EFFECT OF SEGREGATION ON PERFORMANCE OF HOT MIX ASPHALT

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February 1992

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INTRODUCTION

Background

Segregation of hot mix asphalt (HMA) pavements has been one problem that has resulted in poor performance in many pavements. There is currently no procedure available for quantifying segregation to determine how much segregation is too much, in other words, how much coarser the gradation must be before a reduction in performance is expected. Quantifying segregation will result in data necessary to determine the quality of segregated areas and thus, what action should be taken.

Objective

The objective of this study is to determine how much segregation can be tolerated before premature raveling is the likely result.

Scope

Five pavements from the Alabama Highway Department (AHD) Divisions 4 and 6 were selected for inclusion in the study. Visual estimations of the severity of raveling and segregation were made and cores from the pavements were obtained. The density was measured with a thin-lift nuclear gauge and the macro-texture of the pavement surface in the segregated area was determined. A detailed laboratory testing program was performed on the cores obtained from the pavement and evaluated to characterize the mixture properties and its effect on raveling. Traffic data and mix design information was obtained for each pavement.

PLAN OF STUDY

Field Testing

Five pavements which had shown signs of segregation were selected for sampling and evaluation. The pavements selected varied in age and amount of segregation and raveling. A visual ranking of the pavements based on the amount of segregation and raveling was made. The pavements were ranked from 1 to 5 with 5 being the best pavement having little or no segregation and no raveling and 1 representing severe segregation with raveling.

Field testing consisted of obtaining 3 sets of 4 inch diameter cores at each site. One set of cores was taken from segregated areas and one set of cores was taken adjacent to the segregated cores. A third set of 5 to 8 cores was obtained at random locations throughout the test section. The random cores were selected to determine the average aggregate gradation, asphalt content and density of the test section.

The density of the pavement was determined at the location of each segregated core and random core using a thin-lift nuclear gauge. Sand was not used to fill surface voids for thin-lift nuclear gauge testing, hence the density measured in segregated areas was likely lower than the actual density.

The macro-texture of the pavement at the segregated and random core locations was determined in general accordance with ASTM E-965. The deviations from the standard test method consisted of using natural sand, passing the No. 30 sieve and retained on the No. 50

sieve, instead of Ottawa sand or glass spheres as specified. The sand was a commercially available 50 grit blasting sand. Fifty grams of sand were utilized in the test. The diameter of the sand patch was determined to indirectly quantify the amount of raveling. A lower diameter of sand indicated more raveling had occurred.

Laboratory Testing

All of the cores were measured to determine the thickness of the surface layer. Next the surface layer was separated from the remainder of the core with a water cooled rock saw. After sawing, the surface layer was air dried to a constant weight and the bulk specific gravity was determined in accordance with ASTM D-2726. Two of the random cores were selected for determining the maximum theoretical specific gravity in accordance with ASTM D-2041. All of the cores were then extracted to determine the asphalt content (ASTM D2172), and the gradation of the mineral aggregate (ASTM C117 and C136).

State Supplied Data

The average annual daily traffic (AADT), the date of construction, and the mix design information, if available, was supplied by the AHD for each site.

SUMMARY OF TEST RESULTS

Visual Observations

The test sites were located in Divisions 4 and 6 (Figure 1), on level tangents of 4-lane divided highways. The pavements were ranked from 1 to 5 based on the amount of segregation and raveling as previously described. The pavement ranking, condition, age, traffic and location of each test site is shown in Table 1. A brief description of each site is provided below.

Site 1. Site 1 was located in the northbound travel lane of US-280/231 at milepost 41 in Talledega Co. The surface mix consisted of a 416 B mix and was placed in 1988. The segregation at this site appeared to be end of load segregation that is typical of many segregation projects. Part of the coarse aggregate utilized for the surface mix was a steel slag with a higher specific gravity (3.138) than the remainder of the coarse aggregate (2.588). AHD personnel stated that the use of the slag as part of the coarse aggregate aggravated the segregation problem.

The segregation at site 1 had led to spot raveling throughout the test section. The open texture at this site had allowed moisture to be absorbed causing stripping and raveling of the surface aggregates. This site was given a visual rank of 1 as the test site with the most segregation and raveling. Figure 2 shows the end of the load segregation at this site and Figure 3 the raveling associated with the segregation.

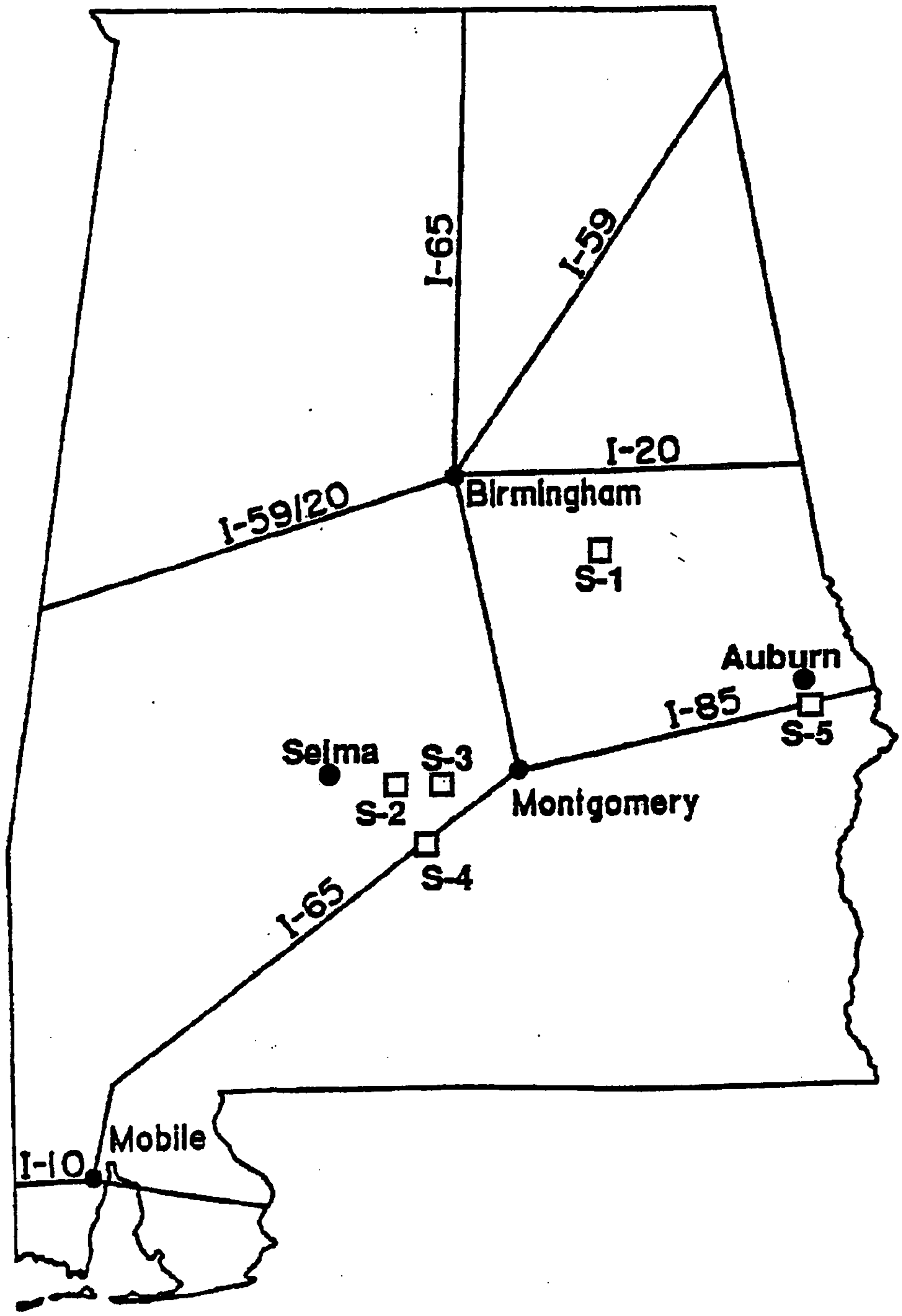

Figure 1. Test site location diagram.

Table 1. Traffic, Age, Rank and Visual Condition Rating

SITE	ROUTE	COUNTY	AADT	AGE (years)	TRAFFIC x 10^6	RANK*	VISUAL CONDITION RATING
1	US-280/231	TALLEDEGA	11,710	2.83	12.1	1	SEVERE SEGREGATION & RAVELING
2	US-80	DALLAS	5,970	1.83	4.0	4	SEGREGATION
3	US-80	LOWNDES	5,970	0.92	2.0	5	SLIGHT SEGREGATION
4	I-65	LOWNDES	15,970	2.25	13.1	2	SEGREGATION & RAVELING
5	I-85	LEE	17,920	3.33	20.7	3	SEGREGATION & SLIGHT RAVELING

* 1 - Worst
5 - Best

Figure 2. Typical end of load segregation at site 1.

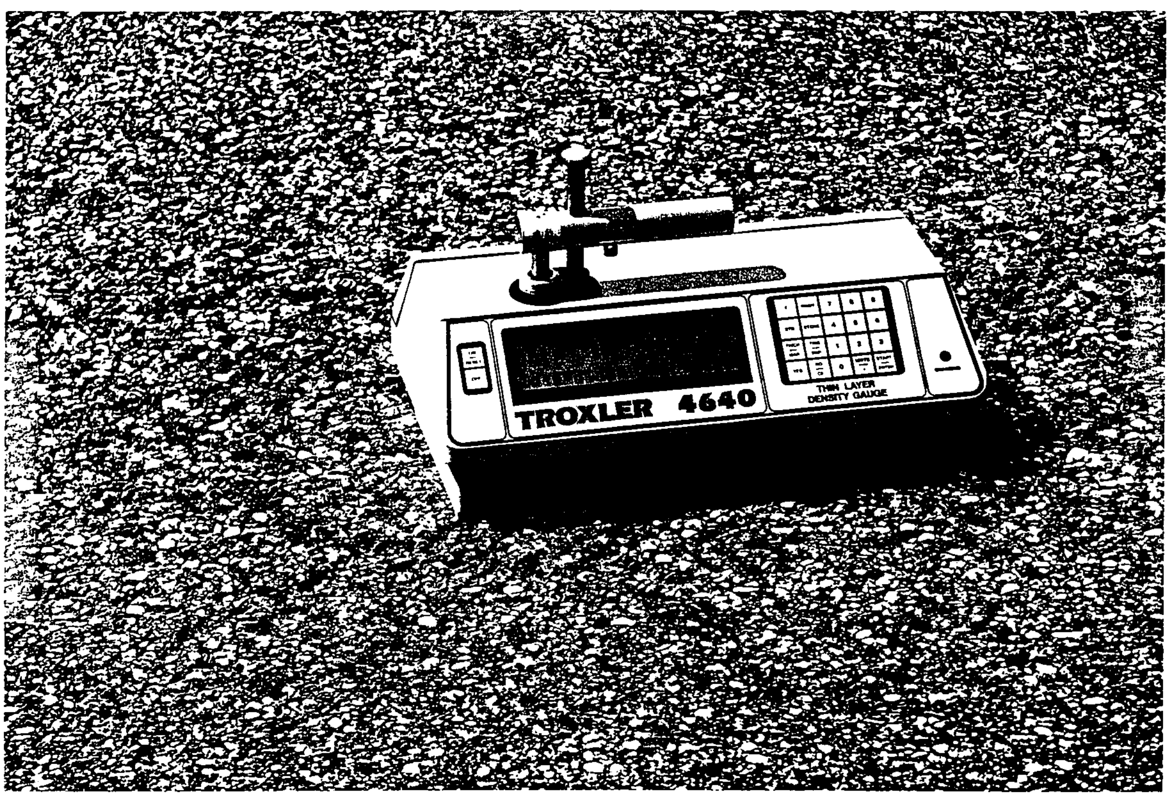

Figure 3. Segregation and raveling at site 1.

Site 2. Site 2 was located in the eastbound travel lane of US-80 at milepost 99 in Dallas Co. The surface mix consisted of a 411 A mix and was placed in 1989. The segregation at this site appeared to be end of the load segregation.

The segregation at site 2 had not led to any raveling at the time of this investigation. The segregated areas were absorbing slight amounts of moisture but stripping and raveling of the surface aggregates had not occurred. This site was given a visual rank of 4 and was described as having segregation but no raveling. Figures 4 and 5 show the end of the load segregation at this site.

Site 3. Site 3 was located in the eastbound travel lane of US-80 at milepost 103 in Lowndes Co. The surface mix consisted of a 416 B mix and was placed in 1990. Site 3 was the newest construction of the 5 sites. Much of the apparent segregation occurring at this site appeared to be associated with pulling of coarse aggregate by the screed tearing the fresh mat. A slight amount of end of the load segregation was also apparent.

The segregation at site 3 had not led to any raveling at the time of this investigation. The segregated areas were absorbing slight amounts of moisture but stripping and raveling of the surface aggregates had not occurred. This site was given a visual rank of 5, being the site with slight segregation and no raveling. Figure 6 shows the pulling and tearing of the mat and Figure 7 shows the segregation at this site.

Figure 4. Typical end of load segregation at site 2.

Figure 5. Segregation without raveling at site 2.

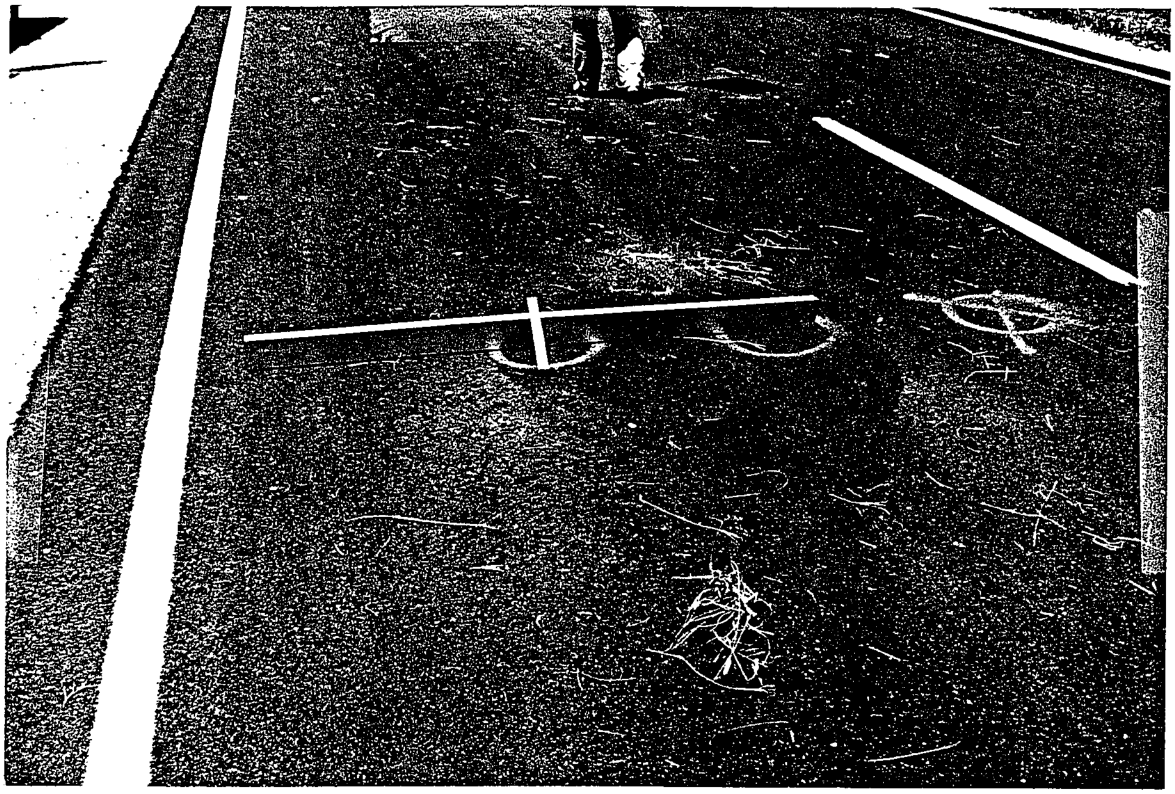

Figure 6. Pulling and tearing of mat at site 3.

