Chater IV

EXPERIMENTAL RESULTS AND DISCUSSION

1. Mixing Water Required to Produce Uniform Coating of Asphalt

A number of silty sand and lateritic soil sample were tested by trial-and-error methods to find a minimum suitable water content to obtain a uniform stabilized mix shown in Table 6

Both emulsions, Penemulsion or the SS-K emulsion comprise asphalt and water, so the added water to coat the soil particles in the mix will be less when the percentage of emulsion is higher. Silty sand or lateritic soil needs a minimum amout of precoated water before mixing with emulsion in order to prevent immediate chemical reaction between the negative charge at the surface of soil grains and the cationic emulsion and also to delay the mixing time. In the case of lateritic soil, it may be difficult to completely coat some of the large particles. Satisfactory mixes need not to be completely coated with asphalt emulsion to achieve the desired performance. Less than a 100 % coating of the coarse particles does not affect the desired and results if the fine matrix of the mix is uniformly coated. During the compaction process, the filter-emulsion matrix generally surrounds the large aggregate particles. Therefore, for lateritic soil-emulsion mixes, mixing water required to produce uniform coating of asphalt was achieved when the fine matrix of the mix is uniformly coated. From Table 6, it appears that the minimum amount of mixing water for lateritic soil-emulsion

Table 6

Mixing Water Required to Produce Uniform Coating of Asphalt

Soil	Emulsion or Penemulsion*,%	Mixing Water*,% (Water to be mixed with)	
		Emulsion	Penemulsion
Silty Sand	2	16	16
Silty Sand	3	16	16
Silty Sand	4	15	15
Silty Sand	5	15	15
Silty Sand	6	14	14
Lateritic Soil	2	14	14
Lateritic Soil	3	14	14
Lateritic Soil	4	13	13
Lateritic Soil	5	13	13
Lateritic Soil	6	12	12

*Percent by weight of oven dry soil

is less than silty sand-emulsion mixed for the same percentage of asphalt emulsion. For Soils-Penemulsion and soils-emulsion (SS-K) mixed require the same percentage of mixing water content to obtain a uniform mix as shown in Table 6.

2. Hveem Test Results on Silty Sand Mixtures

Hveem test results for silty sand mixtures are shown in Table 7 to 10 and Figures 6 to 15

2.1 Density - Liquid Content Curves

As shown in Figure 6 and 10, the dry density and liquid content relationship were plotted. "Liquid Content" refers to the water in the soil plus the water to be added, and volatiles in the emulsion used. Both emulsion have lubrication property, therefore after being added to the soil the amount of water required to compact the soil to the maximum dry density may be decreased to a certain amount. It is alreadily shown that maximum dry density also increases with the adding of Penemulsion or the SS-K emulsion. The Penemulsion mixture tended to give higher maximum dry density compared with the SS-K mixture, but it increased slightly.

2.2 Stabilometer R-Value and C-Value V.S. Emulsion Contents

Various mix samples were prepared at both emulsion contents from 2 % to 6 % by the method stated in preparation of specimens. The moisture vapor susceptibility was applied to study the behaviour of the sample under worst condition.

Figure 7 and 8 show the stabilometer R-value and C-value of the Penemulsion mixtures and the SS-K mixtures at different percentages of emulsion contents. Figure 7 and 8 present the

Table 7 - Hveem Test Results for Silty Sand Stabilized with Penemumlsion by Standard Method.

Sample		Liquid Content, %	Dry Density, lb/cu.ft	R-Value	C-Value	Rt-Value =R+0.05C
S+2P,	1	9.2	122.5	55	127.1	61.4
	2	7.3	124.2	79	151.9	86.6
	3	6.2	122.9	83.5	166.6	91.8
	4	3.8	116.2	83	234.7	94.7
	5	2.0	114.3	75	120	81
S+3P,	1	9.7	121.9	47	116.7	58.2
	2	7.2	124.9	81	130.1	87.5
	3	5.8	123.3	86	184.7	95.1
	4	4.7	121.6	86.5	128.2	92.9
	5	3.4	119.6	85	302.6	100.1
	6	2.0	115.4	73	163.4	81.2
S+4P,	1	9.1	124.5	62	126.5	68.3
	2	7.9	125.6	73	132.4	79.6
	3	6.8	126.1	83	146.4	90.4
	4	6.4	125.7	84	158.8	92
	5	4.7	121.8	87	250.2	99.5
	6	3.0	117.5	82	97.5	86.9
S+5P,	1	10.3	122.2	43	129.7	49.5
	2	8.4	125.[illegible]	64.5	151.5	73
	3	5.7	125.8	87	200.0	97.0
	4	4.3	122.2	88.5	260.2	101.5
	5	2.6	116.0	84.5	402.9	104.6
	6	1.5	115.8	74	159.3	82
S+6P,	1	8.2	123.8	54	128.3	60.4
	2	7.2	125.8	72	158	80
	3	5.6	126.2	85.5	220.3	96.5
	4	3.9	120.4	87	282	101.1
	5	1.9	115.6	82	273,9	95.7

Table 8 - Hveem Test Results for Silty Sand Stabilized

with SS-K Emulsion by Standard Method.

