CHAPTER 4

DESIGN AND TESTING OF SULPHUR EXTENDED ASPHALT MIXES

4.1 General

In this experiment, 2 gradations of aggregate which conform to the DOH specification limits were used. One is for the determination of optimum SEA binder content; the other is for the study of the influence of compaction temperature on stability levels and unit weight of mixtures.

4.2 Plan of experiments

4.2.1 Determination of optimum binder content

In this series of experiments using the first grading, 5 SEA binder percentages* will be used, namely 20-80, 30-70, 40-60, 50-50 and 60-40. These are the weight percent of sulphur-asphalt in the SEA binder. Four levels of SEA binder content in terms of percent by weight of aggregates will be investigated for each of SEA binder percentages. These represent the lower binder concentration feasible, the upper binder content feasible and two intermediate values. For each experiment, three specimens will be tested. Thus a total of 5 x 4 x 3 = 60 specimens will be tested. In addition, a 0-100 SEA binder percentage, i.e. pure asphalt cement, is used as control percentage. For this project 5 percentages of A.C. by weight of aggregate, namely 4.5 %, 5.0%, 5.5%, 6.0%, and 6.5% will be adopted. Therefore for the control experiment, 5 x 3 = 15 tests will be conducted. In summary then, a total of 75 specimens will be tested.

4.2.2 Influence of compaction temperature

Using the second gradation, 5 levels of SEA binder percentage, 4 levels of compaction temperature and 3 specimens for each temperature, a total of 5 x 4 x 3 = 60 samples will be tested to investigate the influence of compaction temperature on stability of the design mixtures. The SEA binder contents which give maximum stability values for each of the SEA binder percentages which yields the maximum stability will be employed.

* See Glossary

4.3 Control experiments

It should be noted that from control experiments, the optimum bitumen content determined will be used as the lower binder concentration for SEA; it will also be used in determing the upper binder content. The steps involved in carrying control experiments are as follows:

a) Compute of amount of aggregates required for preparation of samples or specimens, which conform to specification limits. Table 11 shows result of the computation.

b) Determine the amount of asphalt binder required as shown in Table 12.

c) Prepare specimens to be tested in accordance with ASTM designation D 1559-76.

d) Conduct tests on the specimen, results are as tabulated in Table 13. and plotted in Figures 7-12.

e) Determine the optimum asphalt content which is the average of:
   - Asphalt content at maximum stability.
   - Asphalt content at maximum unit weight.
   - Asphalt content at 4 % air voids

4.3.1 Determination of optimum asphalt content.

From Figures 7, 9, 10, the values of asphalt content are:

Asphalt content at maximum stability	= 5.50 %
Asphalt content at maximum unit weight	= 5.80 %
Asphalt content at 4 % air voids	= 5.05 %
Thus, optimum asphalt content	= 5.45 %

This value represents the lower binder content feasible of SEA.

4.4 Design of SEA Mixes

The current state-of-the-art for designing SEA mixes(16) utilizes conventional Marshall or Hveem design methods with well graded aggregates conforming to a particular organization's specifications. In the present study the Marshall design procedure is employed. The procedure is fully described in the Asphalt Institute Manual series No. 2 (MS-2)(31) and in the ASTM standard designation D. 1559, given in Appendix B.

Optimum SEA binder levels are determined from guideline manual for design(16) as follows:

1) Determine the optimum asphalt content of a mix with an asphalt binder. Note that this value will represent the lower binder concentration feasible for SEA.

2) Select a sulphur substitution level (i.e. 20-, 30-pct, etc.) and calculate the SEA binder content in a mix in which an equal volume of SEA binder replaces the asphalt in the optimum asphalt mix of step 1 above using equations 4.1 or 4.2 below. Note that this is the upper SEA binder concentration feasible and represents a 2 for 1 weight substitution of sulphur for asphalt.

3) Using the values obtained in steps 1 and 2 above as maximum and minimum parameters, establish intermediate points at uniform increments for use in laboratory justification tests.

4) Perform Marshall justification tests and determine the optimum SEA binder concentration.

The SEA binder content in step 2 may be calculated using either of the following formulas:

$$\text{SEA (Equal volume replacement) wt-pct} = \frac{10000\,AR}{10000R - 1000P_s(R-1) + AP_s(R-1)} \quad \ldots 4.1$$

$$\text{SEA (Approximate equal volume replacement) wt-pct} = \frac{200A}{200-P_s} \quad \ldots 4.2$$

Equation 4.1 will produce the mathematical equivalent volume replacement of asphalt with sulphur when $R = \frac{G_s}{G_a}$

Where: A = Weight percent A/C in conventional design,

R = Sulphur substitution ratio,

P_s = Weight percent sulphur in the SEA binder.

G_a = Specific gravity of asphalt at ambient temperature,

G_s = Specific gravity of sulphur at ambient temperature.

Table 11. Calculation of the amount of each size of aggregate used in sea mix design.

	% PASSING			% RETAINED ON		WT. OF 1 SAMPLE (GRM)		WT. OF 3 SAMPLES (GRM)	
SIEVE SIZE (US)	SPEC.	1st GRAD.	2nd GRAD.	1st GRAD.	2nd GRAD.	1st GRAD.	2nd GRAD	1st GRAD.	2nd GRAD.
				(1)	(2)	$(1) \times \frac{1200}{100} = (3)$	$(2) * \frac{1200}{100} = (4)$	(3) x 3	(4) x 3
3/4 IN.	100	100	100	0	0	0	0	0	0
3/8 IN.	60-80	75	85	25	15	300	180	900	540
NO. 4	40-65	55	65	20	20	240	240	720	720
NO. 8	30-50	38	47	17	18	204	216	612	648
NO. 16	20-40	28	37	10	10	120	120	360	360
NO. 30	15-35	20	27	8	10	96	120	288	360
NO. 50	10-25	15	20	5	7	60	84	180	252
NO. 100	7-17	10	10	5	10	60	120	180	360
NO. 200	5-9	5	5	5	5	60	60	180	180
ON PAN	0	0	0	5	5	60	60	180	180
			TOTAL	100		1200	1200	3600	3600

Table 12. Amount of asphalt binder used in control experiment.

% ASPHALT BINDER (BY WEIGHT)	WT. OF ASPHALT BINDER (FOR 15 SAMPLES) - GRAMS
4.5	162
5.0	180
5.5	198
6.0	216
6.5	234

Table 13. Bituminous mix design data by the Marshall method

SP.GR.AC 1.02
AVG.SP.GR.BLEND 2.72
PEN.GRADE AC 80-100

PROVING RING CONSTANT 4.543 KG/DIV.
75 BLOW COMPACTION

S-AC %
0-100

%EFF AC = $\frac{b-(100-b) \times X}{100}$
WHERE X = BINDER ABSORPTION KG OF AC OR SEA. PER 100 KG OF AGG, X = 0.4%

% AC SPEC NO.	% AC SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS IN AIR	WEIGHT-GRAMS SAT. SUR. DRY	WEIGHT-GRAMS IN WATER	BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL AC	VOLUME-%TOTAL AGG.	VOLUME-%TOTAL %AIR VOIDS	VOID -% %VMA	VOID -% %VFB	STABILITY-KG MEAS.	STABILITY-KG ADJUST.	FLOW (0.25 mm)
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	q	r
% AC BY WT OF AGG	% AC BY WT. OF MIX	%EFF. AC BY WT. OF MIX					d1-e	d/f	$\frac{b1 \times g}{Gsea}$	$\frac{(100-b)}{Gag/g}$	100-i -j	100-j	$\frac{i \times 100}{l}$			
			6.228	1196.0	1201.5	706.3	495.2	2.415						767	782	14
4.5	4.31	3.93	6.246	1203.5	1210.1	712.4	497.7	2.418						857	870	12
			6.580	1209.0	1212.3	710.0	502.3	2.407						791	751	9
							AVG.	2.413	9.30	85.20	5.50	14.8	62.82	AVG.	801	12
			6.176	1203.3	1205.5	717.2	492.3	2.444						1045	1091	15
5.0	4.76	4.38	6.454	1196.9	1200.4	706.8	493.6	2.424						954	930	18
			6.565	1240.9	1242.7	730.1	512.6	2.421						999	989	17
							AVG.	2.430	10.41	85.22	4.37	14.78	70.43	AVG.	1003	17
			6.508	1263.0	1265.0	751.5	513.5	2.460						1244	1194	18
5.5	5.21	4.84	6.281	1217.1	1218.7	720.7	498.4	2.444						1096	1121	19
			6.169	1204.7	1205.7	715.1	490.6	2.456						1110	1153	16
							AVG.	2.453	11.64	85.80	2.56	14.20	81.97	AVG.	1156	18

Table 13. (Cont.)