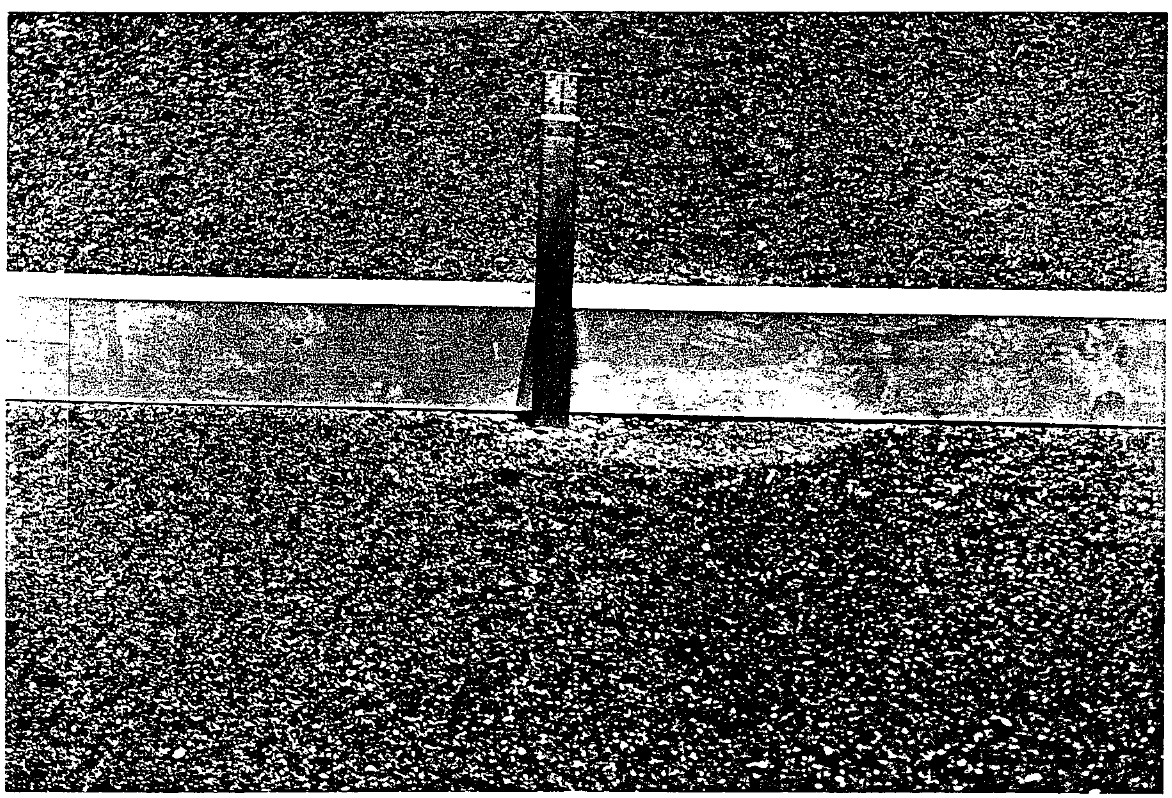

Figure 7. Segregation with no raveling at site 3.

Site 4. Site 4 was located in the northbound travel lane of I-65 between mileposts 143 and 144 in Lowndes Co. The surface mix consisted of a 416 B mix and was placed in 1989. The segregation at this site appeared to be end of the load segregation.

The segregation had led to spot raveling throughout the test section. The open texture at this site had led to absorption of moisture causing stripping and raveling of the surface aggregates. The raveling at this site was not as severe as that occurring at site 1, so site 4 was given a visual rank of 2 as having segregation and raveling. Figures 8 and 9 show the end of load segregation with raveling.

Site 5. Site 5 was located in the northbound travel lane of I-85 between mileposts 56 and 57 in Lee Co. The mix was a 416 B mix and was placed in 1988. The segregation at this site appeared to be end of the load segregation. The segregation was beginning to lead to spot raveling throughout the test section and the open texture had led to absorption of moisture. Stripping and raveling of the surface aggregates had begun. The raveling at this site was not as severe as that occurring at sites 1 and 4, so site 5 was given a visual rank of 3 as having segregation with slight raveling. Figures 10 and 11 show the end of the load segregation with raveling occurring at this site.

Test Data

The results of the sand patch test, thin-lift nuclear gauge density and bulk density from the pavement cores are shown in Table 2. The results from the extraction and gradation analysis are shown in Table 3 along with the available Job Mix Formulas.

Figure 8. Typical end of load segregation at site 4.

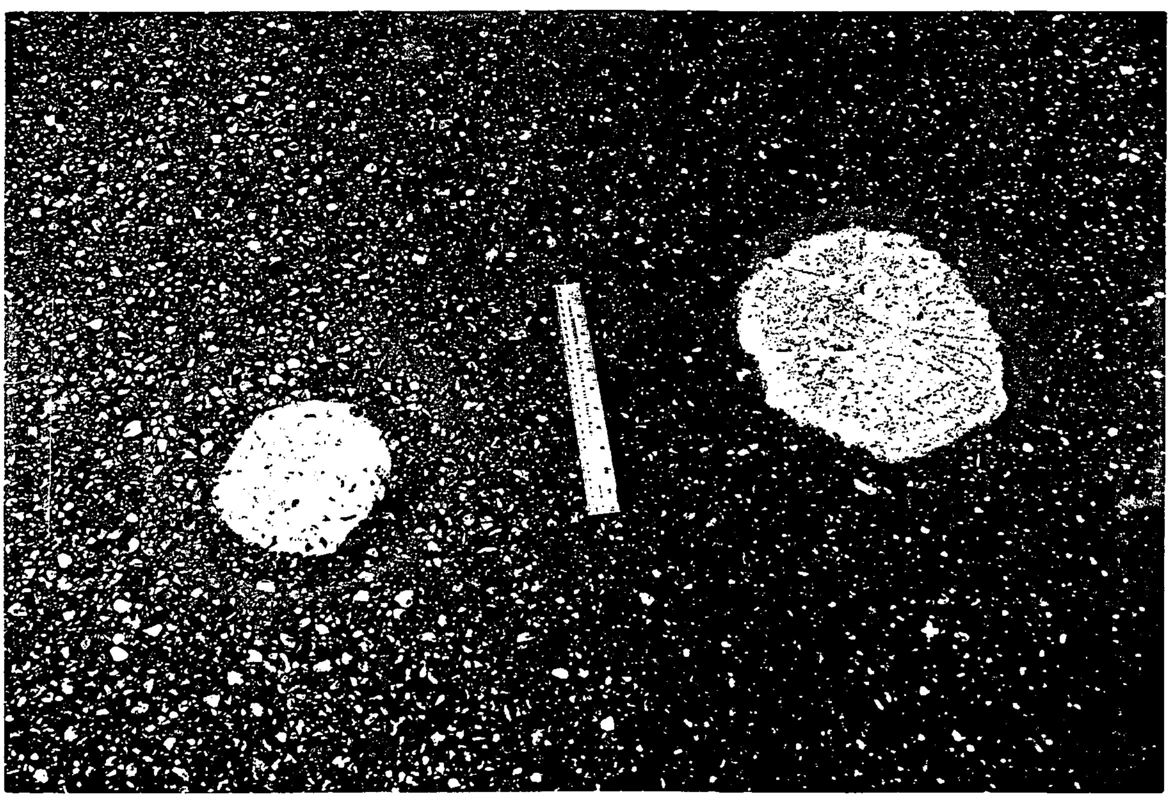

Figure 9. Segregation with raveling at site 4.

Figure 10. Typical end of load segregation at site 5.

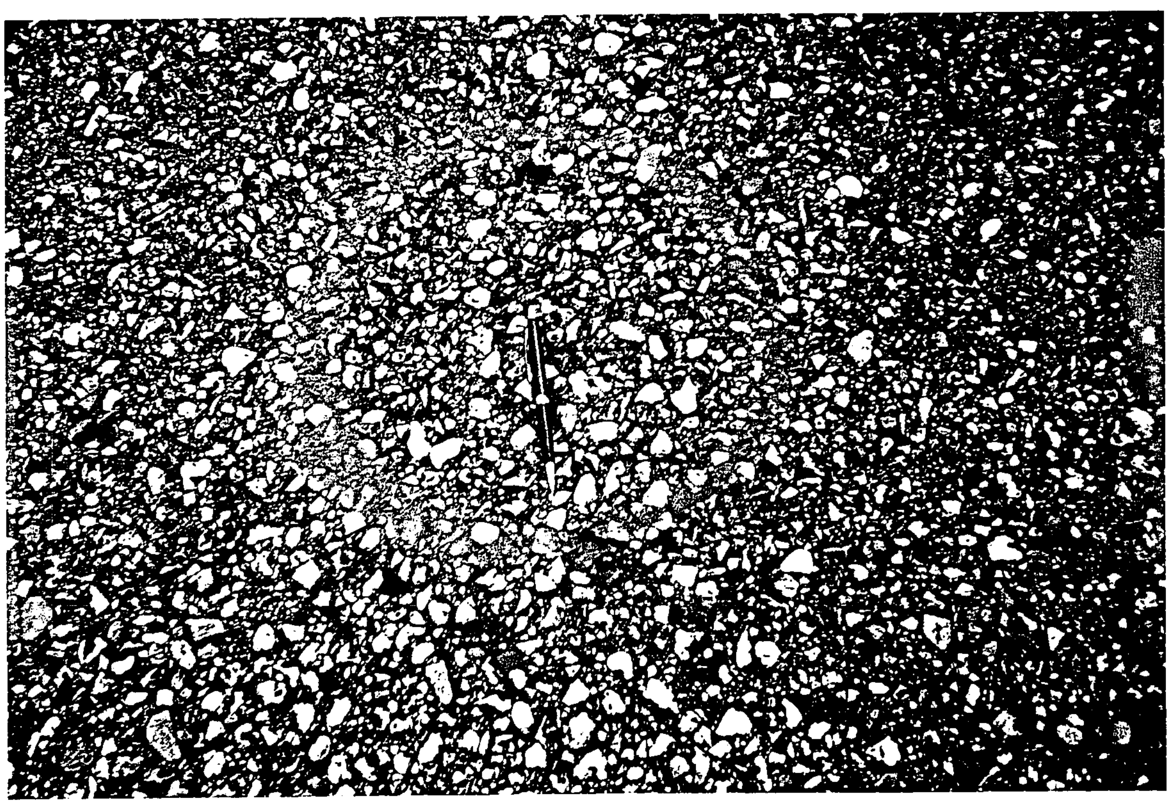

Figure 11. Segregation with slight raveling at site 5.

Table 2. Sand Patch, Core and Nuclear Gauge Data.

SITE NUMBER	SAMPLE	SAMPLE LOCATION	SAND PATCH DIAMETER (in)	SAND PATCH DEPTH (in)	CORE BULK DENSITY (pcf)	NUCLEAR GAUGE DENSITY (pcf)
1	A	1	8.438	0.0392	147.3	135.1
1	A	2	11.938	0.0196	143.5	141.3
1	B	1	6.688	0.0624	145.9	126.1
1	B	2	10.750	0.0241	145.5	144.3
1	C	1	5.094	0.1075	152.5	124.9
1	C	2	11.125	0.0225	146.8	141.5
1	D	1	4.969	0.1129	144.8	120.5
1	D	2	10.125	0.0272	143.8	136.2
1	E	1	5.656	0.0872	148.3	111.8
1	E	2	10.719	0.0243	144.4	141.1
1	RANDOM	1	10.750	0.0241	143.1	140.5
1	RANDOM	2	11.938	0.0196	146.4	141.9
1	RANDOM	3	11.281	0.0219	147.6	142.3
1	RANDOM	4	11.688	0.0204	149.3	142.4
1	RANDOM	5	10.625	0.0247	145.5	140.5
1	RANDOM	6	12.250	0.0186	145.9	143.8
1	RANDOM	7	11.219	0.0222	144.2	141.0
1	RANDOM	8	10.688	0.0244	144.8	139.5
1	RANDOM	AVG.	11.305	0.0220	145.8	141.5
2	A	1	8.750	0.0364	149.3	135.8
2	A	2	10.063	0.0275	146.0	137.0
2	B	1	10.188	0.0269	148.4	134.3
2	B	2	11.000	0.0230	142.6	139.7
2	C	1	9.938	0.0282	150.4	138.0
2	C	2	10.500	0.0253	144.1	139.9
2	D	1	9.500	0.0309	149.2	137.4
2	D	2	10.500	0.0253	143.7	137.9
2	E	1	9.563	0.0305	149.0	138.6
2	E	2	10.000	0.0279	145.2	138.4
2	RANDOM	1	N/T	N/T	146.3	143.5
2	RANDOM	2	11.125	0.0225	146.3	144.6
2	RANDOM	3	11.000	0.0230	147.0	144.5
2	RANDOM	4	N/T	N/T	146.8	145.3
2	RANDOM	5	N/T	N/T	147.2	145.1
2	RANDOM	AVG.	11.063	0.0228	146.7	144.6

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

N/T = Sample not tested.

Table 2. (Cont.) Sand Patch, Core and Nuclear Gauge Data.

SITE NUMBER	SAMPLE	SAMPLE LOCATION	SAND PATCH DIAMETER (in)	SAND PATCH DEPTH (in)	CORE BULK DENSITY (pcf)	NUCLEAR GAUGE DENSITY (pcf)
3	A	1	10.563	0.0250	146.4	135.7
3	A	2	11.125	0.0225	147.4	144.5
3	B	1	9.500	0.0309	139.6	130.4
3	B	2	11.188	0.0223	143.6	143.1
3	C	1	11.375	0.0216	141.5	140.7
3	C	2	12.063	0.0192	146.1	145.9
3	D	1	8.375	0.0398	140.0	131.5
3	D	2	10.375	0.0259	141.2	139.7
3	E	1	7.563	0.0488	142.1	122.6
3	E	2	11.188	0.0223	142.2	140.7
3	RANDOM	1	12.000	0.0194	146.4	146.3
3	RANDOM	2	N/T	N/T	147.0	148.6
3	RANDOM	3	N/T	N/T	148.1	145.9
3	RANDOM	4	12.500	0.0178	147.4	148.1
3	RANDOM	5	N/T	N/T	148.0	144.8
3	RANDOM	AVG.	12.250	0.0186	147.4	146.7
4	A	1	8.063	0.0429	142.6	132.3
4	A	2	9.938	0.0282	144.8	131.3
4	B	1	9.313	0.0322	146.6	131.5
4	B	2	9.813	0.0290	142.5	133.2
4	C	1	8.438	0.0392	143.8	126.5
4	C	2	10.813	0.0239	143.1	132.6
4	D	1	7.000	0.0569	145.1	127.4
4	D	2	11.750	0.0202	146.3	141.3
4	E	1	8.063	0.0429	146.8	130.3
4	E	2	10.813	0.0239	145.7	136.9
4	RANDOM	1	N/T	N/T	145.5	139.4
4	RANDOM	2	11.313	0.0218	145.8	137.2
4	RANDOM	3	11.000	0.0230	146.4	139.2
4	RANDOM	4	N/T	N/T	145.2	137.4
4	RANDOM	5	N/T	N/T	145.8	137.8
4	RANDOM	AVG.	11.156	0.0224	145.7	138.2

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

N/T = Sample not tested.

Table 2. (Cont.) Sand Patch, Core and Nuclear Gauge Data.

SITE NUMBER	SAMPLE	SAMPLE LOCATION	SAND PATCH DIAMETER (in)	SAND PATCH DEPTH (in)	CORE BULK DENSITY (pcf)	NUCLEAR GAUGE DENSITY (pcf)
5	A	1	7.813	0.0457	146.5	129.2
5	A	2	10.313	0.0262	144.2	131.5
5	B	1	8.625	0.0375	147.7	132.4
5	B	2	10.688	0.0244	145.7	137.7
5	C	1	7.813	0.0457	147.1	128.3
5	C	2	9.750	0.0293	146.2	131.2
5	D	1	6.375	0.0686	146.3	119.7
5	D	2	9.063	0.0340	147.3	127.5
5	E	1	6.000	0.0775	143.9	117.6
5	E	2	9.313	0.0322	144.7	132.5
5	RANDOM	1	10.750	0.0241	145.4	140.3
5	RANDOM	2	10.875	0.0236	145.4	135.8
5	RANDOM	3	10.250	0.0265	146.8	136.1
5	RANDOM	4	10.188	0.0269	147.3	138.0
5	RANDOM	5	10.625	0.0247	144.8	133.2
5	RANDOM	AVG.	10.538	0.0252	146.0	136.7

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

Table 3. Extraction and Gradation Analysis.