Sample	Liquid Content, %	Dry Density, lb/cu.ft	R-Value	C-Value	Rt-Value =R+0.05C
S+2E, 1	6.7	120.7	80	116.5	85.5
2	7.1	121.4	81	118.5	86.9
3	8.1	122.3	78	115.4	84.3
4	8.6	122.4	59.3	119.3	69.5
5	9.0	122.0	56.1	122.9	62.6
S+3E, 1	9.0	121.7	65	153.2	73
2	6.5	123.3	82	165.0	90.7
3	5.2	121.0	83.5	179.3	92.5
4	3.5	119.2	81	244.1	93.2
S+4E, 1	8.8	123.3	65	132.4	71.6
2	6.1	125.5	84.5	179.7	93.5
3	5.9	123.4	82.5	196.5	92.3
4	3.6	119.2	83	300.3	98
5	2.2	118.2	80.5	247.9	92.9
S+5E, 1	8.5	124.2	56	118.8	62
2	6.9	126.3	76	150.5	84
3	4.4	124.0	85	261	98
4	3.5	123.2	83	306	98.3
5	2.6	121.6	80	373.4	98.7
S+6E, 1	5.8	126.5	74.5	215	84.6
2	7.3	126.3	61.5	155.5	69.3
3	8.4	124.1	57.8	127.2	63.4
4	8.8	124.0	52.4	135.5	59.3
S, 1	4.7	120.2	70	122.2	76.1
2	7.6	121.3	72	125.1	78.3
3	9.3	122.0	63	131	69.5
4	10.2	120.4	52	128	58.4

Table 9 - Hveem Test Results for Silty Sand Stabilized with Penemulsion after Moisture Vapor Susceptibility.

Sample	Before		After		Water absorbed %	R-Value	C-Value	Rt-Value =R+0.05C
	L/C,%	γdry, lb/cu.ft.	L/C,%	γdry lb/cu.ft				
S+6P, 1	12.3	120.9	12.5	120.9	0.2	40	119	46
2	8.4	124.1	8.9	124	0.5	61	155	69
3	6.6	126.9	7.6	126.2	1.0	78	188	87
4	4.5	125.2	7.4	125.4	2.9	73	195	83
5	3.1	114.7	8.6	114.5	5.5	67	202	77
S+5P, 1	10.3	121.2	10.5	121.0	0.2	48	132	55
2	8.2	124.7	9.2	124.7	1.0	74	151	82
3	6.4	126.7	8.5	125.9	2.1	83	172	92
4	3.6	119.6	10.9	119.2	7.3	76	185	85
5	2.3	117.7	8.2	117.7	5.9	67	190	77
S+4P, 1	9.0	122.5	9.8	122.3	0.8	49	141	56
2	8.0	125.2	9.1	125.2	1.1	75	151	83
3	5.2	124.7	9.2	124.7	4.0	81	148	88
4	3.3	118.7	11.8	119.4	8.5	74	146	81
5	2.3	116.7	14.1	115.9	11.8	57	119	63
S+3P, 1	8.0	123.8	9.3	123.7	1.3	72	143	79
2	7.4	124.6	9.1	124.0	1.7	77	148	84
3	5.8	124.8	9.0	124.1	3.2	81	138	88
4	3.9	121.6	11.5	121.5	7.6	74	145	81
5	1.5	119.9	12.2	120.3	10.7	49	131	55
S+2P, 1	9.0	121.5	10.1	121.8	1.1	61	119	67
2	6.8	124.5	9.2	124.4	2.4	79	139	86
3	5.3	123.3	9.8	122.8	4.5	79	128	85
4	4.8	122.0	10.4	122.3	5.6	77	127	83
5	2.1	120.9	11.9	121.0	9.8	61	113	61

Table 10 Hveem Test Results for Silty Sand Stabilized with SS-K Emulsion after Moisture Vapor Susceptibility.