SP.GR.AC 1.02
AVG.SP.GR.BLEND 2.72
PEN.GRADE AC 80-100

PROVING RING CONSTANT 4.543 KG/DIV.

75 BLOW COMPACTION

S-AC %

%EFF AC = $\frac{b-(100-b) \times X}{100}$

WHERE X = BINDER ABSORPTION KG OF AC OF SEA. PER 100 KG OF AGG, X = 0.4%

% AC SPEC NO.	% AC SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS			BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL			VOID -%		STABILITY-KG		FLOW (0.25 mm)
				IN AIR	SAT. SUR. DRY	IN WATER			AC	AGG.	%AIR VOIDS	%VMA	%VFB	MEAS.	ADJUST.	
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	q	r
% AC. BY WT. OF AGG	% AC BY WT. OF MIX	%EFF. AC BY WT. OF MIX					d1-e	d/f	$\frac{b1 \times g}{Gsea}$	$\frac{(100-b)}{Gag/g}$	100-i -j	100-j	$\frac{i \times 100}{l}$			
			6.255	1219.0	1220.2	722.3	497.9	2.448						1045	1070	20
6.0	5.66	5.28	6.177	1205.6	1206.5	715.3	491.2	2.454						907	947	19
			6.141	1197.7	1199.0	711.0	433.0	2.454						907	957	20
							AVG.	2.452	12.76	85.81	1.43	14.49	89.92	AVG.	991	20
			6.309	1235.6	1236.8	731.8	505.0	2.447						818	826	24
6.5	6.10	5.72	6.214	1219.9	1200.5	704.3	496.2	2.458						818	826	20
			6.373	1243.8	1245.4	736.5	508.9	2.444						999	993	20
							AVG.	2.450	13.74	84.89	1.37	15.11	90.90	AVG.	888	21

4.5 Preparation and testing of samples

4.5.1 Preparation of SEA binder

There are two methods for preparing the SEA binder. The first involves preheating of reguired amounts of sulphur and asphalt to the 121° to 149°C temperature range before blending them together.(See Fig. 13). The second method is by weighing the individual amounts of sulphur and asphalt into a steel bowl and heat in the oven at 138° to 149°C for five minutes. This method was used in the present experiment.

4.5.2 Preparation of samples for determining optimum binder percentage

For each of the SEA binder percentages, 4 levels of SEA binder concentration were used. These are, the lower point, 2 intermediate points and the upper point. Table 14 shows the calculation of specfic gravity of SEA binder at each particular percentage of sulphur and asphalt. The upper point binder contents were computed as in Table 15. For each of the SEA binder percentages, the 4 values of binder content used to final the optimum binder value, are tabulated in Table 16. The quantities of sulphur and asphalt used in triplicate samples for each level of SEA binder concentration and each level of SEA binder percentage are given in Table 17.

The samples were prepared according to the standard Marshall procedures with certain modifications as recommended by Mcbee The modified Marshall method is given in Appendix C.

4.5.3 Preparation of samples for investigation of influence of compaction temperature

The SEA binder percentages used in the investigation of compaction temperature effects on stabilily level are the same as previous experiments namely, 20-80, 30-70, 40-50, 50-50 and 60-40 However, for studying the influence of temperature on the unit weight of samples, only the 40-60 percentage was used; this is the optimum SEA binder percentage as determined from the first series of experiment.

Four compaction temperature levels were employed for each binder percentage. These are 104°C (220°F), 116°C (240°F), 127°C (260°F) and 138°C (280°F).

The SEA binder concentrations used in the investigation were those that gave maximum stablity values as determined in the first series of experiments. Table 18 gives the amounts of SEA binder required for triplicate samples as well as the individual amounts of sulphur and asphalt.

The samples were prepared in accordance with the modified Marshall method.

4.5.4 Testing of samples

All samples were tested in accordance with Marshall procedure as listed in section 4 of Appendix B. Results of the experiment for determination of the optimum SEA binder percentage are tabulated in Tables 19, 20, 21, 22, and 23. Results of tests on the effects of compaction temperature on stability levels and unit weight of mixtures are given in Tables 24, 25, 26, 27 and 28.

Table 14. Calculation of specific gravity of sea binder.

$P_s - P_a$ % BY WEIGHT	$G_{SEA} = \dfrac{100}{\dfrac{P_s}{G_s} + \dfrac{P_a}{G_a}}$, $G_s = 2.00$, $G_a = 1.02$
20 - 80	1.13
30 - 70	1.20
40 - 60	1.27
50 - 50	1.35
60 - 40	1.44

Table 15. Calculation of the upper points of sea binder

THE OPTIMUM AC. CONTENT BY WT. OF AGGREGATE IS 5.45%
OR 5.17% = A, BY WT. OF MIX.

$G_{ac} = 1.02$, $G_{sulphur} = 2.00$, $R = \frac{2.00}{1.02} = 1.96$

% BY WT.	UPPER POINTS	
	% BY WT. OF MIX	% BY WT. OF AGG.
$P_s - P_a$	$\frac{10000\ AR}{10000R-100P_s(R-1)-AP_s(R-1)}$ (B)	$\frac{100(B)}{100-(B)}$
20-80	5.70	6.04
30-70	6.01	6.39
40-60	6.35	6.78
50-50	6.73	7.22
60-40	7.17	7.72

Table 16. The lower, intermediate & upper points of sea binder

$P_s - P_a$	% BINDER BY WT. OF AGGREGATE			
	LOWER POINT	INTERMEDIATE POINTS		UPPER POINT
20-80	5.45	5.65	5.85	6.04
30-70	5.45	5.75	6.05	6.39
40-70	5.45	5.90	6.35	6.78
50-50	5.45	6.05	6.65	7.22
60-40	5.45	6.02	6.95	7.72

Table 17. Amounts of sulphur and asphalt used in 3 samples at each point (grams)

$P_s - P_a$	LOWER POINT			INTERMEDIATE POINT			INTERMEDIATE POINT			UPPER POINT		
% BY WT.	WT. OF SEA. BINDER	WT. OF SULPHUR	WT. OF AC.	WT. OF SEA. BINDER	WT. OF SULPHUR	WT. OF AC.	WT. OF SEA. BINDER	WT. OF SULPHUR	WT. OF AC.	WT. OF SEA. BINDER	WT. OF SULPHUR	WT. OF AC.
20-80	196.20	39.24	156.96	203.40	40.68	162.72	210.60	42.12	168.48	217.44	43.49	173.95
30-70	196.20	58.86	137.34	207.00	62.10	144.90	217.80	65.34	152.46	230.04	69.01	161.03
40-60	196.20	78.48	117.72	212.40	84.96	127.44	228.60	91.44	137.16	244.08	97.63	146.45
50-50	196.20	98.10	98.10	217.80	108.90	108.90	239.40	119.70	119.70	259.92	129.96	129.96
60-40	196.20	117.72	78.48	223.20	133.92	98.28	250.20	150.12	100.08	277.92	166.75	111.17

Table 18. Amount of SEA (sulphur & asphalt) used.