SITE NO.	SAMPLE	SAMPLE LOC.	AC (%)	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
				PERCENT PASSING									
1	A	1	5.4	99	88	74	49	38	31	24	15	8	4.2
1	A	2	6.2	100	94	83	58	46	38	29	18	10	4.9
1	B	1	5.4	94	84	72	46	35	28	22	14	9	4.7
1	B	2	6.5	95	88	80	56	45	37	28	17	9	3.9
1	C	1	4.2	95	77	57	32	25	21	17	12	7	3.5
1	C	2	6.1	99	92	79	56	45	37	29	18	10	4.5
1	D	1	2.5	98	82	61	33	25	21	18	13	9	5.5
1	D	2	4.0	98	93	83	57	44	36	28	19	12	7.0
1	E	1	3.2	93	72	53	31	25	22	18	13	8	4.7
1	E	2	6.6	100	90	80	54	43	36	28	18	10	4.9
1	RANDOM	1	5.4	100	93	81	57	45	37	28	17	9	5.3
1	RANDOM	2	5.4	100	94	83	58	45	37	28	18	10	5.6
1	RANDOM	3	6.0	100	92	81	58	47	37	25	12	6	5.2
1	RANDOM	4	5.4	99	90	78	55	44	36	28	17	10	5.3
1	RANDOM	5	6.1	98	91	83	58	46	38	29	18	10	4.7
1	RANDOM	6	6.4	97	90	81	58	46	38	28	17	9	4.3
1	RANDOM	7	5.8	99	94	84	59	45	36	26	15	9	5.6
1	RANDOM	8	5.7	99	92	80	58	46	37	28	17	9	5.2
1	RANDOM	AVG.	5.8	99	92	81	58	45	37	27	16	9	5.1
1	JMF		5.4	99	90	76	56	46	N/A	27	16	10	4.2
2	A	1	4.4	95	77	68	53	40	33	25	15	11	9.4
2	A	2	4.7	99	87	77	59	45	37	28	16	12	10.5
2	B	1	5.5	99	83	74	55	39	30	21	10	6	4.6
2	B	2	4.1	98	76	66	50	38	30	20	7	3	3.0
2	C	1	7.4	95	69	61	44	31	23	15	6	4	2.8
2	C	2	6.3	99	81	73	57	42	33	24	11	7	5.4
2	D	1	4.5	97	76	67	51	37	30	22	10	6	4.7
2	D	2	5.1	97	87	80	63	46	36	25	11	7	4.8
2	E	1	4.8	99	78	67	51	37	30	22	10	6	4.3
2	E	2	4.9	97	79	70	50	38	31	23	10	6	3.9
2	RANDOM	1	4.1	97	85	78	62	47	38	27	14	10	8.7
2	RANDOM	2	5.0	98	85	78	62	47	37	26	12	7	5.5
2	RANDOM	3	4.6	96	86	79	62	46	36	24	10	6	4.3
2	RANDOM	4	4.3	100	90	82	65	49	39	28	15	11	9.4
2	RANDOM	5	6.0	99	87	79	62	48	38	27	13	8	6.3
2	RANDOM	AVG.	4.8	98	87	79	63	47	37	26	13	9	6.8
2	JMF		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

N/A = Data Not Available

Table 3. (Cont.) Extraction and Gradation Analysis.

SITE NO.	SAMPLE	SAMPLE LOC.	AC (%)	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
				PERCENT PASSING									
3	A	1	9.7	99	88	78	60	44	33	22	10	5	3.3
3	A	2	6.2	100	91	80	59	43	33	23	11	6	4.1
3	B	1	5.9	100	86	75	53	40	32	22	12	7	4.4
3	B	2	5.6	99	81	72	54	40	31	22	11	7	4.6
3	C	1	6.3	99	89	76	55	40	30	20	14	9	3.6
3	C	2	5.3	99	88	80	62	46	35	23	11	6	4.1
3	D	1	6.7	98	83	69	48	35	26	18	8	5	3.1
3	D	2	5.3	100	87	75	54	39	30	20	9	5	3.4
3	E	1	4.9	96	80	65	47	37	30	23	15	10	8.6
3	E	2	5.4	99	79	69	51	39	32	24	15	11	9.5
3	RANDOM	1	5.6	98	89	78	59	46	37	26	15	12	10.0
3	RANDOM	2	5.4	99	89	81	62	46	36	19	14	11	10.0
3	RANDOM	3	6.2	99	88	76	59	42	33	17	8	5	3.9
3	RANDOM	4	6.1	99	90	81	65	50	40	29	17	15	12.3
3	RANDOM	5	6.7	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T
3	RANDOM	AVG.	6.0	99	89	79	61	46	37	23	13	11	9.0
3	JMF		5.0	98	93	81	56	45	36	28	15	9	5.7
4	A	1	4.1	99	80	64	45	38	33	26	13	9	5.2
4	A	2	4.5	97	78	63	42	35	29	23	10	6	3.5
4	B	1	5.2	100	88	76	55	45	38	29	13	8	4.7
4	B	2	5.2	100	85	73	54	45	39	30	13	8	4.7
4	C	1	4.8	100	86	75	54	45	39	30	14	9	5.5
4	C	2	4.9	99	84	73	53	44	38	29	14	9	4.8
4	D	1	4.4	100	82	65	43	35	30	23	11	7	4.0
4	D	2	6.1	99	89	78	58	47	40	30	13	8	4.1
4	E	1	4.5	99	85	66	41	33	28	22	11	7	4.2
4	E	2	5.5	99	86	73	54	44	37	28	12	7	4.3
4	RANDOM	1	5.6	99	87	74	51	41	35	26	11	6	3.4
4	RANDOM	2	5.7	100	88	77	55	44	37	28	12	7	4.4
4	RANDOM	3	5.4	99	85	73	51	41	34	26	12	7	4.3
4	RANDOM	4	5.9	100	89	77	56	46	38	29	13	8	5.0
4	RANDOM	5	6.2	100	87	76	57	46	39	29	12	8	4.6
4	RANDOM	AVG.	5.8	100	87	75	54	44	36	28	12	7	4.3
4	JMF		5.65	98	85	71	54	46	N/A	29	13	9	5.5

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

N/A = Data Not Available
N/T = Not Tested

Table 3. (Cont.) Extraction and Gradation Analysis.

SITE NO.	SAMPLE	SAMPLE LOC.	AC (%)	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
				PERCENT PASSING									
5	A	1	4.5	97	76	64	46	37	31	23	14	8	5.4
5	A	2	5.6	99	89	79	59	47	38	26	15	8	5.7
5	B	1	4.6	96	78	67	49	39	32	22	13	7	4.9
5	B	2	5.8	100	88	77	56	45	36	25	14	7	4.8
5	C	1	4.8	96	78	66	47	39	31	22	13	8	5.4
5	C	2	4.3	100	86	77	59	48	38	27	16	9	6.6
5	D	1	3.4	97	66	51	34	28	24	18	12	7	4.5
5	D	2	5.0	100	87	74	54	43	35	25	14	8	5.4
5	E	1	3.3	96	65	48	33	28	24	19	12	7	4.8
5	E	2	4.6	99	86	73	52	42	34	25	15	8	5.6
5	RANDOM	1	5.1	99	84	73	55	44	36	25	15	8	5.6
5	RANDOM	2	5.3	97	87	76	55	44	36	25	15	9	5.5
5	RANDOM	3	4.9	98	82	70	53	42	34	25	14	8	5.5
5	RANDOM	4	4.7	99	82	69	49	40	32	24	14	8	5.4
5	RANDOM	5	5.3	100	85	72	51	39	22	11	7	6	5.2
5	RANDOM	AVG.	5.1	98	84	72	53	42	32	22	13	8	5.5
5	JMF		5.0	98	85	76	57	45	N/A	28	16	10	6.5

Note: For samples A-E sample location 1 is segregated area and sample location 2 is adjacent to a segregated area.

N/A = Data Not Available

ANALYSIS OF DATA

The data was analyzed to determine how much segregation would lead to raveling. The dependent variable in the study is the amount of raveling as determined by the sand patch test. The raveled areas have more surface voids resulting in a smaller sand patch diameter. The amount of segregation at each segregated core was determined by subtracting the percent passing the No. 4 sieve for each segregated core from the average percent passing the No. 4 sieve from the random cores. Regression analysis was performed to determine the relationship between test variables and the amount of raveling.

Visual Ranking

It is well known that segregation can lead to raveling and loss of pavement serviceability. To determine how much segregation is required to cause raveling the visual ranking of the surface raveling was compared to the difference between the percent passing the No. 4 sieve for each of the five segregated cores and the average percent passing the No. 4 sieve for the random samples. The results are shown in Figure 12. From this plot it appears that most of the test areas have a difference in the percent passing the No. 4 sieve for individual segregated samples and the average of random samples of greater than 8 to 10%.

Asphalt Cement Content

Normally segregation results in low asphalt cement contents. The relationship between the amount of segregation on the No. 4 sieve and the asphalt cement content of a segregated core for sites 1-5 are shown in Figures 13-17. All of the sites except Site 2 show a decrease in

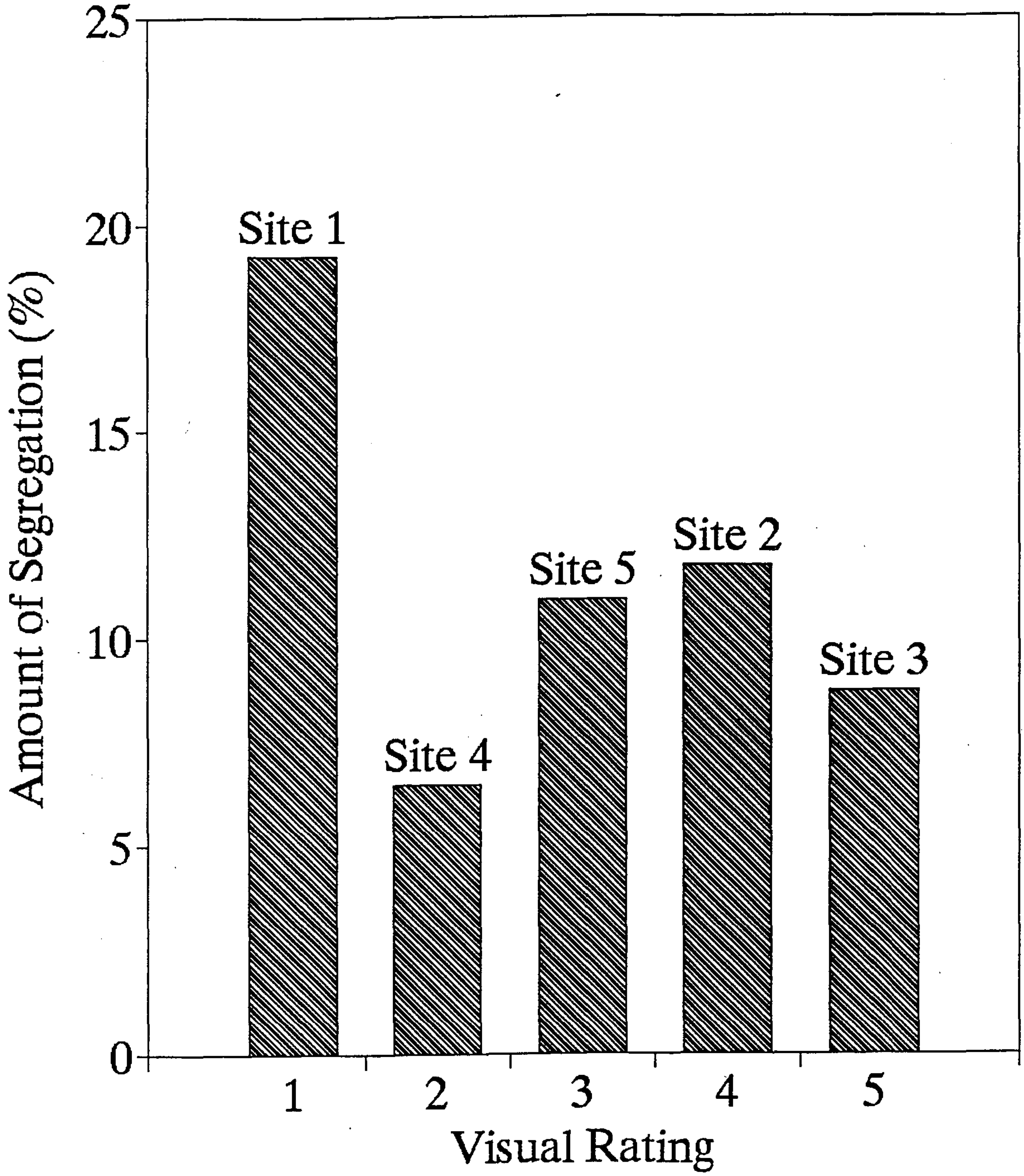

Figure 12. Visual Ranking vs Amount of Segregation

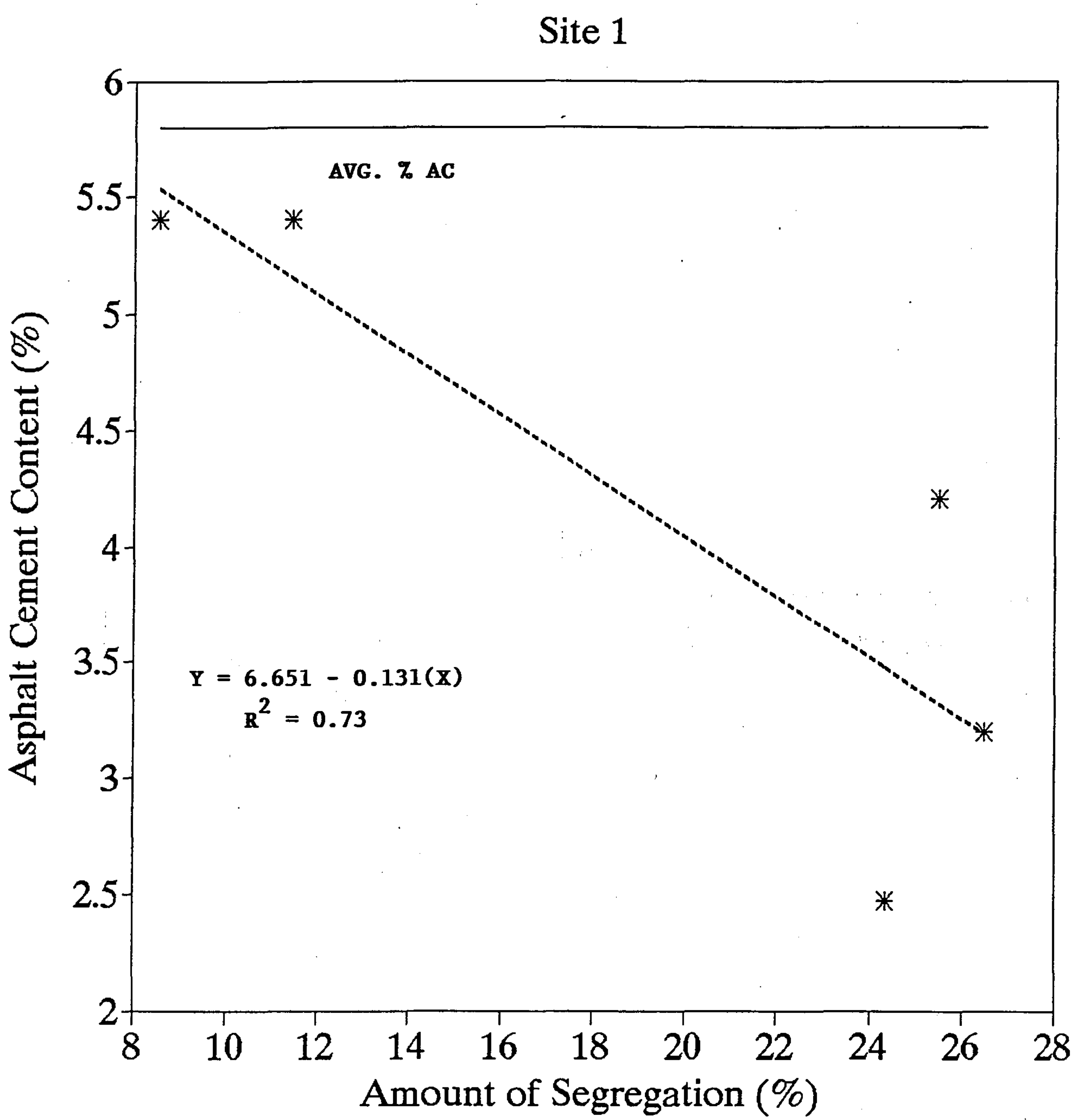

Figure 13. Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for Site 1.