Sample	Before		After		Water absorbed %	R-Value	C-Value	Rt-Value =R+0.05C
	L/C, %	γdry, lb/cu.ft	L/C, %	γdry, lb/cu.ft				
S+2E, 1	6.1	120.4	9.7	121.1	3.6	74	114	80
2	6.3	121.9	9.3	121.9	3.0	73	119	79
3	7.0	121.5	10.2	121.8	3.2	71	129	77
4	9.3	121.0	10.3	120.6	1.0	44	130	50
5	9.8	119.5	10.5	119.0	0.7	40	121	46
S+3E, 1	10.5	118.6	11.1	118.3	0.6	40	115	46
2	8.8	122.3	9.8	122.5	1.0	45	127	51
3	7.6	123.7	9.3	123.6	1.7	64	137	71
4	5.9	122.5	9.4	121.8	3.5	76	134	83
5	2.8	118.5	12.3	118.4	9.5	70	120	76
S+4E, 1	5.6	122.9	9.2	122.1	3.6	77	158	85
2	8.0	123.7	9.4	123.4	1.4	64	144	71
3	8.4	123.2	9.5	122.8	1.1	61	138	69
4	8.7	122.5	9.7	122.0	1.0	58	133	65
S+5E, 1	8.7	122.2	9.7	122.0	1.0	55	144	62
2	6.3	126.4	8.5	126.2	2.2	78	170	87
3	4.1	122.2	10.3	122.0	6.2	77	179	86
4	3.2	118.6	11.7	118.5	8.5	72	178	81
S+6E, 1	5.5	126.6	7.7	126.2	2.2	72	186	81
2	6.6	126.4	7.8	126.4	1.2	68	182	77
3	6.9	126.8	7.8	126.2	0.9	66	171	75
4	8.0	125.0	8.7	124.3	0.7	55	138	62
S, 1	5.6	119.5	11.7	119.1	6.1	66	107	71
2	7.8	121.9	10.5	121.3	2.7	67	110	73
3	8.6	122.1	10.7	122.0	2.1	64	109	69
4	10.5	119.8	12.4	119.2	1.9	54	112	60

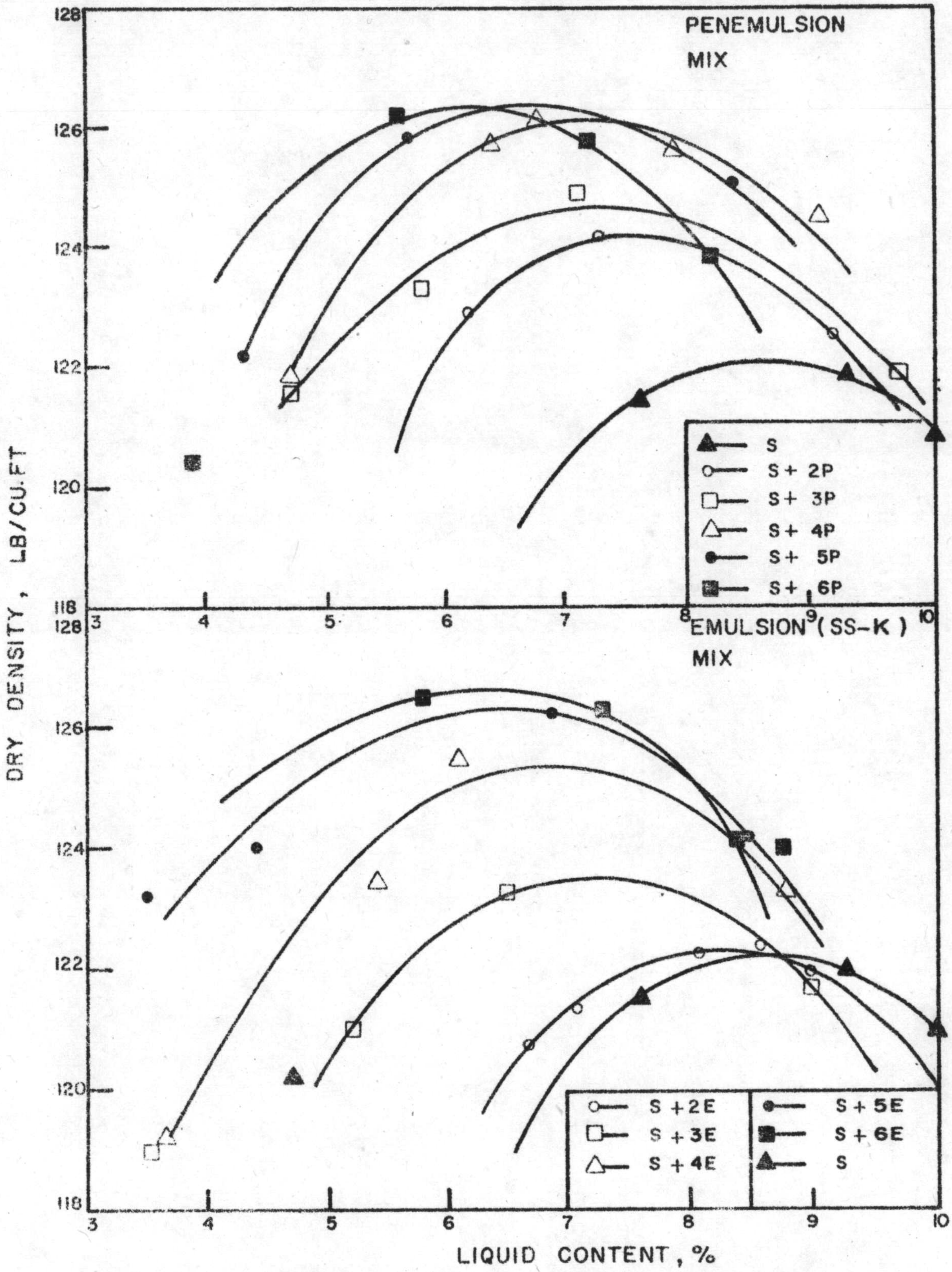

Figure 6. Comparison of Liquid - Density Curves of Silty Sand Stabilized with Penemulsion and Emulsion (SS - K) by Standarc Method.