P_s-P_a	% SEA BINDER AT MAX. STABLITY	WT. OF BINDER OF 3 SAMPLES - GRAMS		
		WT. OF SEA BINDER	WT. OF SULPHUR	WT. OF AC.
20-80	5.90	212.40	42.48	169.92
30-70	5.80	208.80	62.64	146.16
40-60	5.82	209.52	83.81	125.71
50-50	5.78	208.08	104.04	104.04
60-40	5.86	210.96	126.58	84.38

Table 19. SEA mix design data for binder percentage of 20-80

SP.GR.SULPHUR 2.00 SP.GR.AC 1.02 AVG.SP.GR.BLEND 2.72 PEN.GRADE AC 80-100	PROVING RING CONSTANT 4.543 KG/DIV. SP.GR.SEA 1.13 75 BLOW COMPACTION	S-AC % 20-80	%EFF SEA = $\frac{b-(100-b) \times X}{100}$ WHERE X = BINDER ABSORPTION KG OF AC OR SEA. PER 100 KG OF AGG, X = 0.4%

% SEA SPEC NO.	%SEA SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS			BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL			VOID -%		STABILITY-KG		FLOW (0.25 mm)
				IN AIR	SAT. SUR. DRY	IN WATER			SEA	AGG.	%AIR VOIDS	%VMA	%VFB	MEAS.	ADJUST.	
a	b	bl	c	d	dl	e	f	g	i	j	k	l	m	p	q	r
%SEA BY WT OF AGG	%SEA BY WT. OF MIX	%EFF. SEA BY WT. OF MIX					dl-e	d/f	$\frac{bl \times g}{Gsea}$	$\frac{(100-b)}{\frac{Gag}{g}}$	100-i -j	100-j	$\frac{i \times 100}{l}$			
			5.583	1104.5	1105.1	645.1	460.0	2.401						777	964	22
5.45	5.17	4.79	5.299	1057.4	1058.2	613.0	445.2	2.375						703	959	22
			5.820	1162.3	1162.9	671.4	491.5	2.365						818	945	24
							AVG.	2.380	10.09	83.28	6.63	16.72	60.35	AVG.	956	23
			5.493	1085.7	1086.1	631.8	454.3	2.390						750	959	23
5.65	5.35	4.97	5.440	1080.3	1080.5	630.0	450.5	2398						736	959	24
			5.664	1127.0	1127.2	658.6	468.6	2.405						799	966	23
							AVG.	2.398	10.55	83.75	5.70	16.25	64.92	AVG.	961	23
			5.425	1082.6	1083.0	631.2	451.8	2.396						750	981	24
5.85	5.53	5.15	5.670	1133.2	1133.6	662.2	471.4	2.404						863	1041	24
			5.793	1156.2	1156.5	672.9	483.6	2.391						790	920	26
							AVG.	2.397	10.92	83.56	5.52	16.44	66.42	AVG.	981	25
			4.416	925.0	925.2	536.9	388.3	2.382						491	959	25
6.04	5.69	5.32	5.139	1026.9	1027.1	597.6	429.5	2.391						704	1014	27
			4.805	952.0	952.3	550.8	401.5	2.371						559	916	26
							AVG.	2.381	11.21	82.86	5.93	17.14	65.40	AVG.	963	26

Table 20. SEA mix design data for binder percentage of 30-70

SP.GR.SULPHUR 2.00
SP.GR.AC 1.02
AVG.SP.GR.BLEND 2.72
PEN.GRADE AC 80-100

PROVING RING CONSTANT 4.543 KG/DIV.
SP.GR.SEA 1.20
75 BLOW COMPACTION

S-AC %
30-70

%EFF SEA = $\frac{b-(100-b) \times X}{100}$
WHERE X = BINDER ABSORPTION KG OF AC OR SEA.
PER 100 KG OF AGG, X = 0.4%

% SEA SPEC NO.	%SEA SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS IN AIR	SAT. SUR. DRY	IN WATER	BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL SEA	AGG.	%AIR VOIDS	VOID -% %VMA	%VFB	STABILITY-KG MEAS.	ADJUST.	FLOW (0.25 mm)
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	q	r
%SEA BY WT OF AGG	%SEA BY WT. OF MIX	%EFF. SEA BY WT. OF MIX					d1-e	d/f	$\frac{b1 \times g}{Gsea}$	$\frac{(100-b)}{\frac{Gag}{g}}$	100-i -j	100-j	$\frac{i \times 100}{l}$			
			5.166	1035.0	1035.6	606.7	428.9	2.413						727	1037	18
5.45	5.17	4.79	5.117	1025.3	1025.5	602.0	423.5	2.421						691	1002	22
			5.506	1099.0	1099.1	644.8	454.3	2.419						826	1052	21
							AVG.	2.418	9.65	84.61	5.74	15.39	62.70	AVG.	1030	20
			5.371	1077.0	1077.1	632.6	444.5	2.423						795	1060	20
5.75	5.44	5.06	5.789	1160.0	1160.4	684.2	476.2	2436						945	1101	22
			5.539	1097.0	1097.3	645.5	451.8	2.428						863	1087	20
							AVG.	2.429	10.24	84.76	5.00	15.24	67.19	AVG.	1083	21
			5.299	1059.3	1059.6	624.2	435.4	2.433						736	1004	23
6.05	5.70	5.32	6.077	1211.5	1211.7	712.2	499.5	2.425						949	1021	22
			5.741	1147.5	1147.9	637.7	474.2	2.420						859	1013	21
							AVG.	2.426	10.76	84.42	4.82	15.58	69.06	AVG.	1013	22
			5.518	1087.0	1087.0	636.3	450.7	2.412						768	974	26
6.39	6.01	5.63	5.459	1082.6	1082.8	636.2	446.6	2.424						795	1029	23
			5.672	1124.5	1125.0	657.4	467.6	2.405						827	996	27
							AVG.	2.414	11.33	83.72	4.95	15.28	69.59	AVG.	1000	25

Table 21. SEA mix design data for binder percentage of 40-60

SP.GR.SULPHUR 2.00 SP.GR.AC 1.02 AVG.SP.GR.BLEND 2.72 PEN.GRADE AC 80-100	PROVING RING CONSTANT 4.543 KG/DIV. SP.GR.SEA 1.27 75 BLOW COMPACTION	S-AC % 40-60	%EFF SEA = $\frac{b-(100-b) \times X}{100}$ WHERE X = BINDER ABSORPTION KG OF AC OR SEA. PER 100 KG OF AGG, X = 0.4%