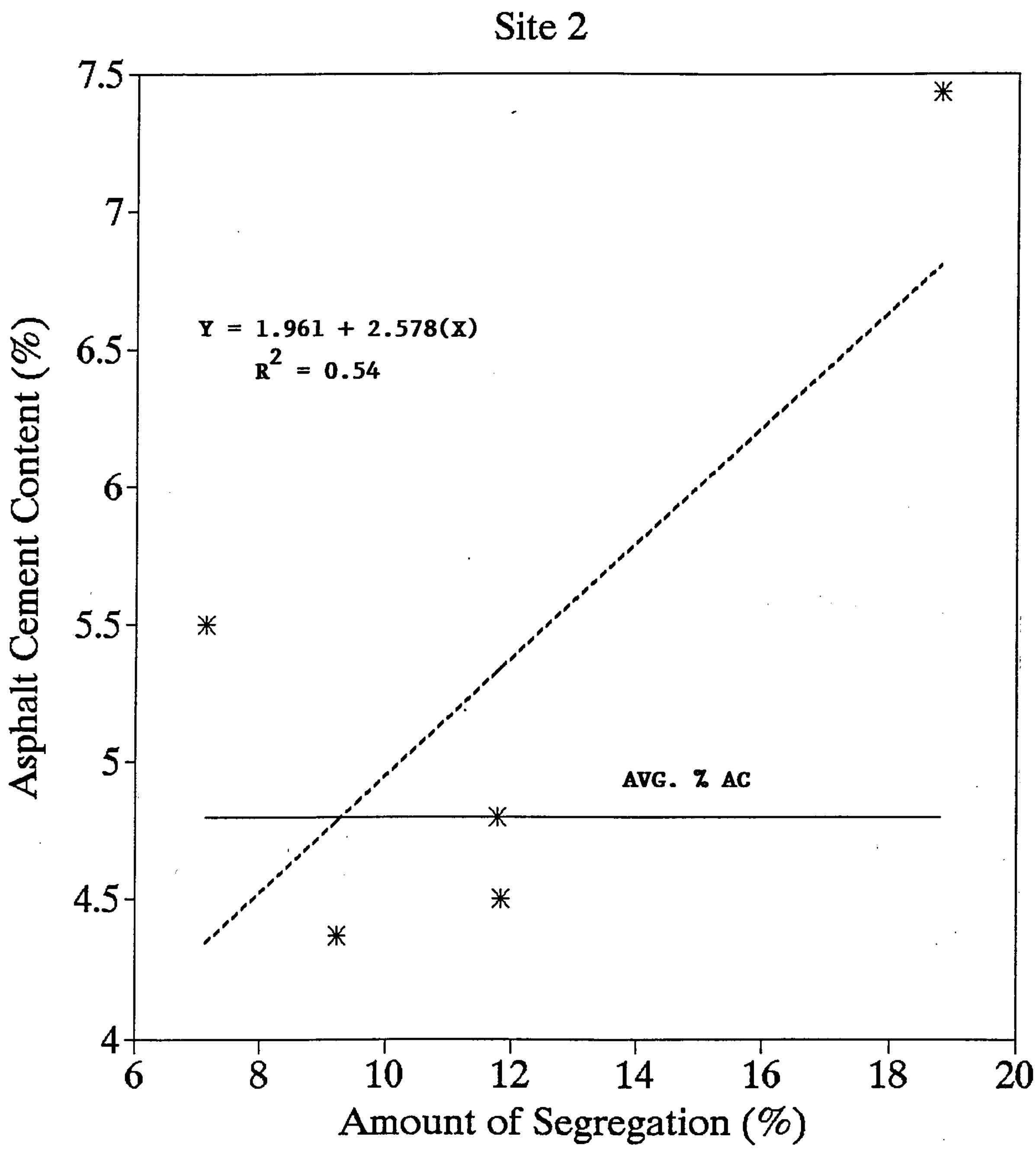

Figure 14. **Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for Site 2.**

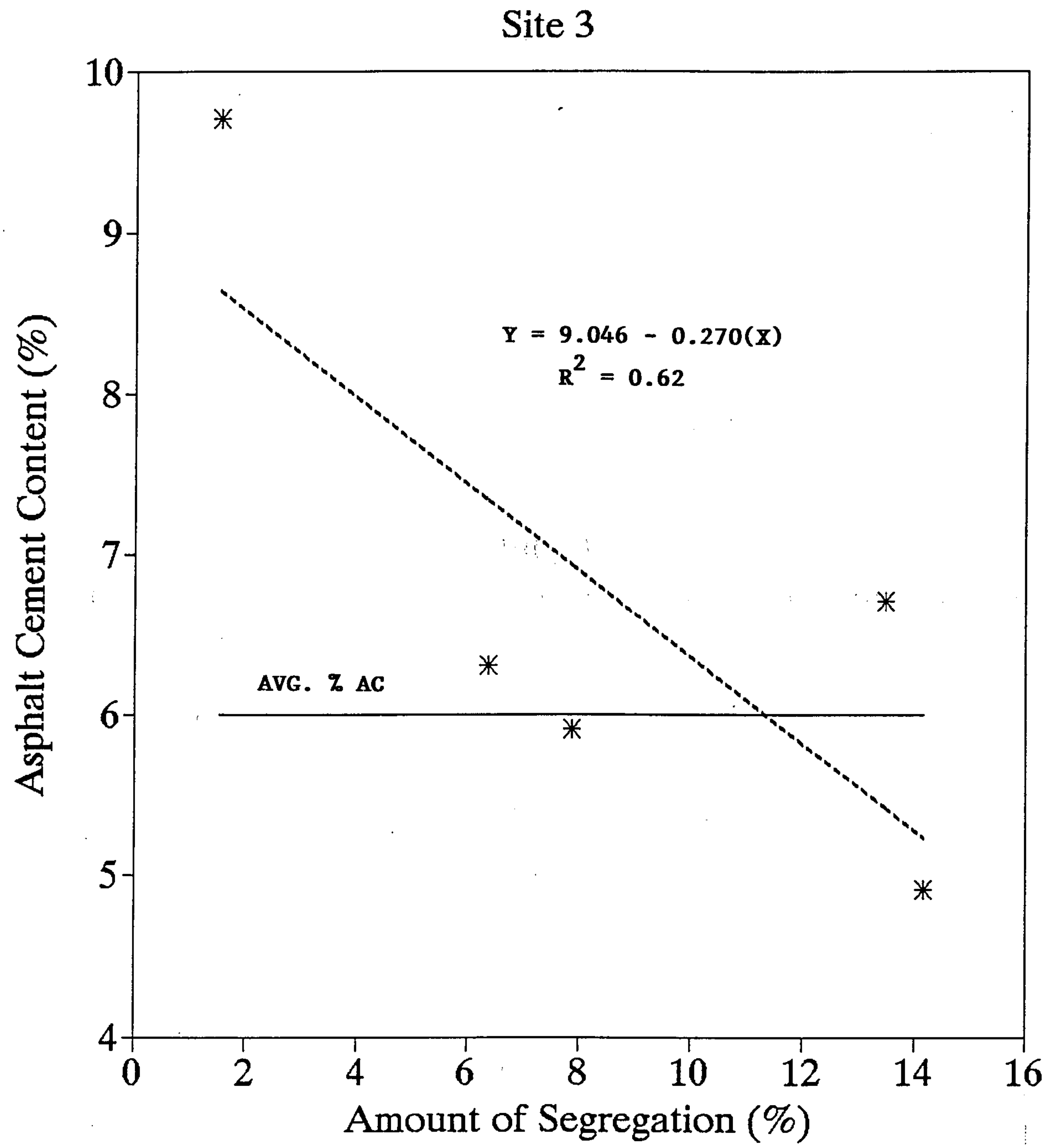

Figure 15. Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for Site 3.

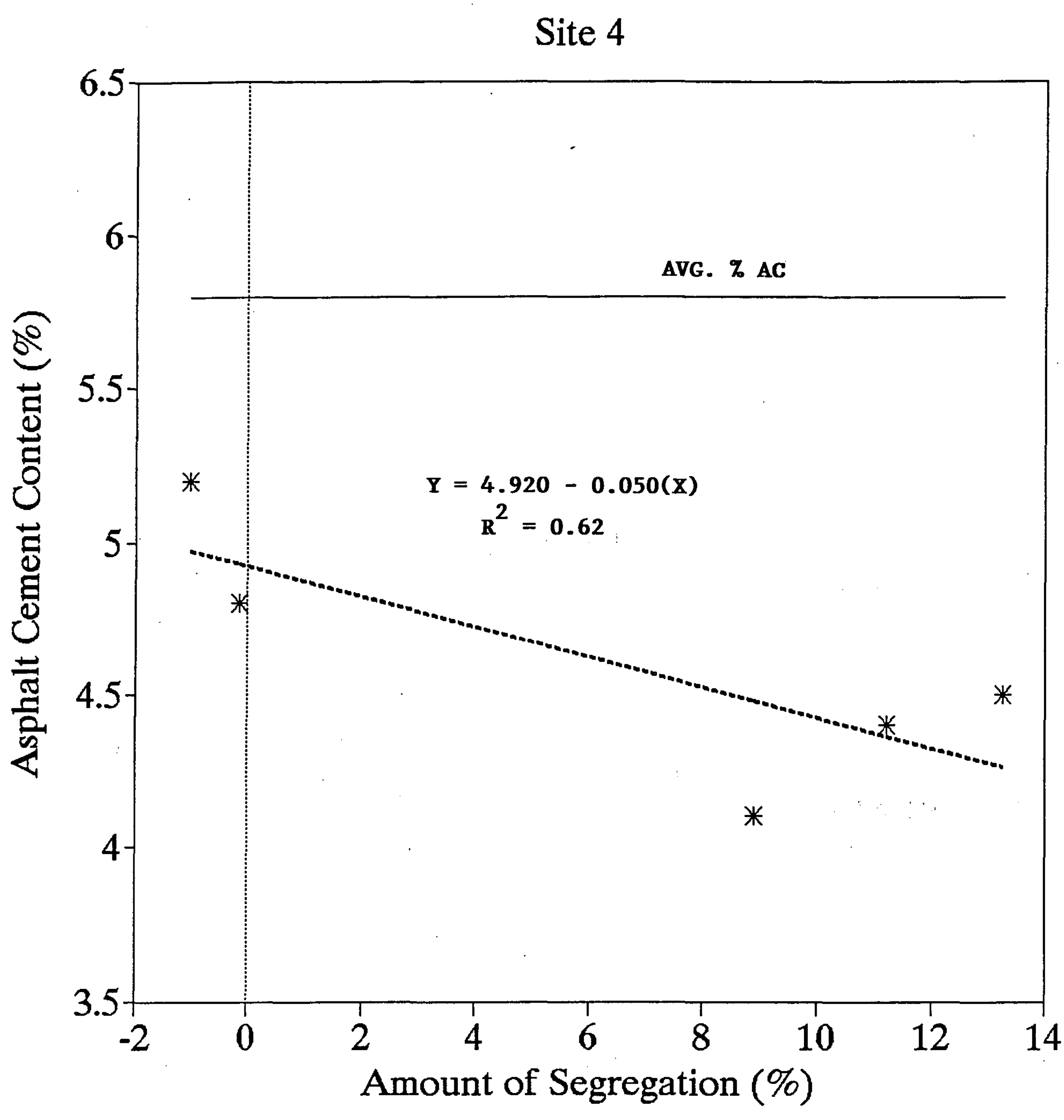

Figure 16. Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for Site 4.

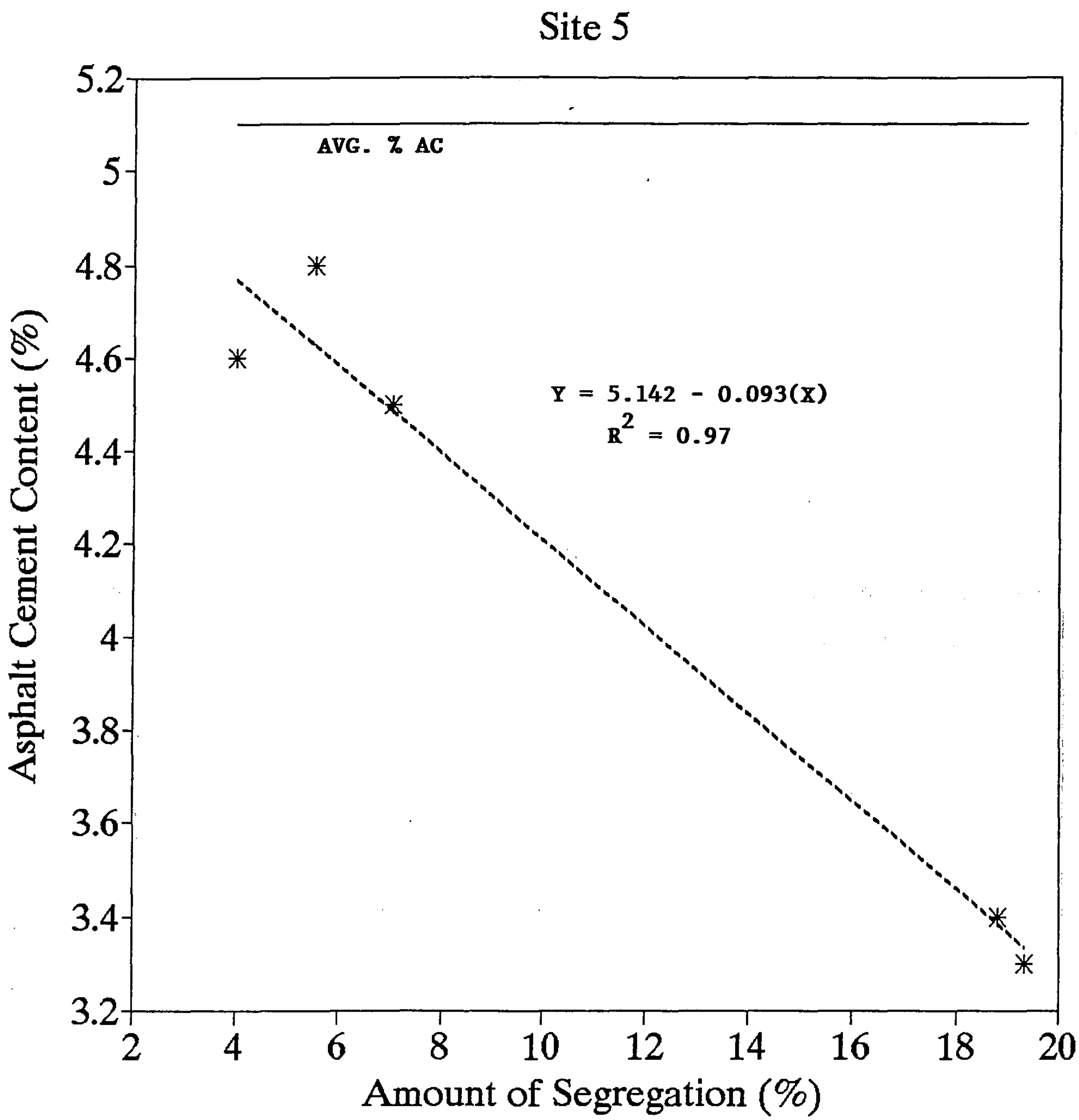

Figure 17. Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for Site 5.

asphalt cement content with an increase in the amount of segregation. The plot of site 2 shown in Figure 14 shows the results are heavily influenced by core C. Excluding this core the regression equation would have the proper slope. The coefficient of determination (R^2) ranged from a low of 0.54 at Site 2 to a high of 0.97 at Site 5. A low R^2 or incorrect slope indicates that some other factor other than segregation is affecting the asphalt cement content.