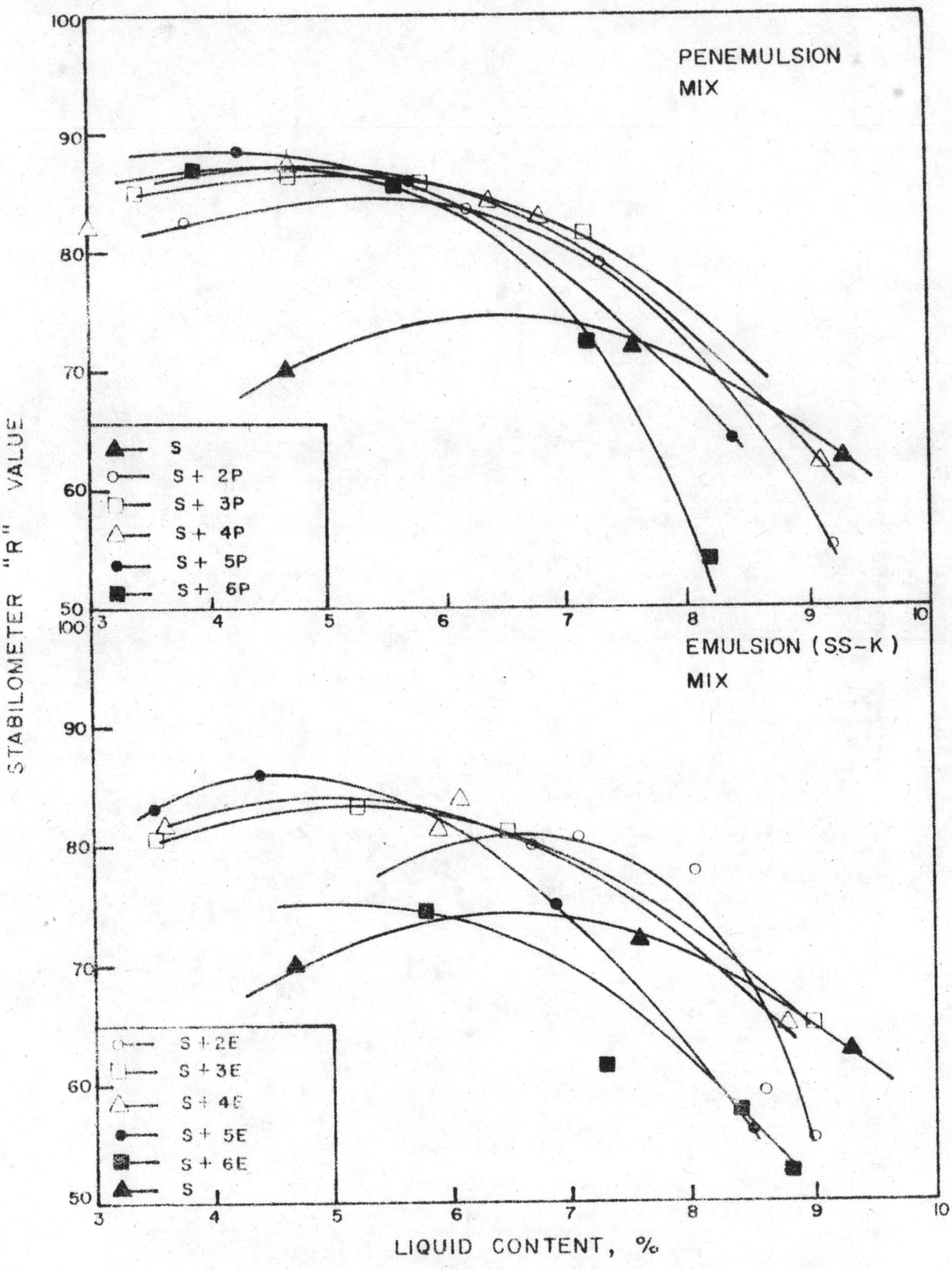

Figure 7. Comparison of Stabilometer "R" Value of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) by "Standard" Method.