% SEA SPEC NO.	%SEA SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS IN AIR	SAT. SUR. DRY	IN WATER	BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL SEA	AGG.	%AIR VOIDS	VOID -% %VMA	%VFB	STABILITY-KG MEAS.	ADJUST.	FLOW (0.25 mm)
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	q	r
%SEA BY WT. OF AGG	%SEA BY WT. OF MIX	%EFF. SEA BY WT. OF MIX					d1-e	d/f	$\frac{b1 \times g}{Gsea}$	$\frac{(100-b)}{\frac{Gag}{g}}$	100-i -j	100-j	$\frac{i \times 100}{l}$			
			6.057	1191.5	1193.0	699.4	493.6	2.414						1826	1975	14
5.45	5.17	4.79	5.120	1026.4	1026.9	603.6	423.3	2.425						1399	2029	12
			5.350	1076.7	1077.1	633.8	443.3	2.429						1372	1841	14
							AVG.	2.419	9.12	84.65	6.23	15.35	59.41	AVG.	1948	13
			6.435	1291.5	1292.5	762.6	529.9	2.437						2144	2090	14
5.90	5.57	5.19	6.242	1252.5	1253.0	739.5	513.5	2.439						2044	2100	16
			5.743	11.7.4	11.7.5	652.0	455.5	2.431						1763	2079	14
							AVG.	2.436	9.95	84.88	5.17	15.12	65.81	AVG.	2093	15
			5.698	1203.9	1204.2	714.0	490.2	2.456						1649	1830	18
6.35	5.97	5.59	6.500	1295.3	1295.6	760.2	535.4	2.419						1790	1723	19
			6.078	1210.2	1211.0	711.4	499.6	2.422						1758	1890	17
							AVG.	2.432	10.70	84.38	4.92	15.62	98.50	AVG.	1814	18
			5.887	1181.6	1181.9	692.0	490.9	2.407						1249	1418	24
6.78	6.35	5.98	6.106	1231.6	1231.9	720.2	511.7	2.407						1549	1652	20
			6.717	1352.1	1352.2	793.4	558.7	2.420						1699	1560	21
							AVG.	2.411	11.35	83.32	5.33	16.68	68.05	AVG.	1543	21

Table 22. SEA mix design data for binder percentage of 50-50

SP.GR.SULPHUR 2.00
SP.GR.AC 1.02
AVG.SP.GR.BLEND 2.72
PEN.GRADE AC 80-100

PROVING RING CONSTANT 4.543 KG/DIV.
SP.GR.SEA 1.35
75 BLOW COMPACTION

S-AC %
50-50

$$\%EFF\ SEA = b - \frac{(100-b) \times X}{100}$$

WHERE X = BINDER ABSORPTION KG OF AC OR SEA.
PER 100 KG OF AGG, X = 0.4%

% SEA SPEC NO.	%SEA SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS IN AIR	SAT. SUR. DRY	IN WATER	BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL SEA	AGG.	%AIR VOIDS	VOID -% %VMA	%VFB	STABILITY-KG MEAS.	ADJUST.	FLOW (0.25 mm)
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	q	r
%SEA BY WT OF AGG	%SEA BY WT. OF MIX	%EFF. SEA BY WT. OF MIX					d1-e	d/f	b1 x g / Gsea	(100-b) / Gag g	100-i -j	100-j	i x 100 / l			
			6.095	1194.6	1195.9	694.8	501.1	2.384						3089	3305	12
5.45	5.17	4.79	6.158	1223.5	1224.3	713.7	510.6	2.396						3139	3296	11
			6.192	1210.0	1213.4	713.2	500.2	2.419						3180	3306	8
							AVG.	2.400	8.52	83.98	7.50	16.02	53.18	AVG.	3302	10
			6.310	1251.3	1251.6	732.0	519.6	2.408						3239	3272	9
6.05	5.70	5.32	5.919	1167.9	1169.0	690.2	478.8	2.439						3080	3464	10
			6.714	1346.2	1346.9	790.4	556.5	2.419						3648	3353	13
							AVG.	2.420	9.54	84.21	6.25	15.79	60.42	AVG.	3363	11
			6.353	1272.9	1273.1	754.2	518.9	2.453						2576	2574	10
6/65	6.24	5.86	6.789	1166.0	1166.5	697.4	469.1	2.486						2317	2700	11
			6.364	1264.4	1265.5	749.6	515.9	2.451						2626	2617	12
							AVG.	2.463	10.69	85.21	4.1	14.79	72.28	AVG.	2630	11
			6.707	1341.5	1342.0	791.8	550.2	2.483						2431	2238	12
7.22	6.73	6.36	6.130	1229.7	1230.0	718.5	511.5	2.404						2076	2198	13
			6.107	1233.0	1233.2	717.7	515.5	2.392						2053	2189	10
							AVG.	2.411	11.36	82.98	5.66	17.02	66.75	AVG.	2208	12

Table 23. SEA mix design data for binder percentage of 60-40

SP.GR.SULPHUR 2.00
SP.GR.AC 1.02
AVG.SP.GR.BLEND 2.72
PEN.GRADE AC 80-100

PROVING RING CONSTANT 4.543 KG/DIV.
SP.GR.SEA 1.44
75 BLOW COMPACTION

S-AC %
60-40

%EFF SEA = $\frac{b-(100-b) \times X}{100}$
WHERE X = BINDER ABSORPTION KG OF AC OR SEA. PER 100 KG OF AGG, X = 0.4%

% SEA SPEC NO.	%SEA SPEC NO.		SPEC HGT. (CM)	WEIGHT-GRAMS IN AIR	SAT. SUR. DRY	IN WATER	BULK VOL. (CC)	UNIT WEIGHT (G/CC)	VOLUME-%TOTAL SEA	AGG.	%AIR VOIDS	VOID -% %VMA	%VFB	STABILITY-KG MEAS.	ADJUST.	FLOW (0.25 mm)
a	b	b1	c	d	d1	e	f	g	i	j	k	l	m	p	c	r
%SEA BY WT. OF AGG	%SEA BY WT. OF MIX	%EFF. SEA BY WT. OF MIX					d1-e	d/f	$\frac{b1 \times g}{Gsea}$	$\frac{(100-b)\frac{Gag}{g}}{}$	100-i-j	100-j	$\frac{i \times 100}{l}$			
			6.507	1250.0	1252.5	727.7	524.8	2.328						5284	5076	11
5.45	5.17	4.79	6.054	1152.6	1154.2	671.2	483.0	2.386						4816	5044	13
			6.442	1234.0	1237.1	717.4	519.7	2.374						5147	5029	9
							AVG.	2.381	7.92	83.32	8.76	16.68	47.48	AVG.	5050	11
			6.079	1213.9	1213.9	708.4	505.5	2.400						4861	5224	14
6.20	5.84	5.46	6.400	1287.1	1288.1	757.8	530.3	2.427						5315	5249	12
			5.942	1156.7	1158.8	684.0	474.8	2.436						4666	5214	14
							AVG.	2.421	9.18	84.12	6.7	15.88	57.81	AVG.	5229	13
			6.373	1243.5	1246.5	745.3	501.2	2.481						3998	3974	15
6.95	6.50	6.13	6.033	1202.1	1202.5	718.7	483.8	2.485						3816	4156	14
			6.318	1248.5	1249.9	751.5	498.4	2.505						4089	4121	13
							AVG.	2.490	10.60	85.91	3.49	14.09	75.23	AVG.	4084	14
			6.482	1304.2	1304.4	763.7	540.7	2.412						3498	3383	14
7.72	7.17	6.80	6.210	1248.4	1248.7	727.5	521.2	2.395						3080	3188	17
			6.271	1252.7	1253.0	725.6	527.4	2.375						3189	3253	17
							AVG.	2.394	11.31	82.01	6.68	17.99	62.87	AVG.	3274	16

Table 24. Influence of compaction temperature on stability levels.

$P_s : P_a$	COMPACTION TEMPERATURE- °F	HEIGHT CM.	STABILITY - KG.	
			MEASURED	ADJUSTED
20-80	220	6.383	1286	1275
		6.289	1272	1291
		6.172	968	1012
			AVG.	1193
	240	6.677	1154	1071
		6.132	927	981
		6.514	1077	1033
			AVG.	1028
	260	6.627	1495	1402
		6.584	1390	1315
		5.882	1059	1203
			AVG.	1307
	280	6.434	1254	1228
		6.148	1149	1210
		6.502	1099	1058
			AVG.	1165

Table 25. Influence of compaction temperature on stability levels.