The plot of all of the data for the variation in asphalt cement content and the amount of segregation is shown in Figure 18. The relationship has an R^2 of 0.22. Two cores, core A from site 3 and core C from Site 2 are outside the 95% confidence limit and appear to be outliers. Treating these two cores as such the relationship has an R^2 of 0.43 and shows that as the amount of segregation increases the deficiency in asphalt cement content increases.

Pavement Density

The density of the pavement at each core location was determined utilizing a thin-lift nuclear gauge. The relative percent compaction of each core was determined by dividing the density of the core by the average density of the random samples from that site. The results were multiplied by 100 to get the answer in percent relative compaction for comparison between sites. The results are shown in Table 4.

The relationship between percent relative compaction and the amount of segregation as measured on the No. 4 sieve is shown in Figures 19-23 for sites 1-5 respectively. The slopes of the regression lines show a decrease in the relative percent compaction with an increase in segregation as measured on the No. 4 sieve for each site except Site 2. The coefficient of determination (R^2) ranged from a high of 0.97 at Site 5 to no relationship at Site 4. The

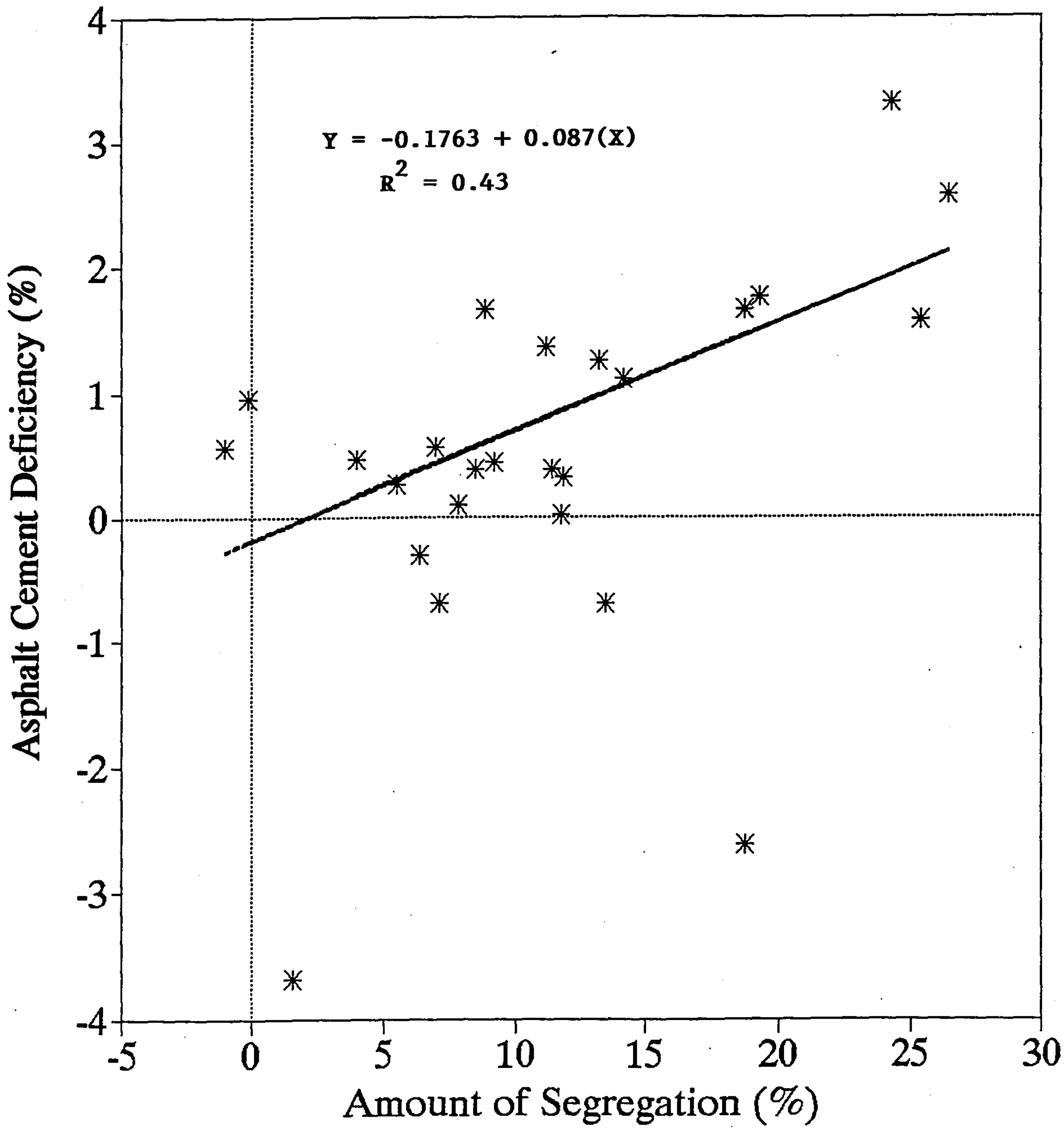

Figure 18. Asphalt Cement Deficiency vs Amount of Segregation Measured on No. 4 Sieve for all Sites.

Table 4. Summary of Test Results From Random and Segregated Cores.

			NUCLEAR GAUGE			ASPHALT CONTENT		No.4 SIEVE	
SITE NO.	SAMPLE	SAMPLE LOC.	DENSITY (psi)	DIFF. FROM RANDOM (psi)	PCT. OF RANDOM (%)	(%)	DIFF. FROM RANDOM (%)	PCT. PASS. (%)	DIFF. FROM RANDOM (%)
1	A	1	135.1	6.4	95.48	5.4	0.38	49.1	8.53
1	B	1	126.1	15.4	89.12	5.4	0.38	46.2	11.46
1	C	1	124.9	16.6	88.27	4.2	1.58	32.2	25.48
1	D	1	120.5	21.0	85.16	2.5	3.31	33.3	24.32
1	E	1	111.8	29.7	79.01	3.2	2.58	31.2	26.48
1	RANDOM	AVG.	141.5	N/A	100.00	5.8	N/A	57.6	N/A
2	A	1	135.8	8.8	93.91	4.4	0.44	53.4	9.22
2	B	1	134.3	10.3	92.88	5.5	-0.69	55.5	7.12
2	C	1	138.0	6.6	95.44	7.4	-2.62	43.8	18.79
2	D	1	137.4	7.2	95.02	4.5	0.31	50.7	11.85
2	E	1	138.6	6.0	95.85	4.8	0.01	50.8	11.79
2	RANDOM	AVG.	144.6	N/A	100.00	4.8	N/A	62.6	N/A
3	A	1	135.7	11.0	92.50	9.7	-3.70	59.6	1.55
3	B	1	130.4	16.3	88.89	5.9	0.10	53.3	7.89
3	C	1	140.7	6.0	95.91	6.3	-0.30	54.8	6.37
3	D	1	131.5	15.2	89.64	6.7	-0.70	47.7	13.49
3	E	1	122.6	24.1	83.57	4.9	1.10	47.0	14.19
3	RANDOM	AVG.	146.7	N/A	100.00	6.0	N/A	61.2	N/A
4	A	1	132.3	5.9	95.73	4.1	1.66	45.0	8.92
4	B	1	131.5	6.7	95.15	5.2	0.56	55.0	-1.04
4	C	1	126.5	11.7	91.53	4.8	0.96	54.1	-0.14
4	D	1	127.4	10.8	92.19	4.4	1.36	42.7	11.22
4	E	1	130.3	7.9	94.28	4.5	1.26	40.7	13.26
4	RANDOM	AVG.	138.2	N/A	100.00	5.8	N/A	53.9	N/A
5	A	1	129.2	7.5	94.51	4.5	0.56	45.6	7.03
5	B	1	132.4	4.3	96.85	4.6	0.46	48.7	4.00
5	C	1	128.3	8.4	93.86	4.8	0.26	47.1	5.53
5	D	1	119.7	17.0	87.56	3.4	1.66	33.9	18.82
5	E	1	117.6	19.1	86.03	3.3	1.76	33.3	19.36
5	RANDOM	AVG.	136.7	N/A	100.00	5.1	N/A	52.7	N/A

Note: For samples A-E sample location 1 is a segregated area.

N/A = Not Applicable.

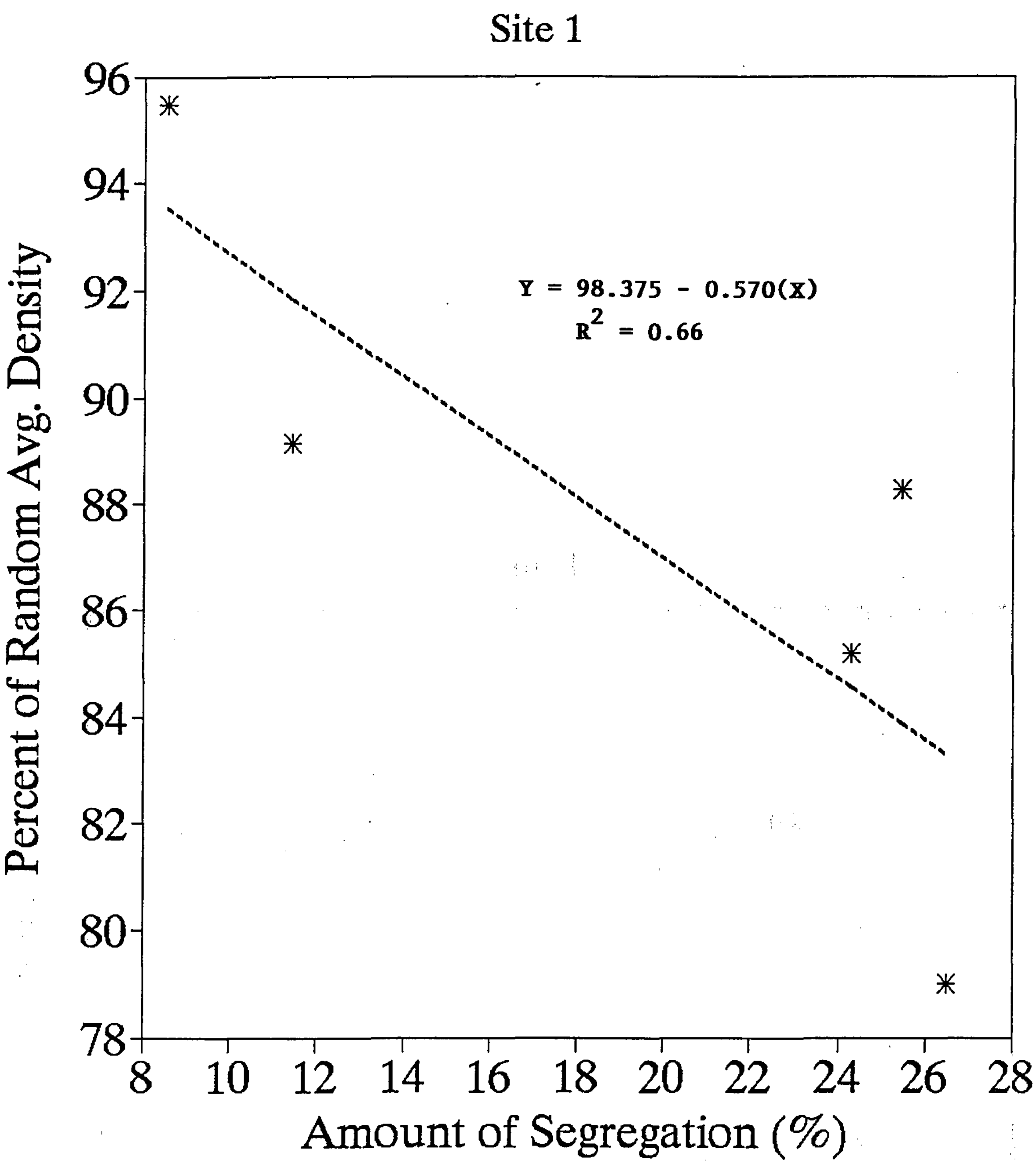

Figure 19. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for Site 1.

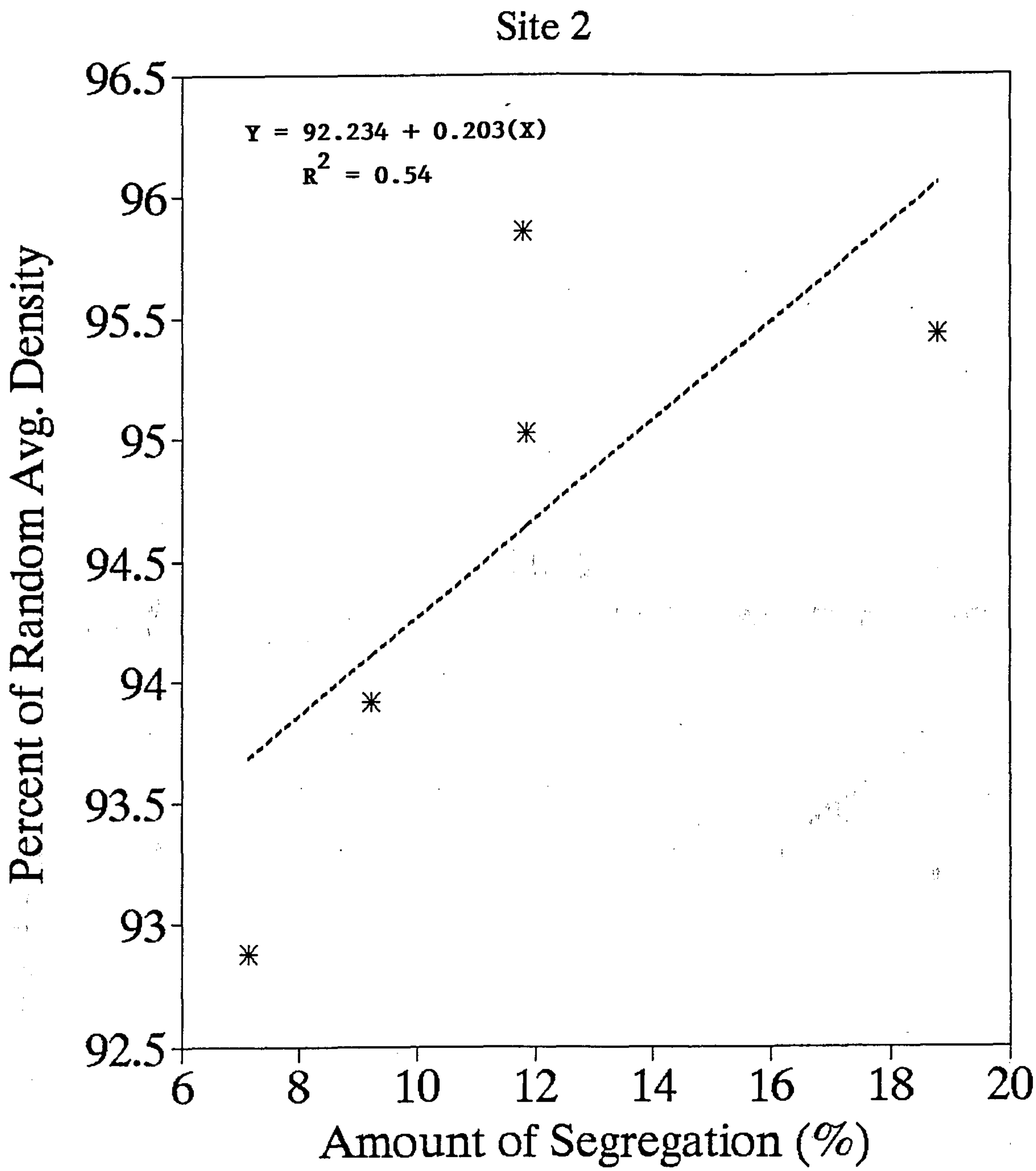

Figure 20. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for Site 2.