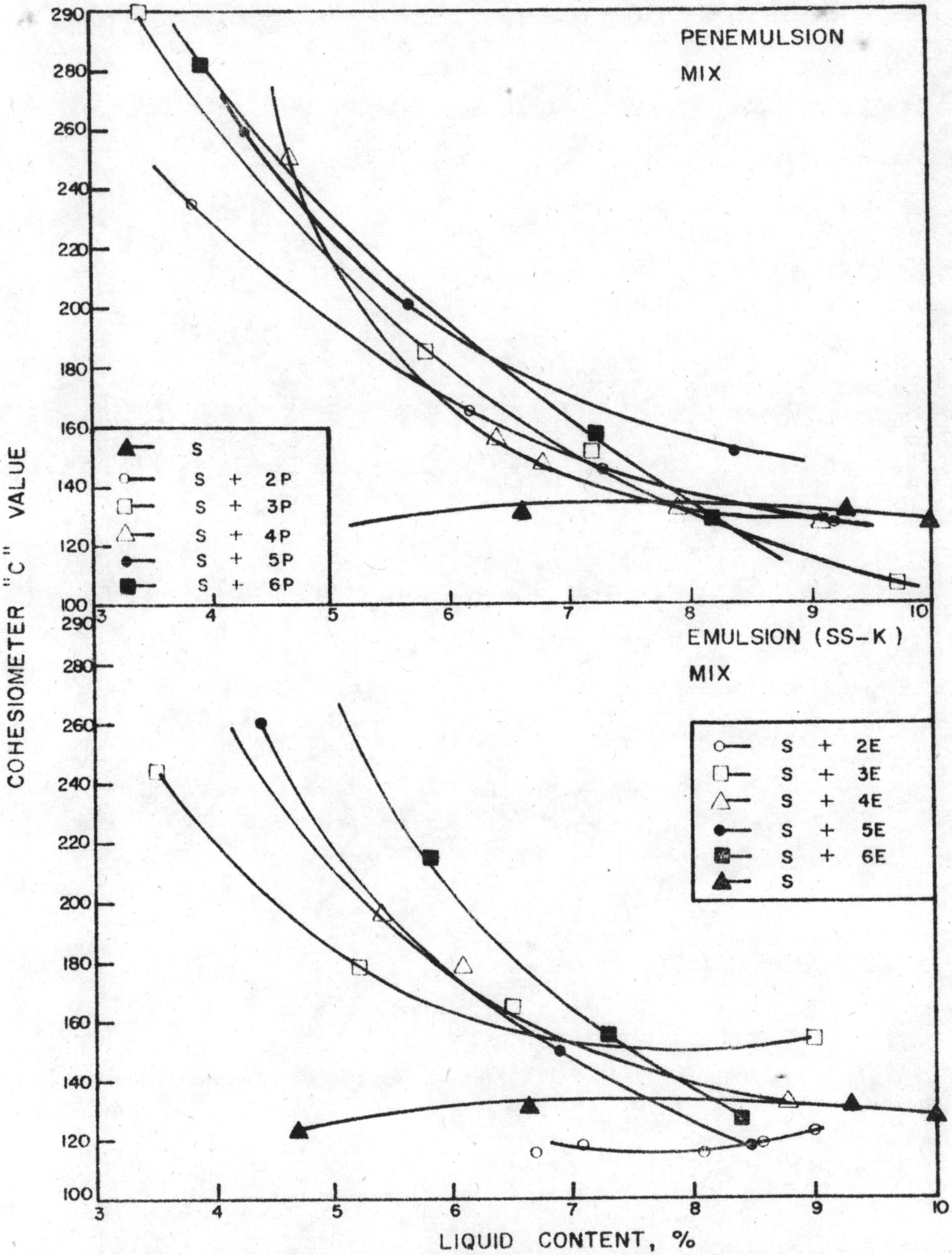

Figure 8. Comparison of Cohesiometer "C" Value of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) by "Standard" Method.