$P_s : P_a$	COMPACTION TEMPERATURE- °F	HEIGHT CM.	STABILITY - KG.	
			MEASURED	ADJUSTED
30-70	220	5.889	1190	1350
		6.975	1480	1215
		6.588	1284	1215
			AGV.	1260
	240	5.736	945	1117
		6.631	1218	1141
		7.045	1436	1217
			AVG.	1158
	260	6.386	1458	1445
		6.349	1399	1400
		6.528	1740	1663
			AVG.	1503
	280	6.615	1658	1559
		5.942	1290	1442
		6.548	1558	1485
			AVG.	1495

Table 26. Influence of compaction temperature on stability levels.

$P_s : P_a$	COMPACTION TEMPERATURE- °F	HEIGHT CM.	STABILITY - KG.		WEIGHT - GRAMS			UNIT WEIGHT GRM/CC
			MEASURED	ADJUSTED	IN AIR	SAT. SUR DRY	IN WARTER	
40-60	220	0.355	1740	1738	1204.1	1204.8	676.3	2.278
		6.563	1499	1424				
		6.418	1590	1563				
			AVG.	1575				
	240	6.629	1894	1776	1266.3	1267.6	718.4	2.306
		6.390	1517	1502				
		6.652	1708	1594				
			AVG.	1624				
	260	6.468	2222	2156	1251.7	1252.9	725.4	2.373
		6.331	2303	2314				
		6.298	2544	2577				
			AVG.	2349				
	280	2.486	2817	2721	1273.3	1274.1	745.3	2.408
		6.535	2635	2517				
		6.454	2667	2597				
			AVG.	2612				

Table 27. Influence of compaction temperature on stability levels.

$P_s:P_a$	COMPACTION TEMPERATURE- °F	HEIGHT CM.	STABILITY - KG. MEASURED	ADJUSTED
50-50	220	6.252	1558	1596
		6.954	1681	1454
		6.652	1317	1230
			AVG.	1428
	240	6.715	1849	1699
		6.751	2103	1914
		6.909	2022	1769
			AVG.	1794
	260	6.624	3562	3343
		6.666	3307	3324
		6.542	3307	3155
			AVG.	3274
	280	6.437	4502	4404
		6.210	4570	4741
		6.651	5324	4971
			AVG.	4705

Table 28. Influence of compaction temperature on stability levels.

$P_s : P_a$	COMPCTION TEMPERATURE- °F	HEIGHT CM.	STABILITY - KG. MEASURED	ADJUSTED
60-40	220	7.347	840	673
		6.965	863	746
		6.746	1127	1026
			AVG.	815
	240	6.799	1181	1704
		6.470	1326	1287
		7.000	1735	1486
			AVG.	1492
	260	7.117	4321	2654
		6.445	3344	3264
		6.853	3026	3680
			AVG.	2933
	280	6.390	4320	4277
		6.594	4370	4127
		6.326	4906	4936
			AVG.	4447