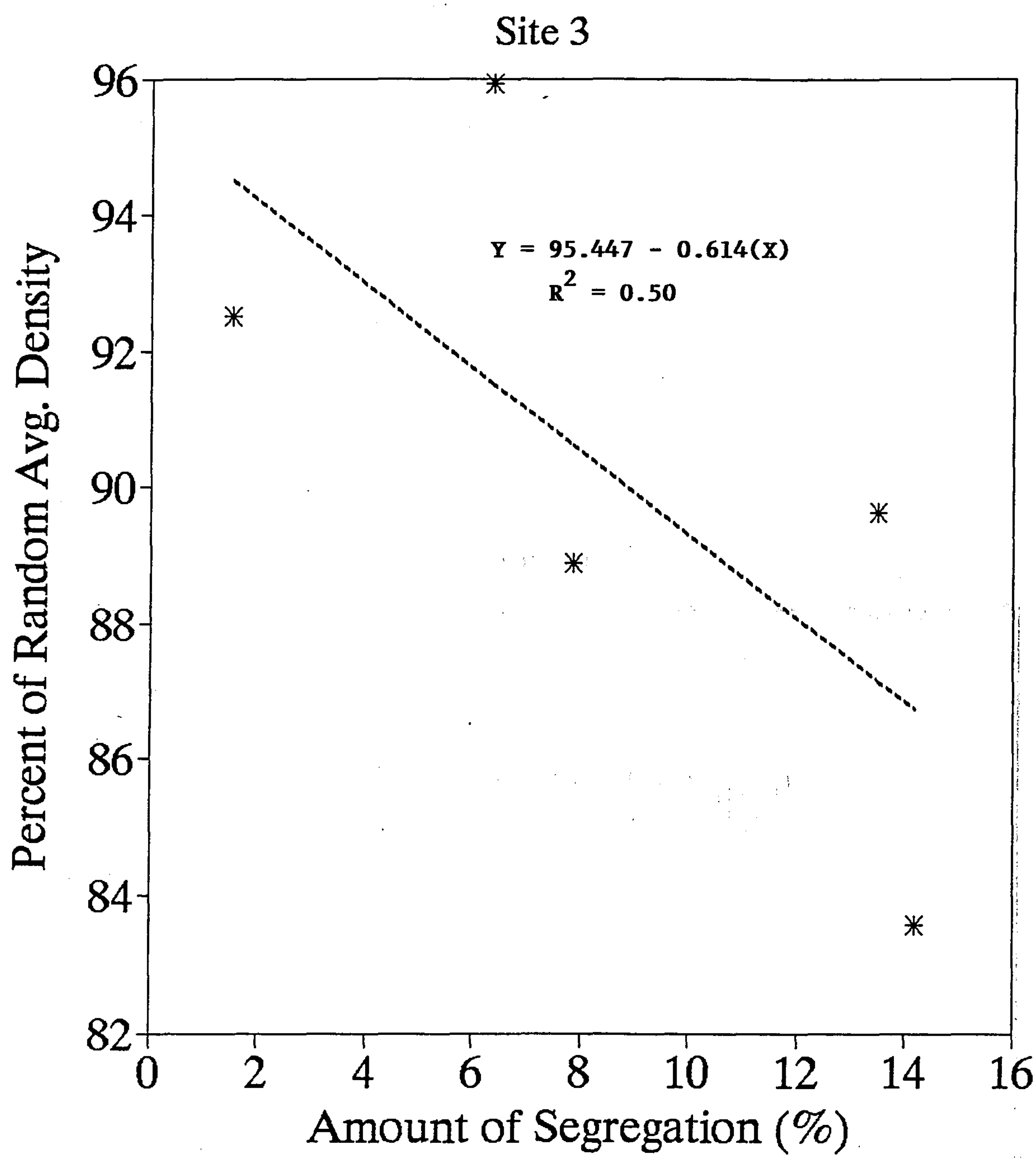

Figure 21. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for Site 3.

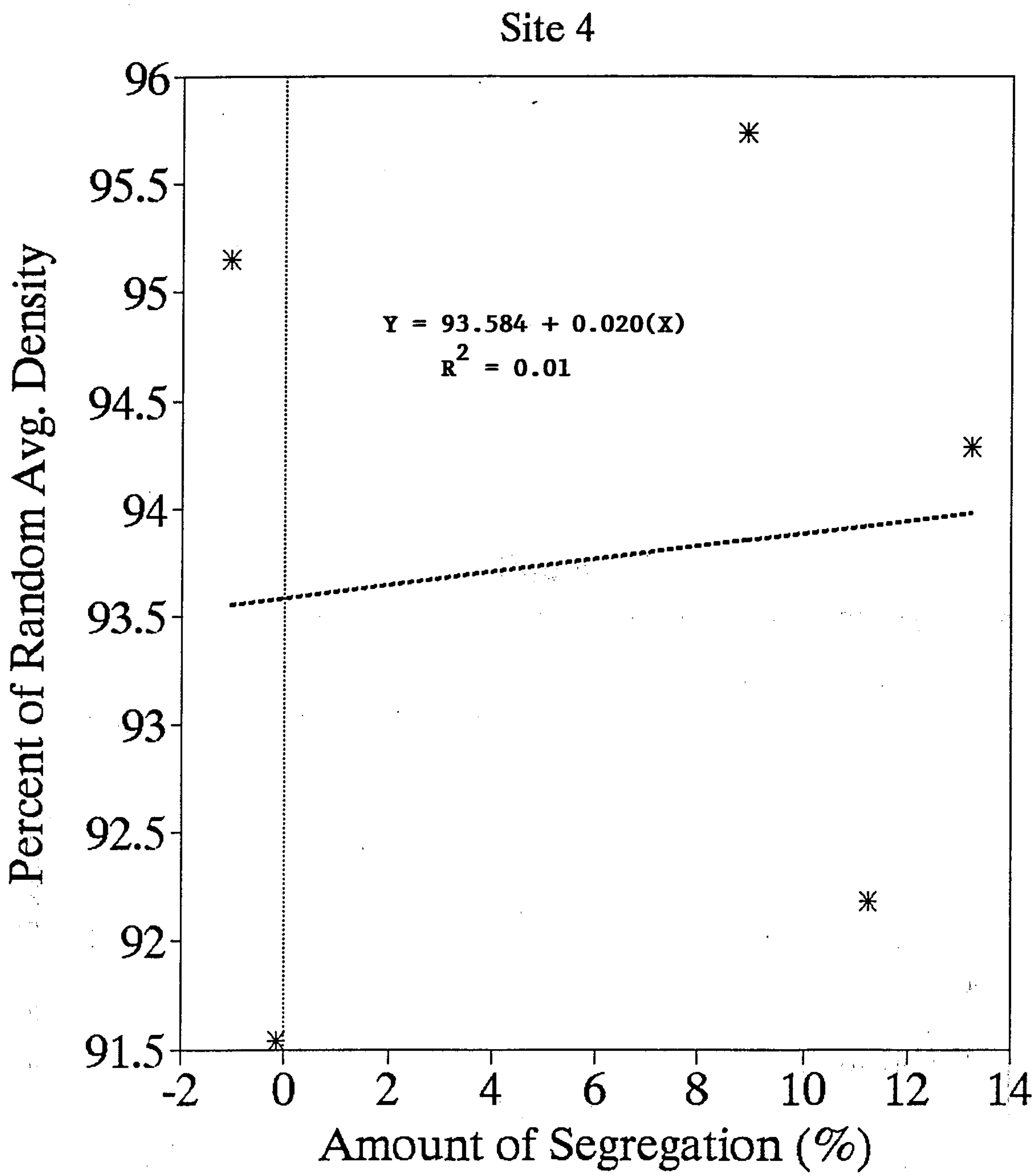

Figure 22. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for Site 4.

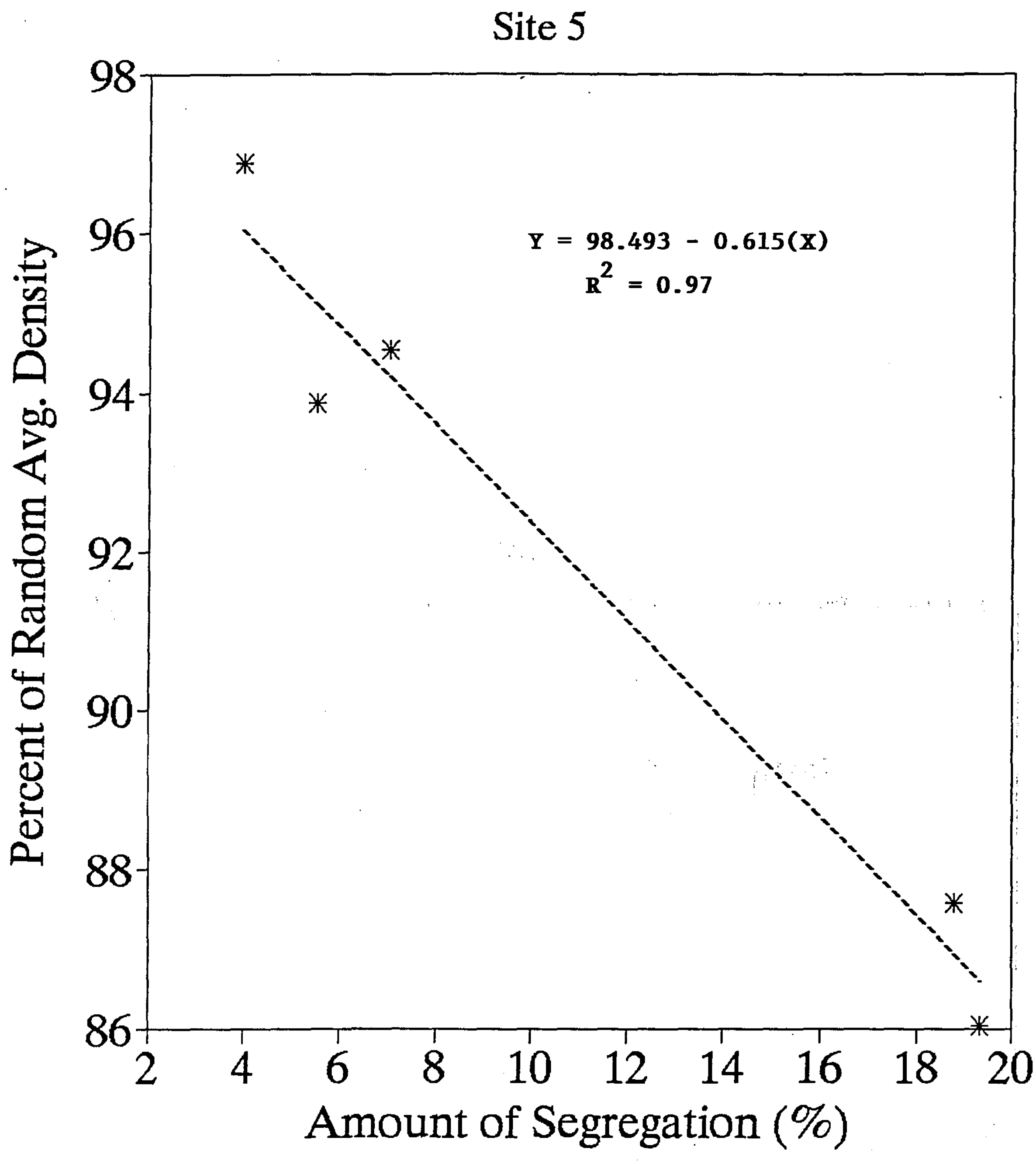

Figure 23. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for Site 5.

relationship for all of the data is shown in Figure 24. The relationship has an R^2 of 0.44 and shows that as the amount of segregation increases the relative percent compaction decreases.

Sand Patch Test

The sand patch diameter for each core and the average sand patch diameter of the random cores for each site are shown in Table 2. The relationship between sand patch diameter and amount of segregation as measured on the No. 4 sieve for sites 1-5 is shown in Figures 25-29, respectively. The figures show that the amount of segregation increases as the sand patch diameter decreases for each site except Site 2. The coefficients of determination ranged from a high of 0.95 at Site 5 to a low of 0.10 at Site 2.

The relationship for all of the data is shown in Figure 30. The plot shows that as the amount of segregation increases the sand patch diameter decreases indicating more raveling. The relationship has an R^2 of 0.60. The plot shows that a sand patch diameter of 8.4 inches would indicate 10 percent segregation on the No. 4 sieve.

Model to predict raveling

From the above data it was shown that the amount of segregation was related to the amount of raveling. The thin-lift nuclear gauge and the sand patch test were both shown to correlate with the measured amount of segregation with the sand patch test having the strongest correlation.

The sand patch diameter is a measure of the amount of raveling. Raveling is caused by traffic therefore the sand patch diameter would be a function of not only the amount of

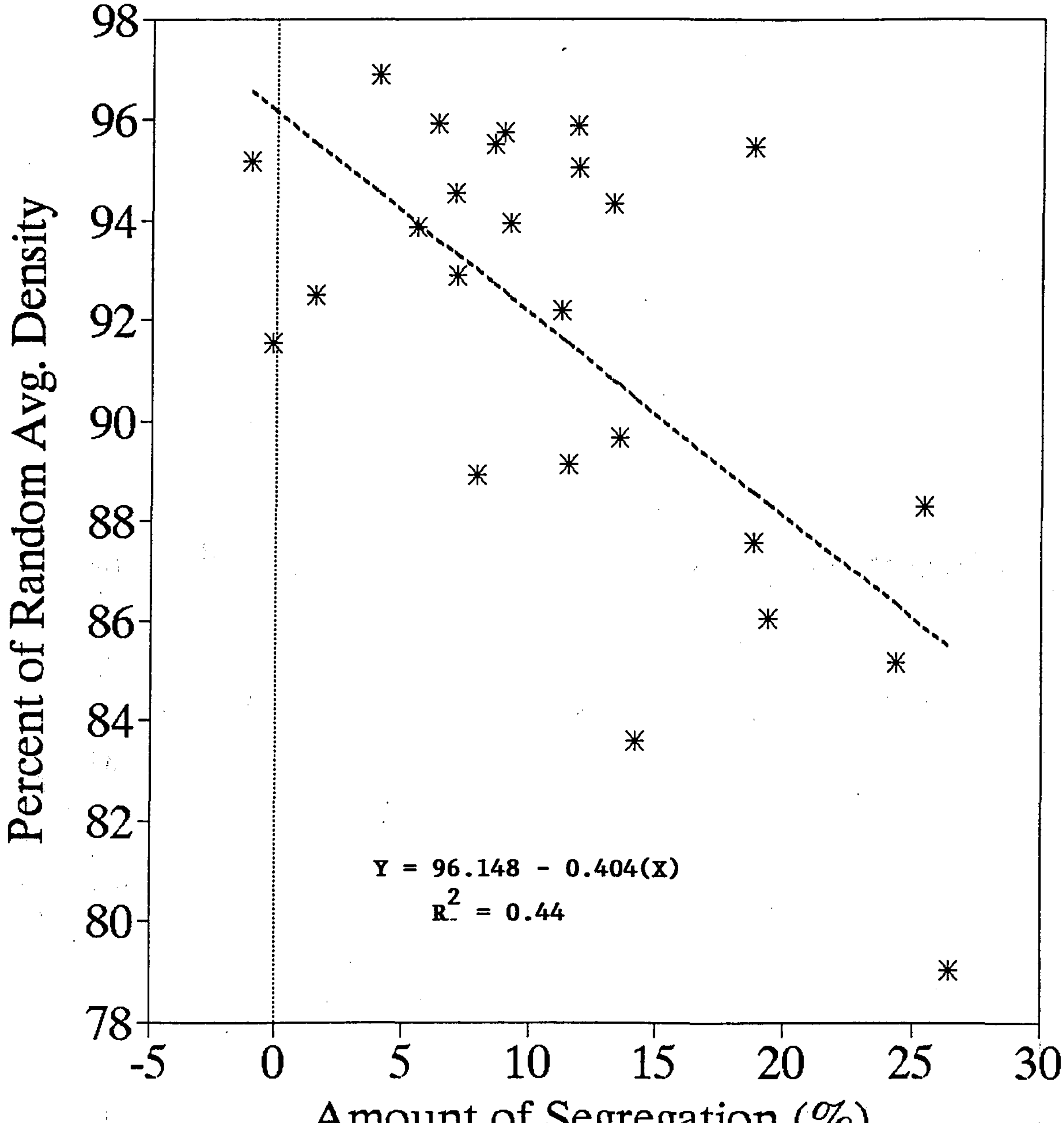

Figure 24. Percent of Random Average Density vs Amount of Segregation Measured on No. 4 Sieve for all Sites.