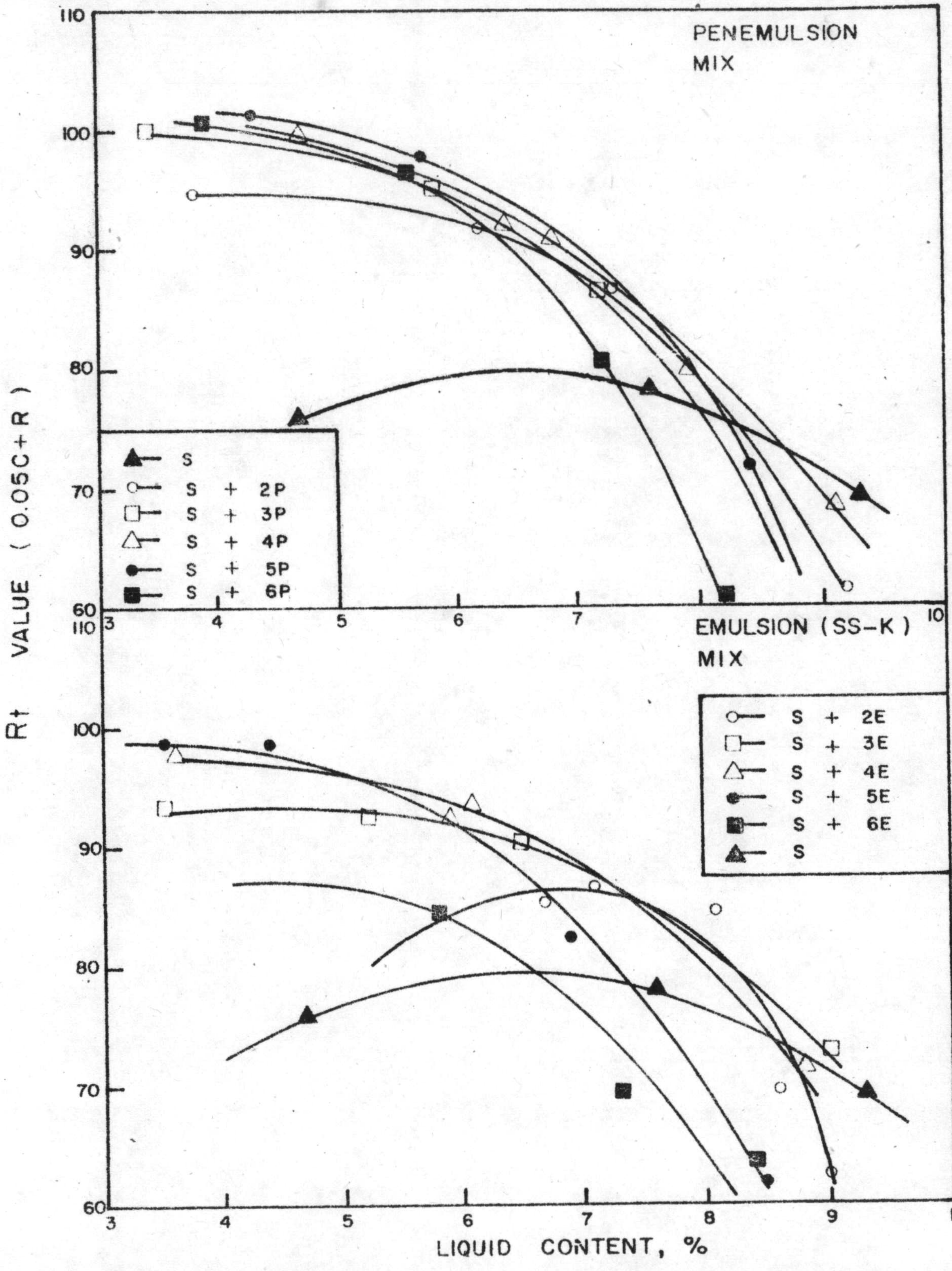

Figure 9. Comparison of "Rt" Value of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) by Standard Method.