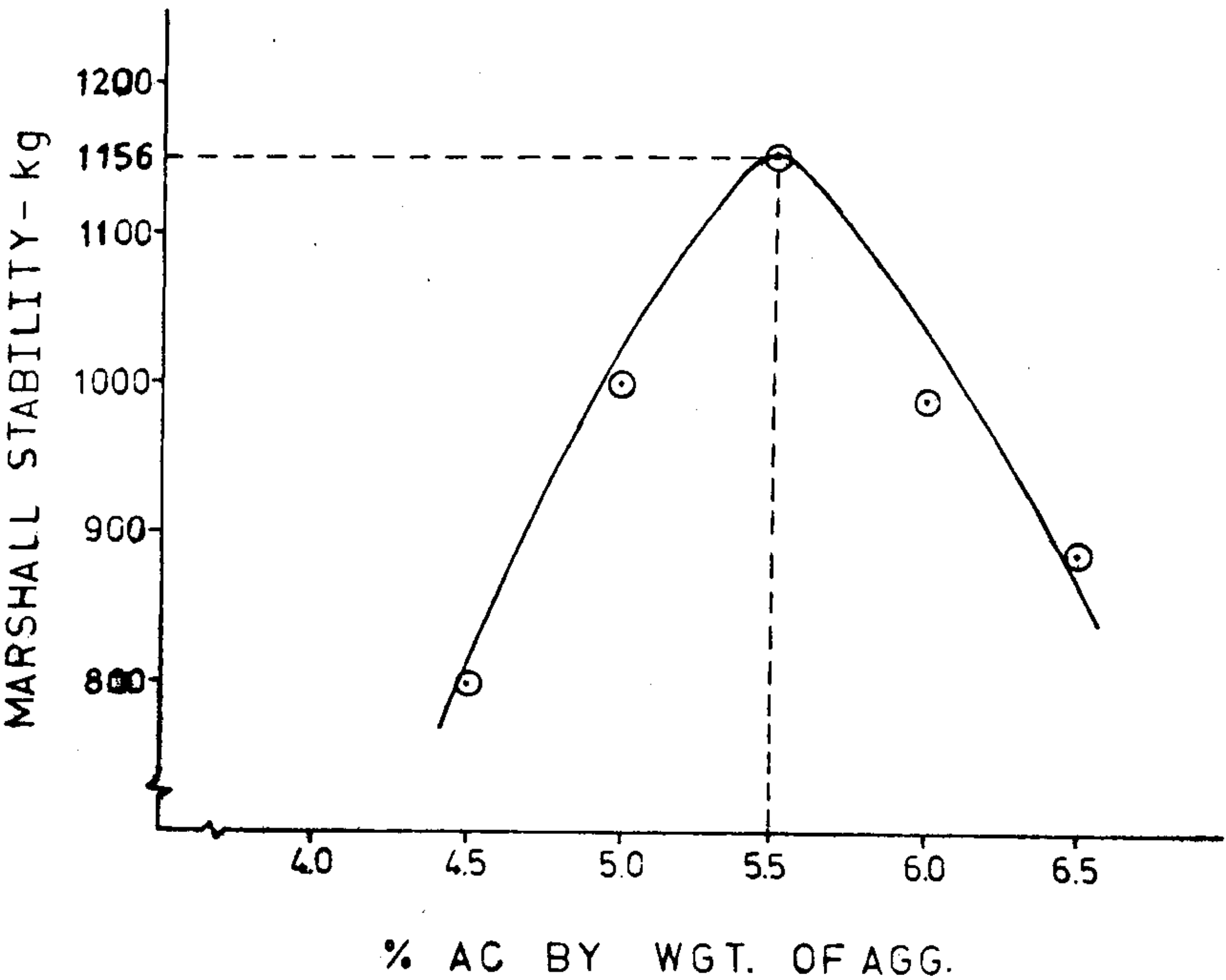

FIGURE 7. VARIATION OF MARSHALL STABILITY WITH ASPHALT CONTENT

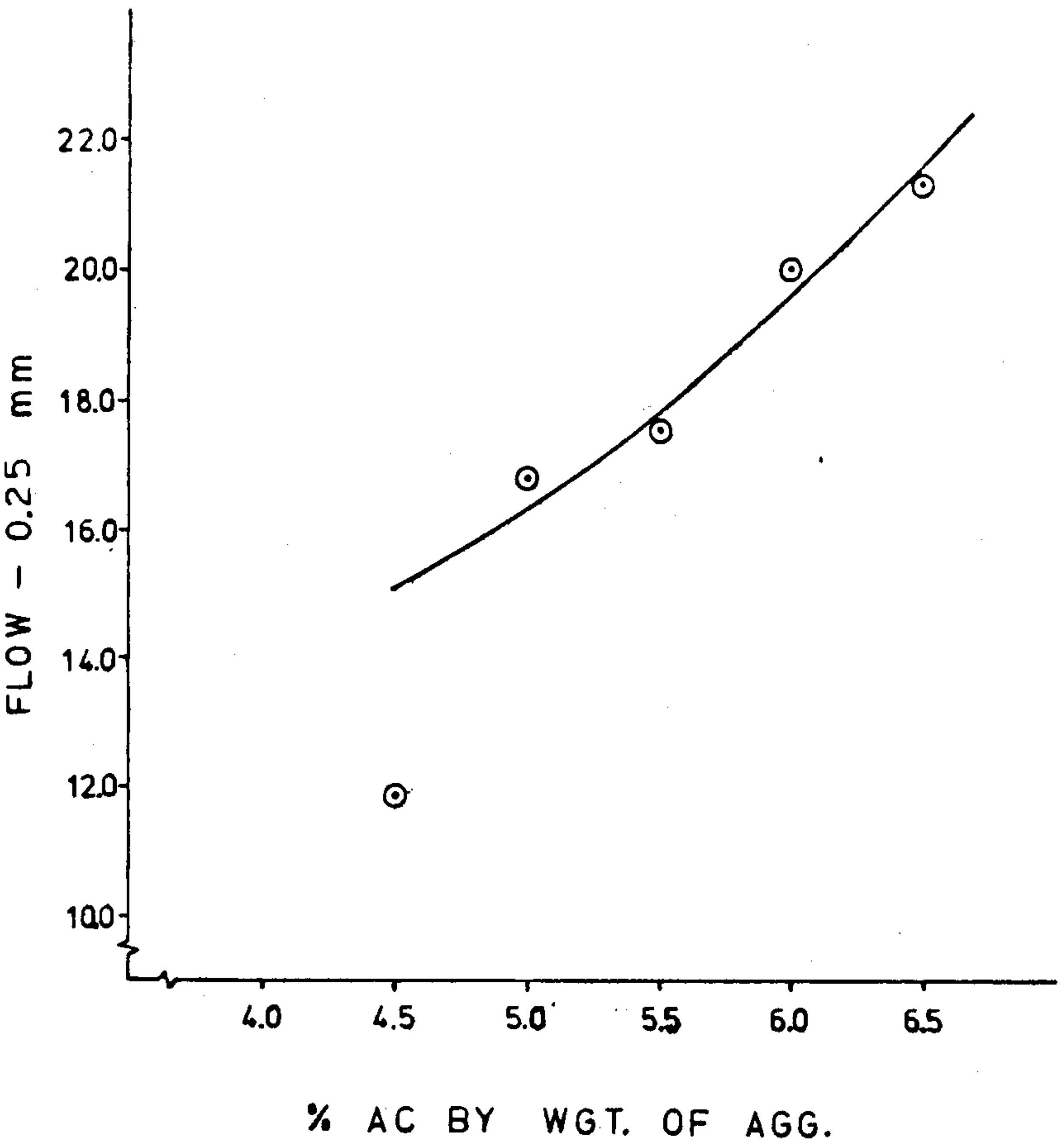

FIGURE 8. VARIATION OF FLOW WITH ASPHALT CONTENT

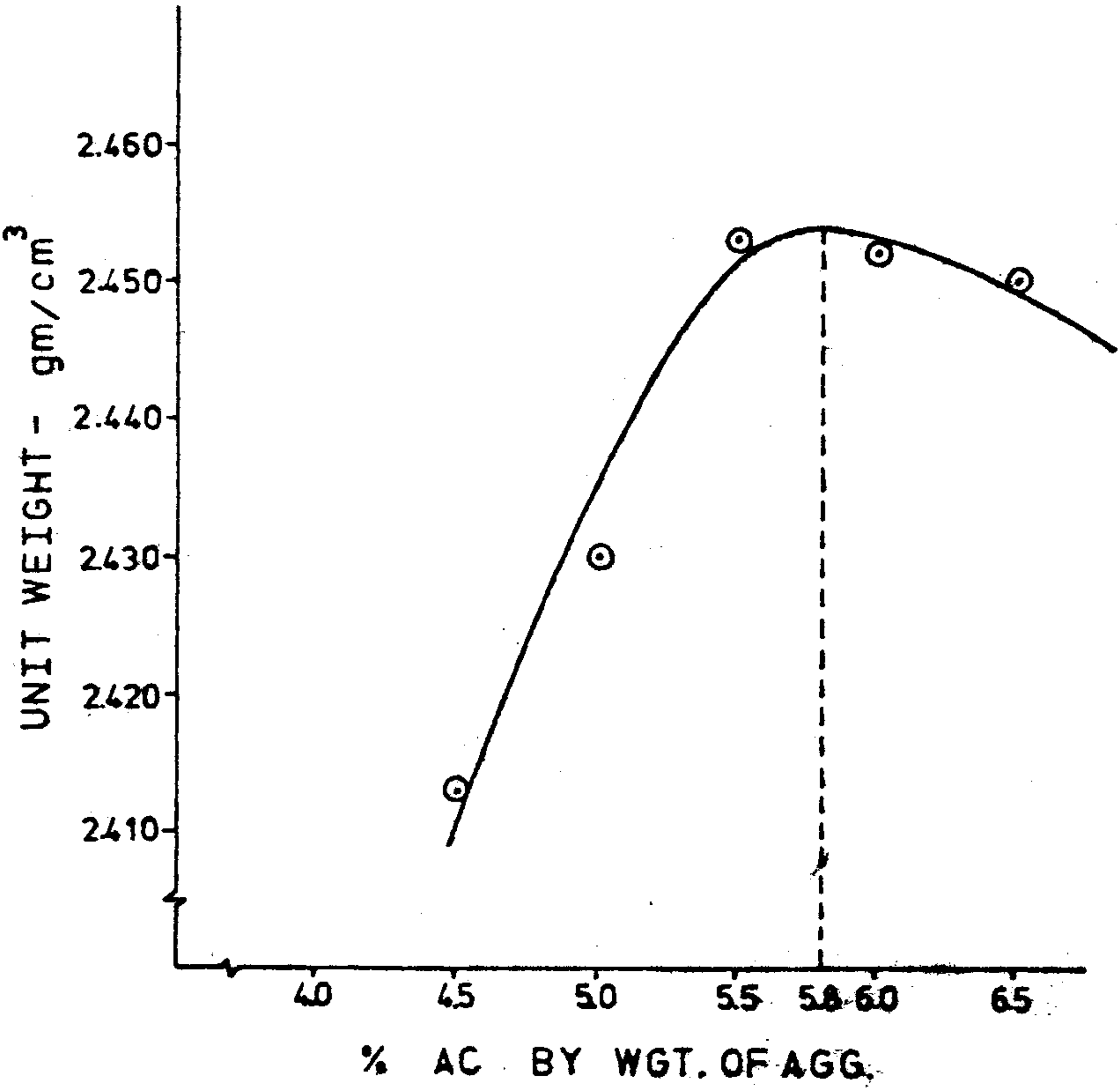