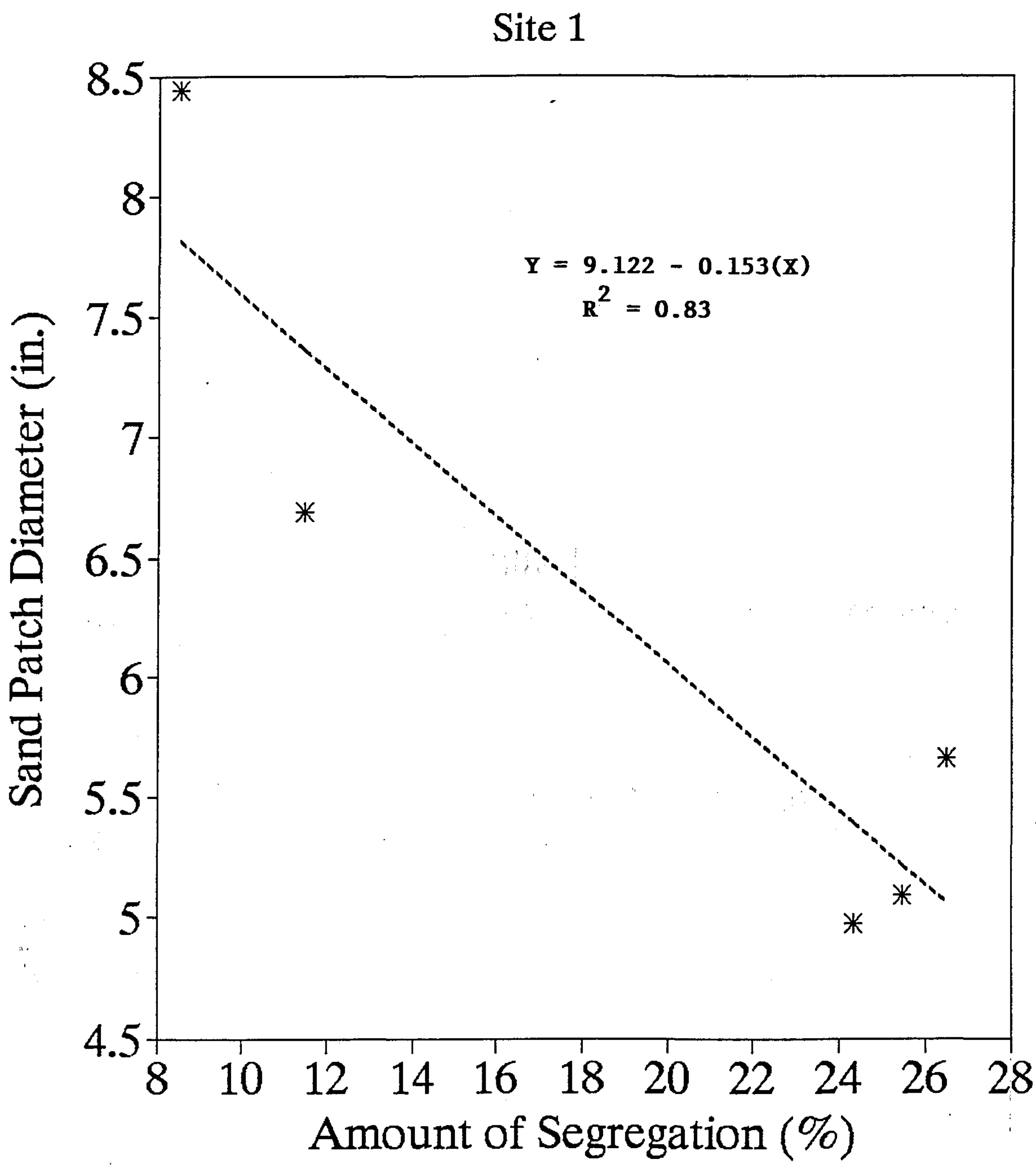

Figure 25. Sand Patch Diameter vs Amount of Segregation Measured on No. 4 Sieve for Site 1.

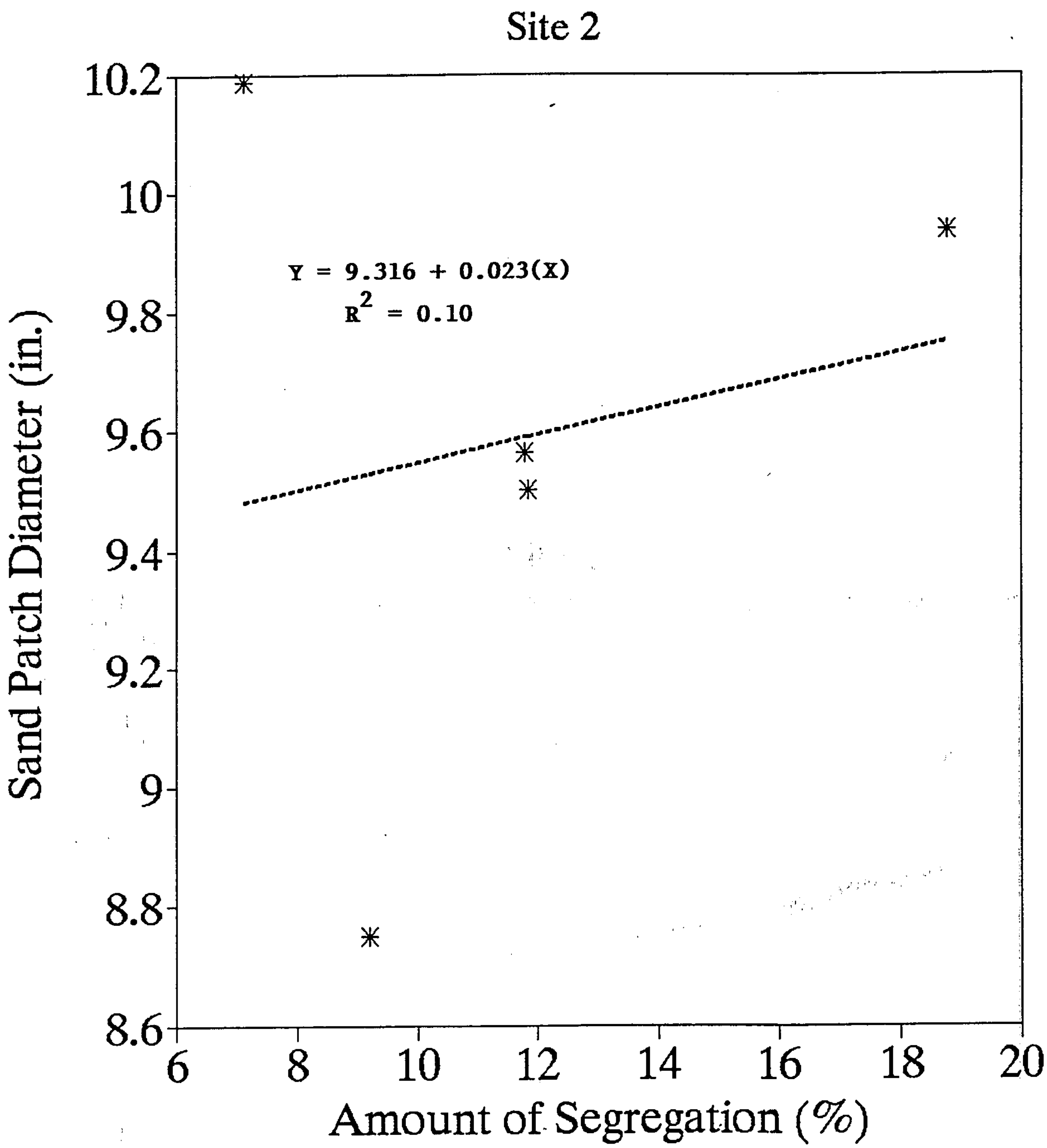

Figure 26. Sand Patch Diameter vs Amount of Segregation Measured on No. 4 Sieve for Site 2.

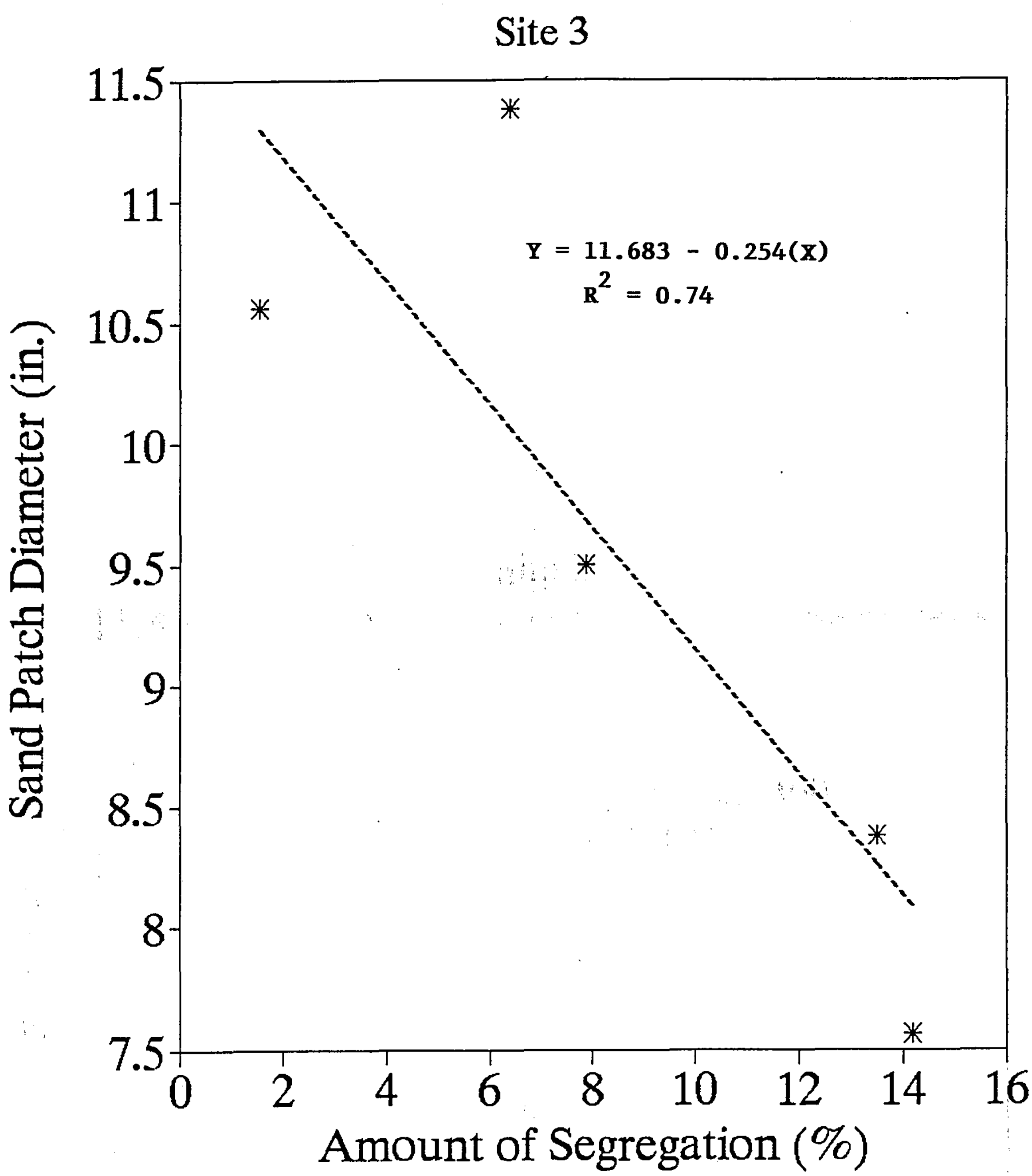

Figure 27. Sand Patch Diameter vs Amount of Segregation Measured on No. 4 Sieve for Site 3.

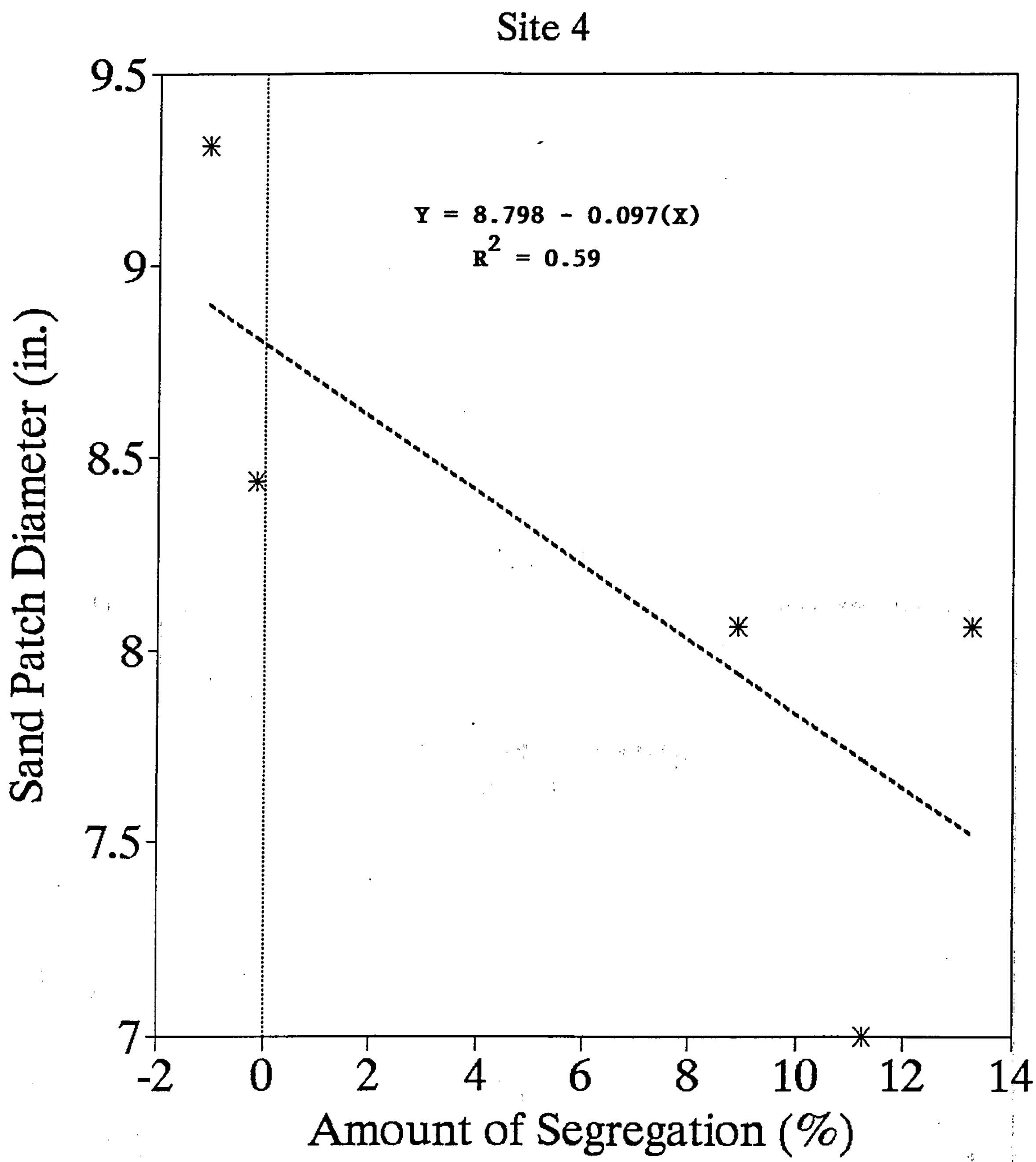

Figure 28. Sand Patch Diameter vs Amount of Segregation Measured on No. 4 Sieve for Site 4.