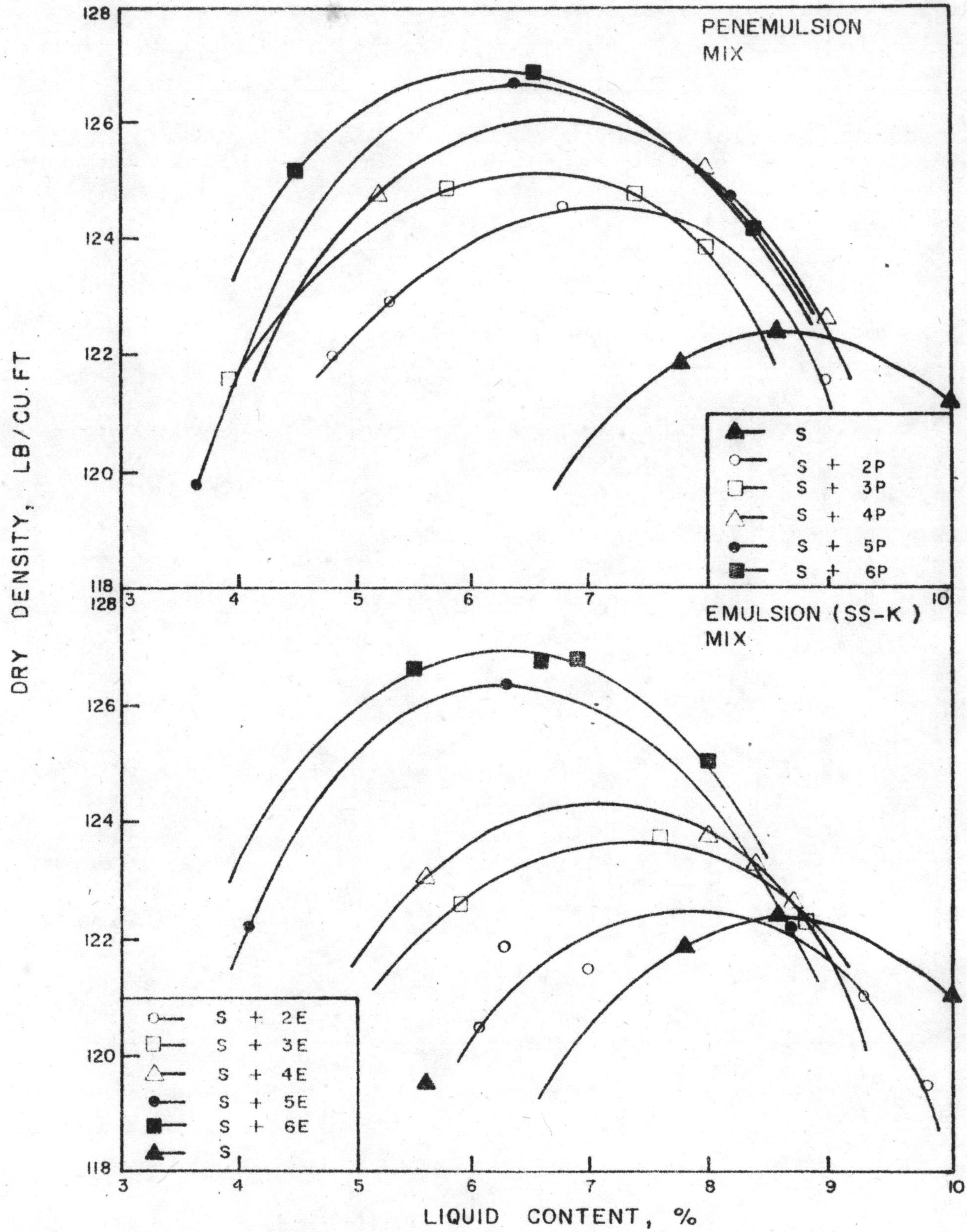

Figure 10. Comparision of Liquid - Density Curves of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) after Moisture Vapor Susceptibility (MVS).