FIGURE 9. VARIATION OF UNIT WEIGHT WITH ASPHALT CONTENT

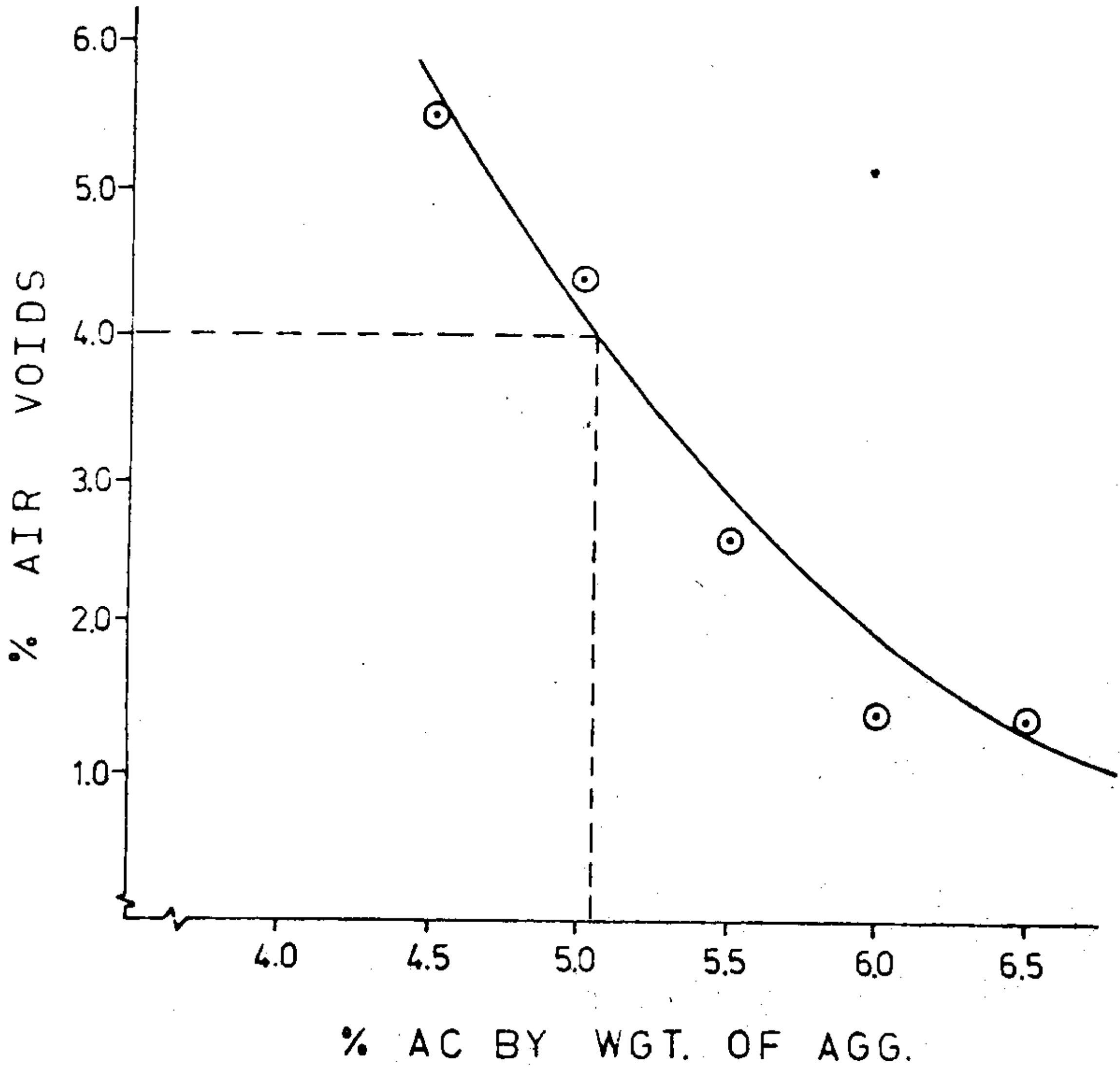

FIGURE 10. VARIATION OF AIR VOIDS WITH ASPHALT CONTENT

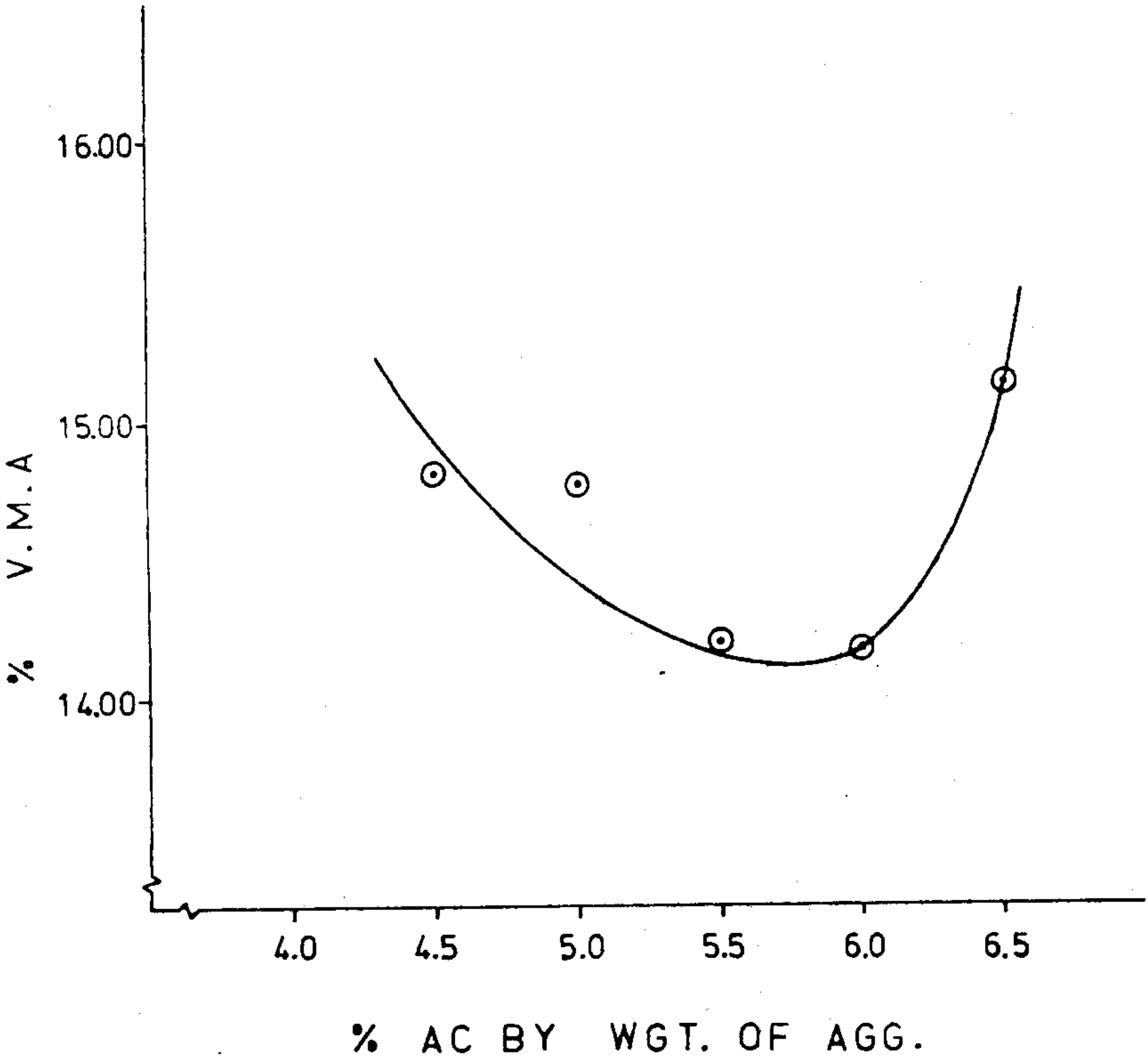

FIGURE 11. VARIATION OF VMA WITH ASPHALT CONTENT