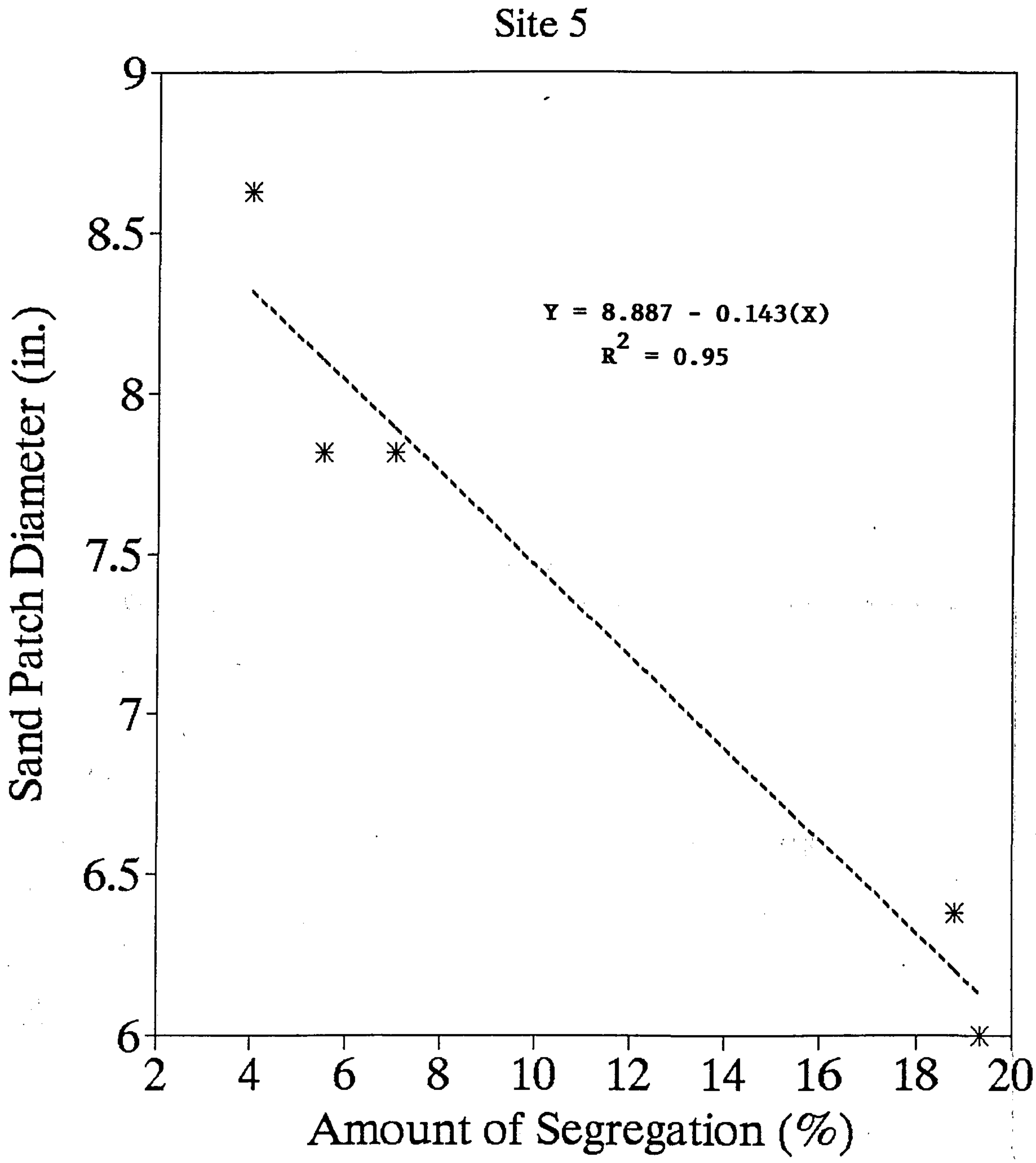

Figure 29. Sand Patch Diameter vs Amount of Segregation Measured on No. 4 Sieve for Site 5.

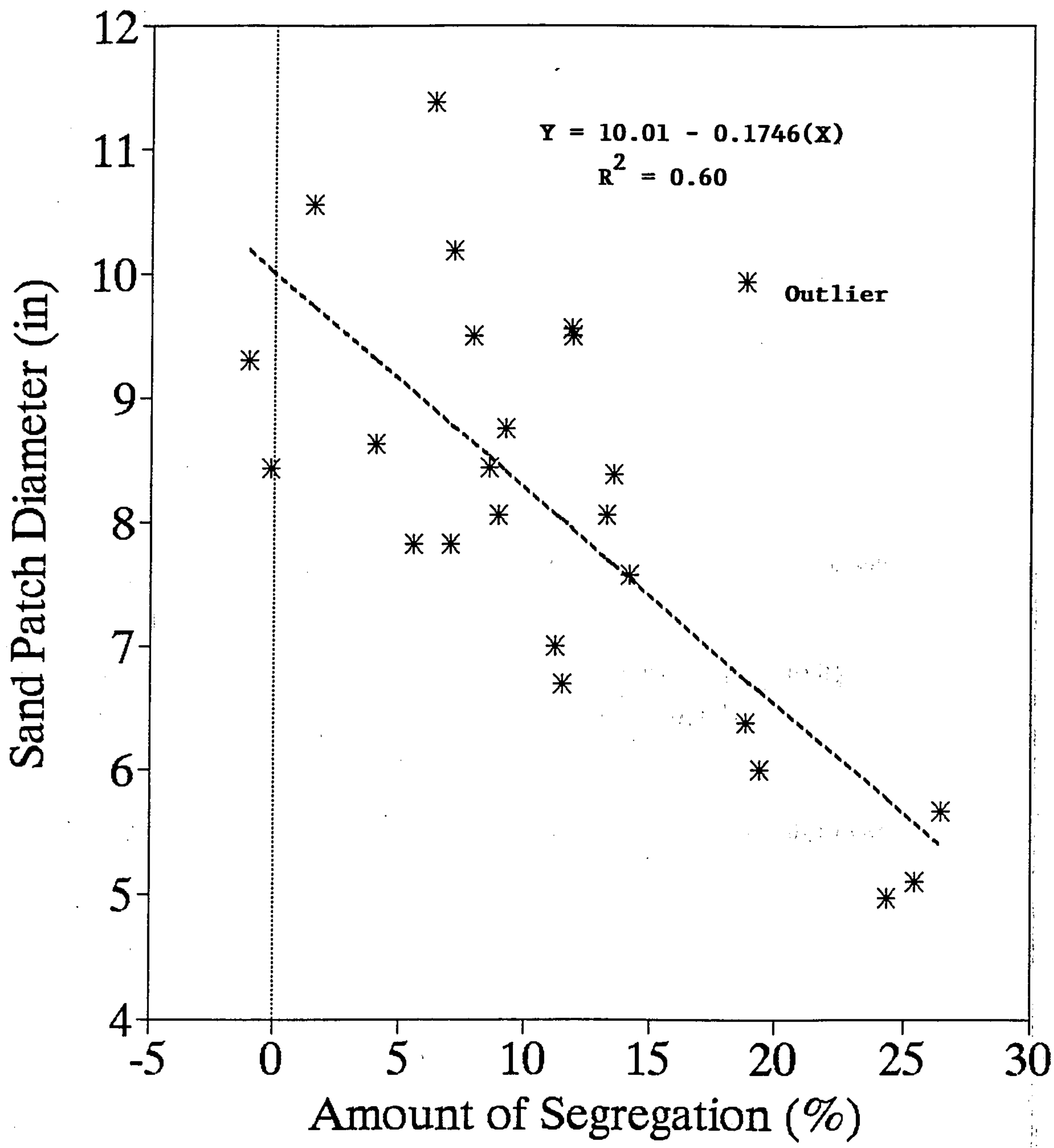

Figure 30. Amount of Segregation Measured on No. 4 Sieve vs Sand Patch Diameter for all Sites.

segregation but also traffic. The relationship between the sand patch diameter with the amount of segregation and traffic has the following form:

$$DIA = 11.158 - 2.74x10^{-7}(T) - 0.1502(SEG)$$

where:

SEG = Amount of segregation on No. 4 Sieve

DIA = Sand patch diameter

T = Total traffic in the sampled lane

The relationship has an R^2 of 0.76. A plot of the actual sand patch diameter (raveling) and the predicted sand patch diameter from the above equation is shown in Figure 31. There is not a lot of data to support this equation but this concept does appear to be reasonable. More testing is needed.

The sand patch diameter was compared to the visual rating to determine if the sand patch diameter would predict the performance of the pavement based on the visual rating. The results of the plot of average sand patch diameter for the segregated cores and the visual rating is shown in Figure 32. Since Sites 2 and 3 had little to no raveling a minimum sand patch diameter of 9 inches is indicative of no raveling. Knowing that the diameter should be at least 9 inches, the model can be used to determine if a given set of traffic and segregation conditions would result in raveling.

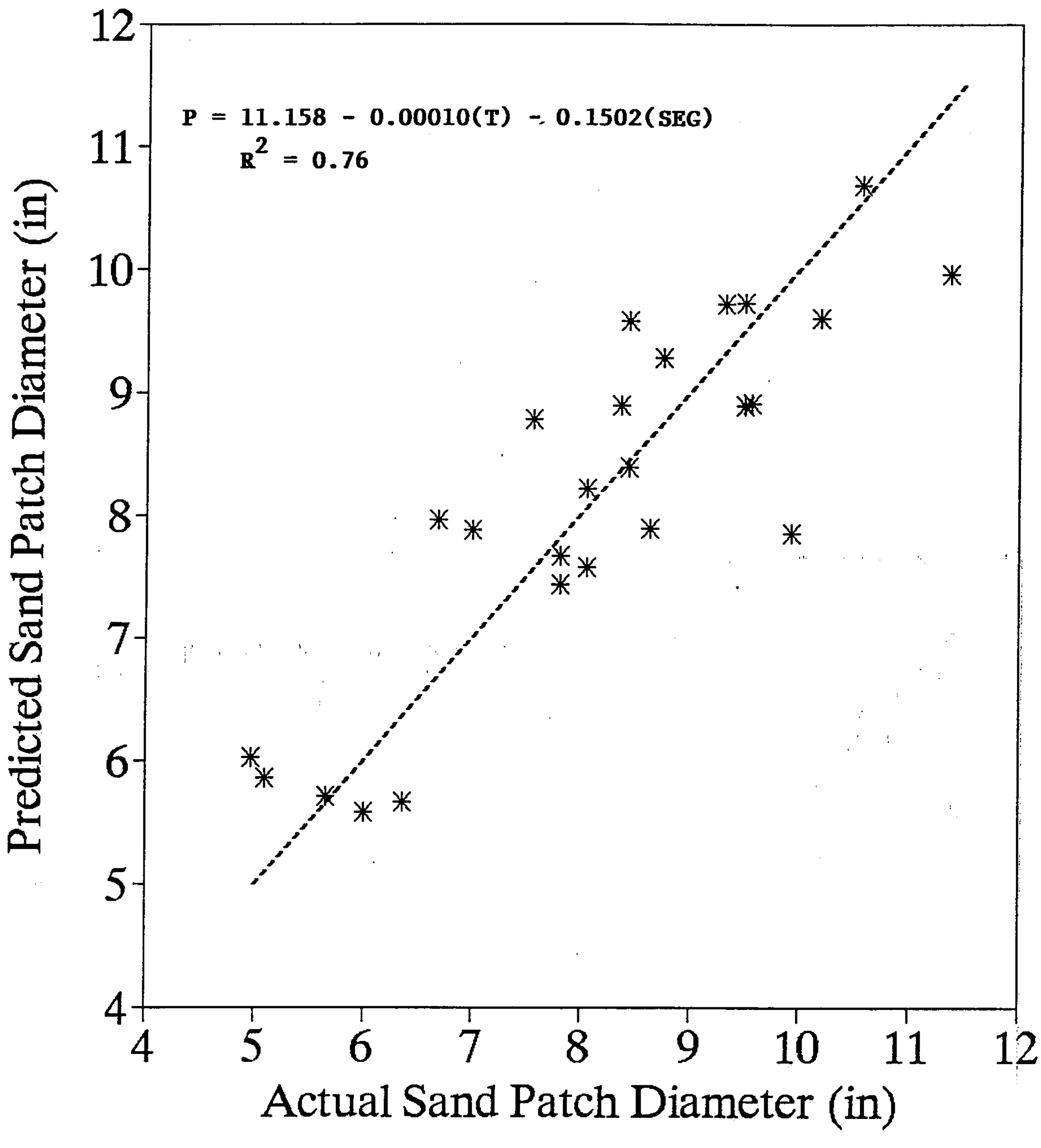

Figure 31. Relationship between Actual Sand Patch Diameter and Predicted Sand Patch Diameter (P) from Measured Amount of Segregation on No. 4 Sieve (SEG) and Traffic (T).

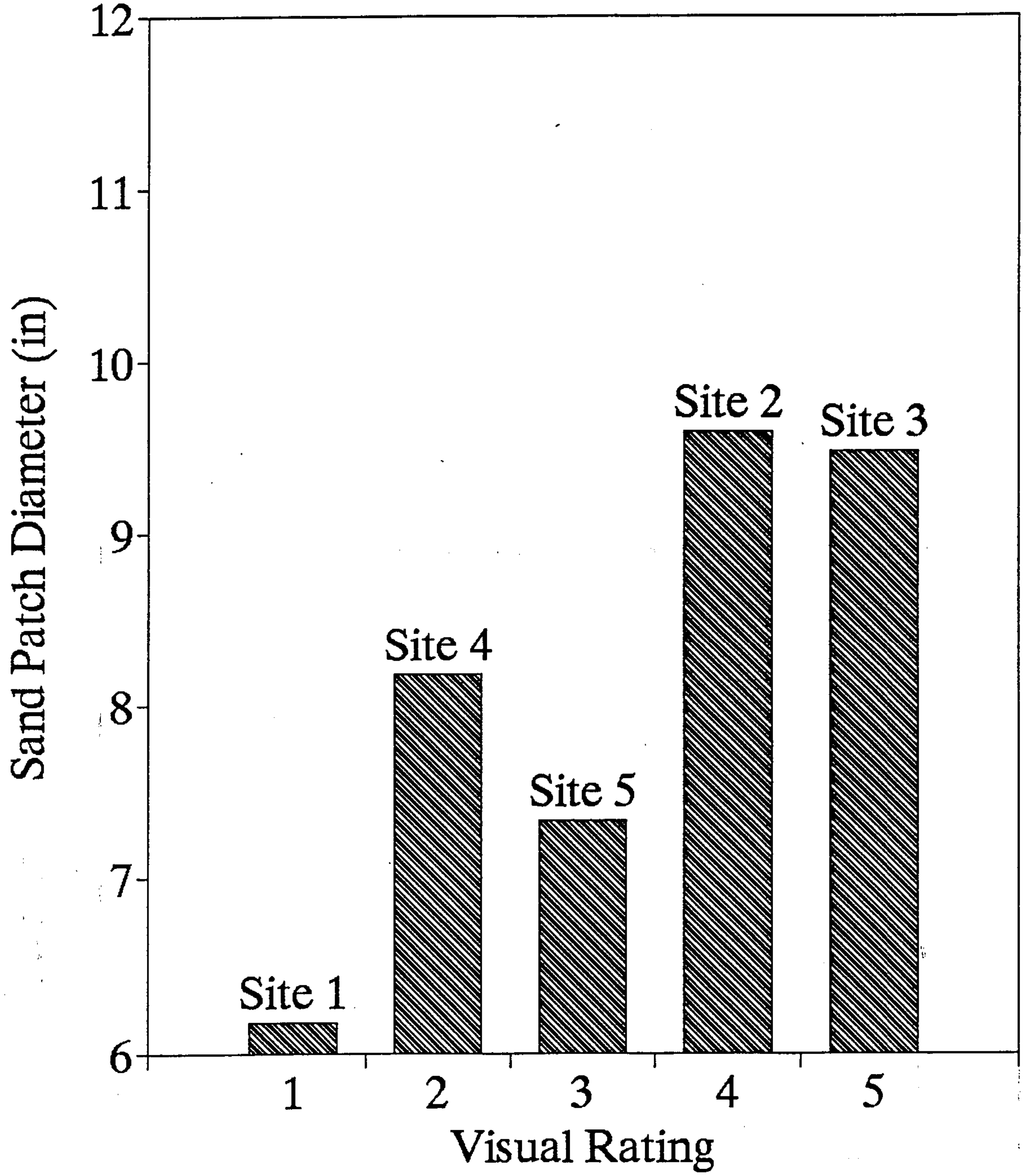

Figure 32. Visual Rating vs Average Sand Patch Diameter for Each Site.

CONCLUSIONS

1. A variation in the percent passing the No.4 sieve greater than 10 to 12% can lead to significant raveling.

2. Segregated areas of a pavement have lower asphalt content than that of the average asphalt content of the test section.

3. Segregated areas of a pavement have lower in-place density than the average density of the pavement.

4. Segregated areas of a pavement after 2-3 years have smaller sand patch diameters than the average sand patch diameter of the pavement indicating raveling and some differences in surface texture.

5. Traffic as measured by age and AADT has an effect on the sand patch diameter and hence raveling.

6. The sand patch diameter which can be quantified correlates to the amount of raveling.