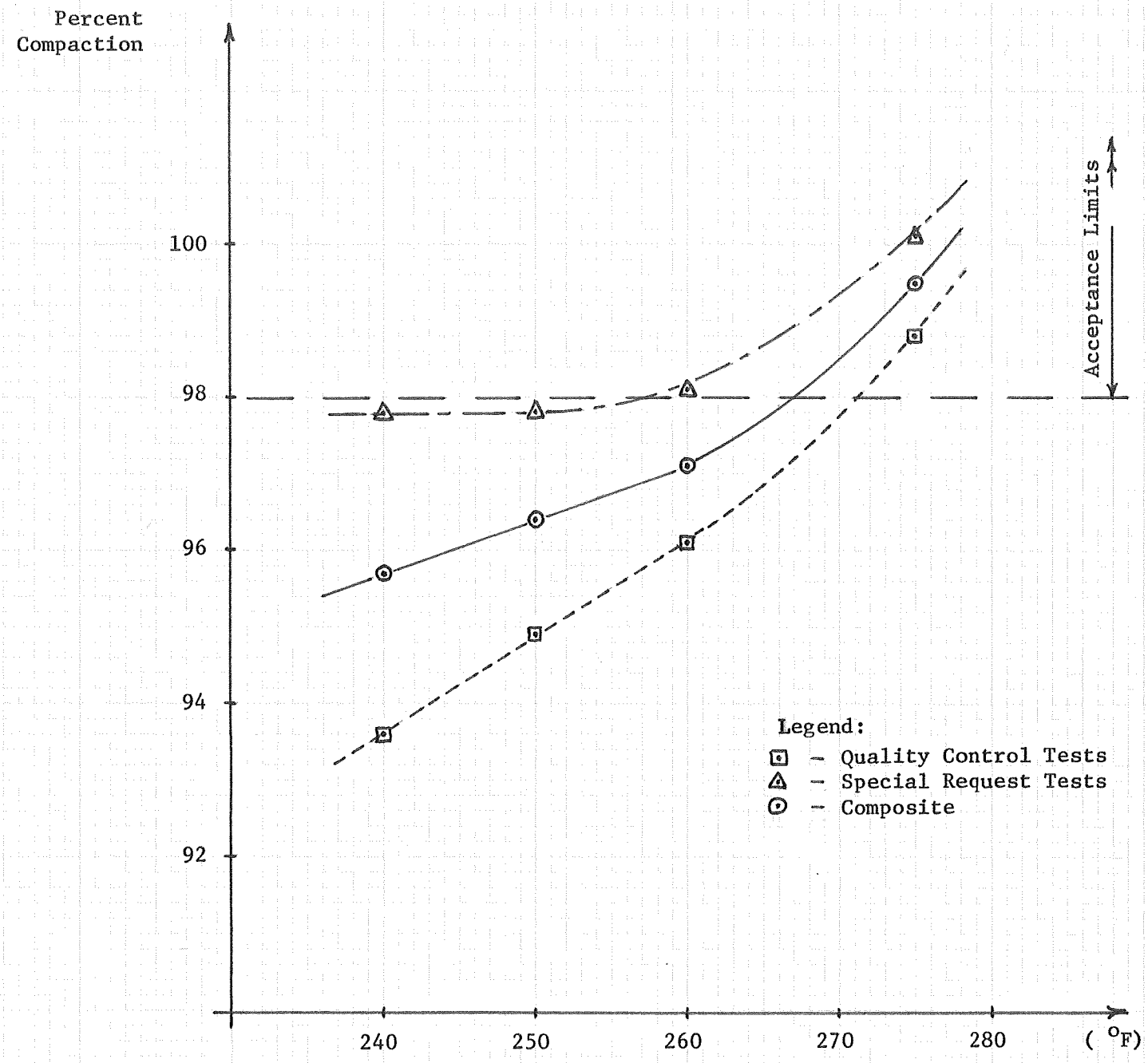


FIGURE 5

SURFACE CHARACTERISTICS-ROUGHNESS
MAY'S RIDE METER