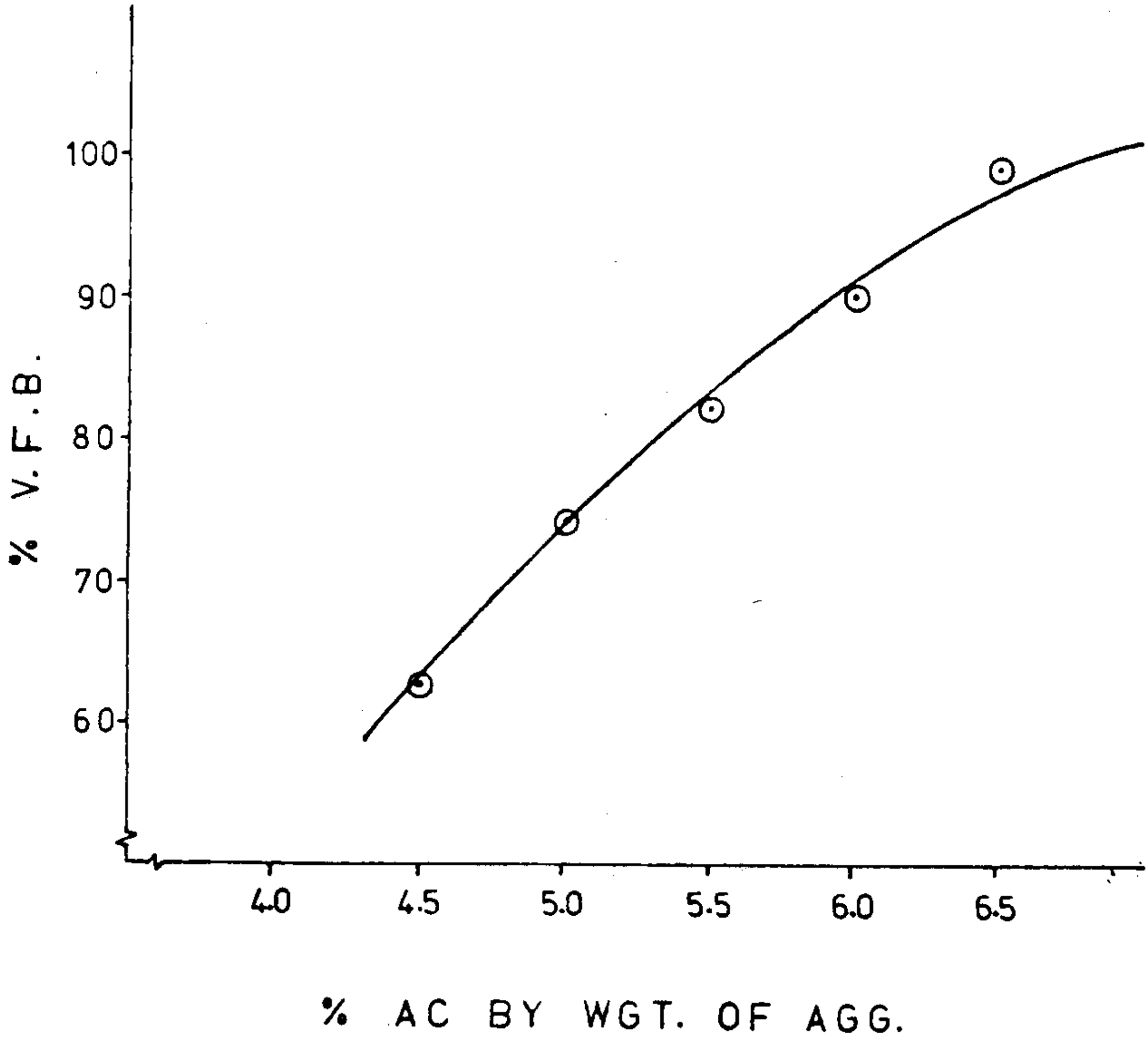

FIGURE 12. VARIATION OF VOIDS FILLED WITH BINDER WITH ASPHALT CONTENT

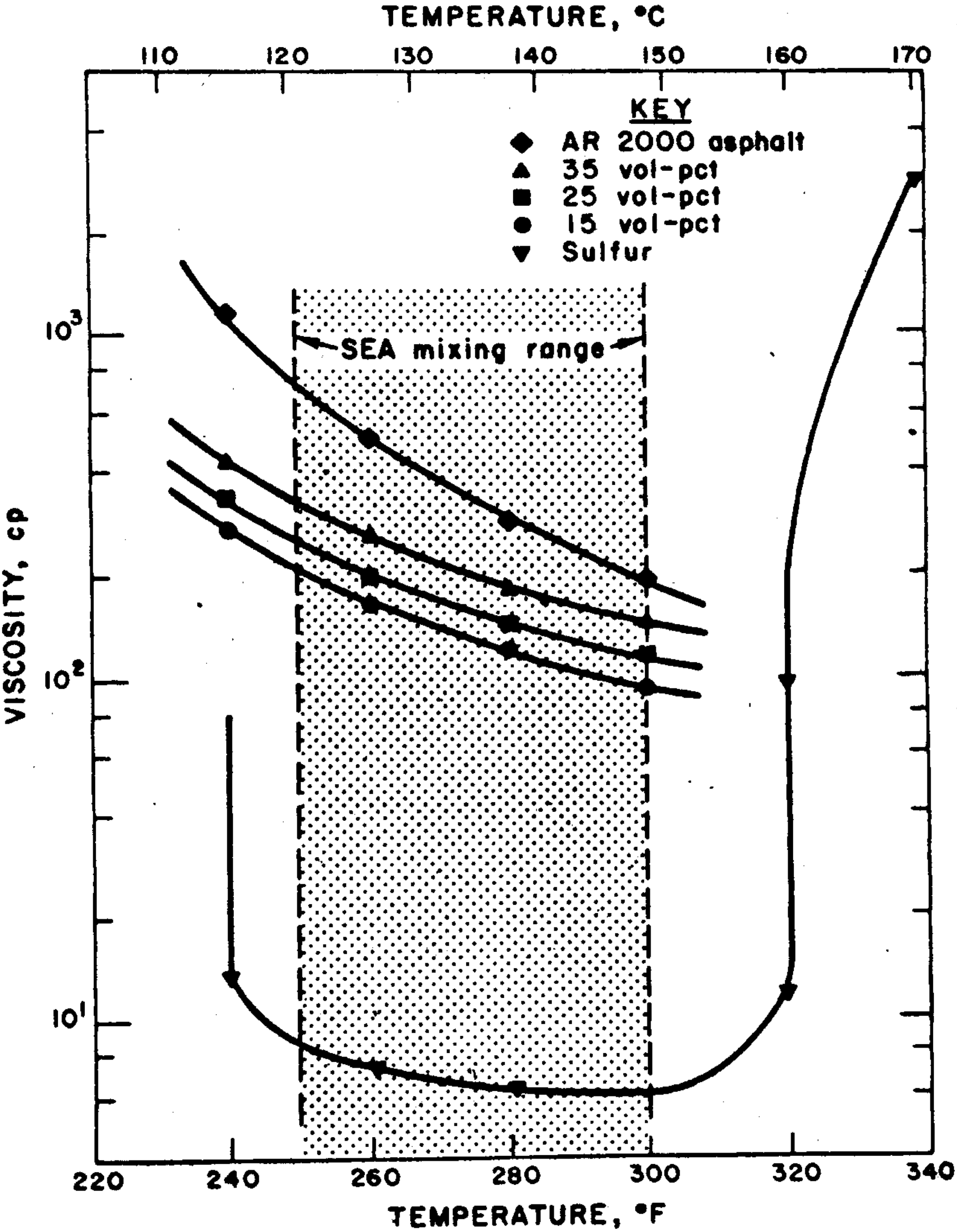

FIGURE 13. SEA MIXING TEMPERATURE RANGE (after Mcbee 1980)