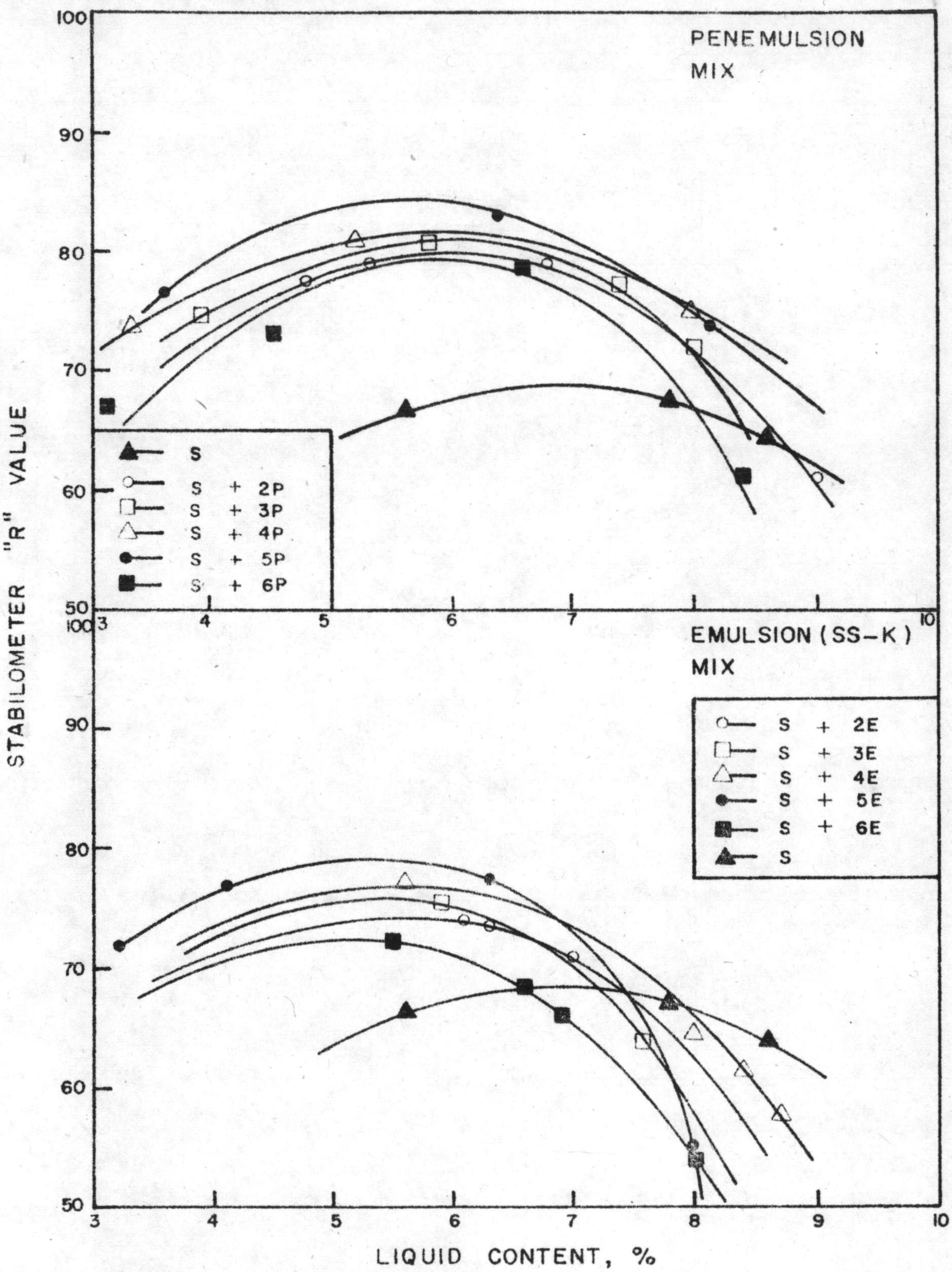

Figure 11. Comparison of Stabilometer "R" Value of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) after Moisture Vapor Susceptibility (MVS).

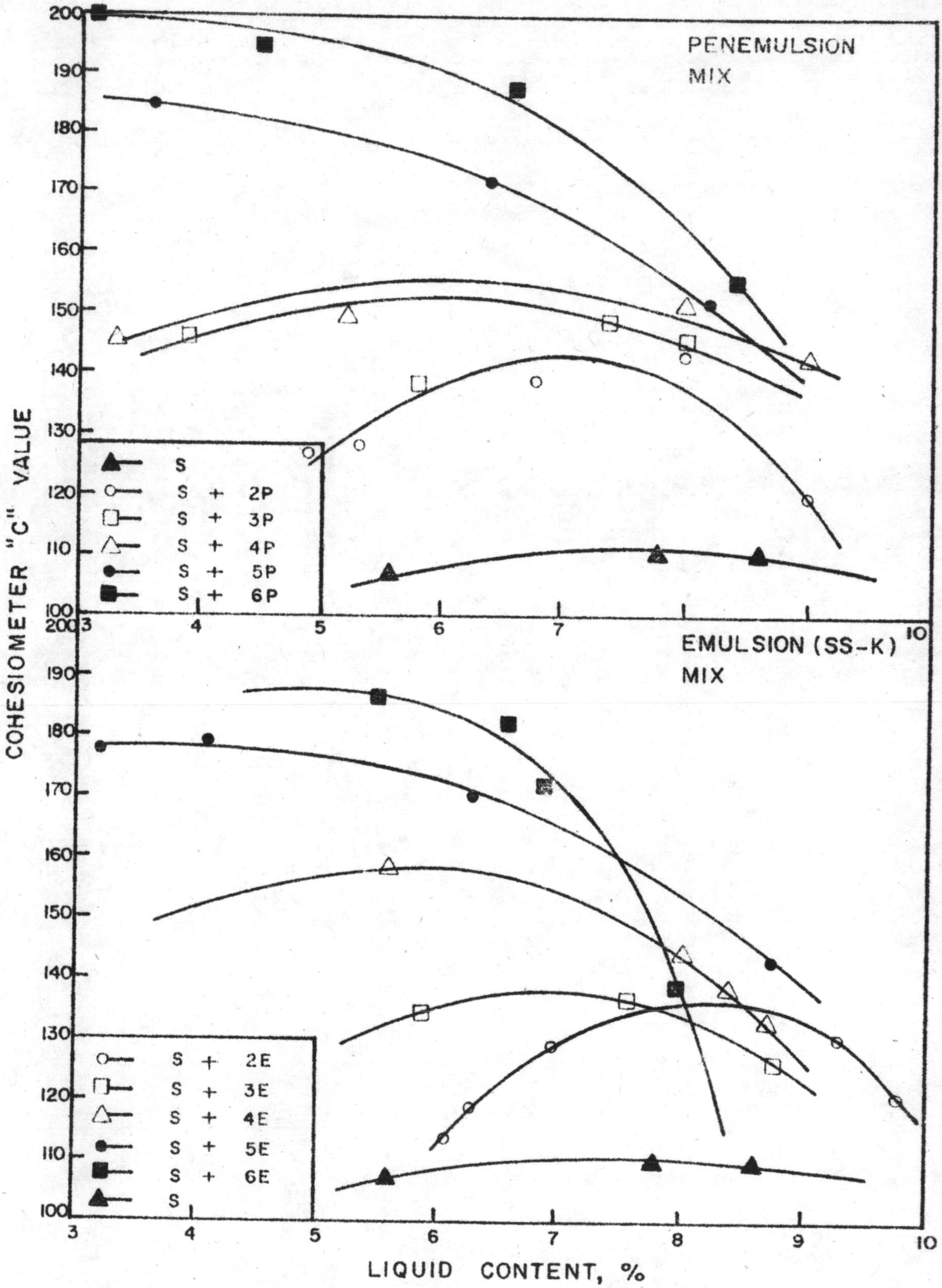

Figure 12. Comparison of Cohesiometer "C" Value of Silty Sand Stabilized with Penemulsion and Emulsion (SS-K) after Moisture Vapor Susceptibility (MVS).

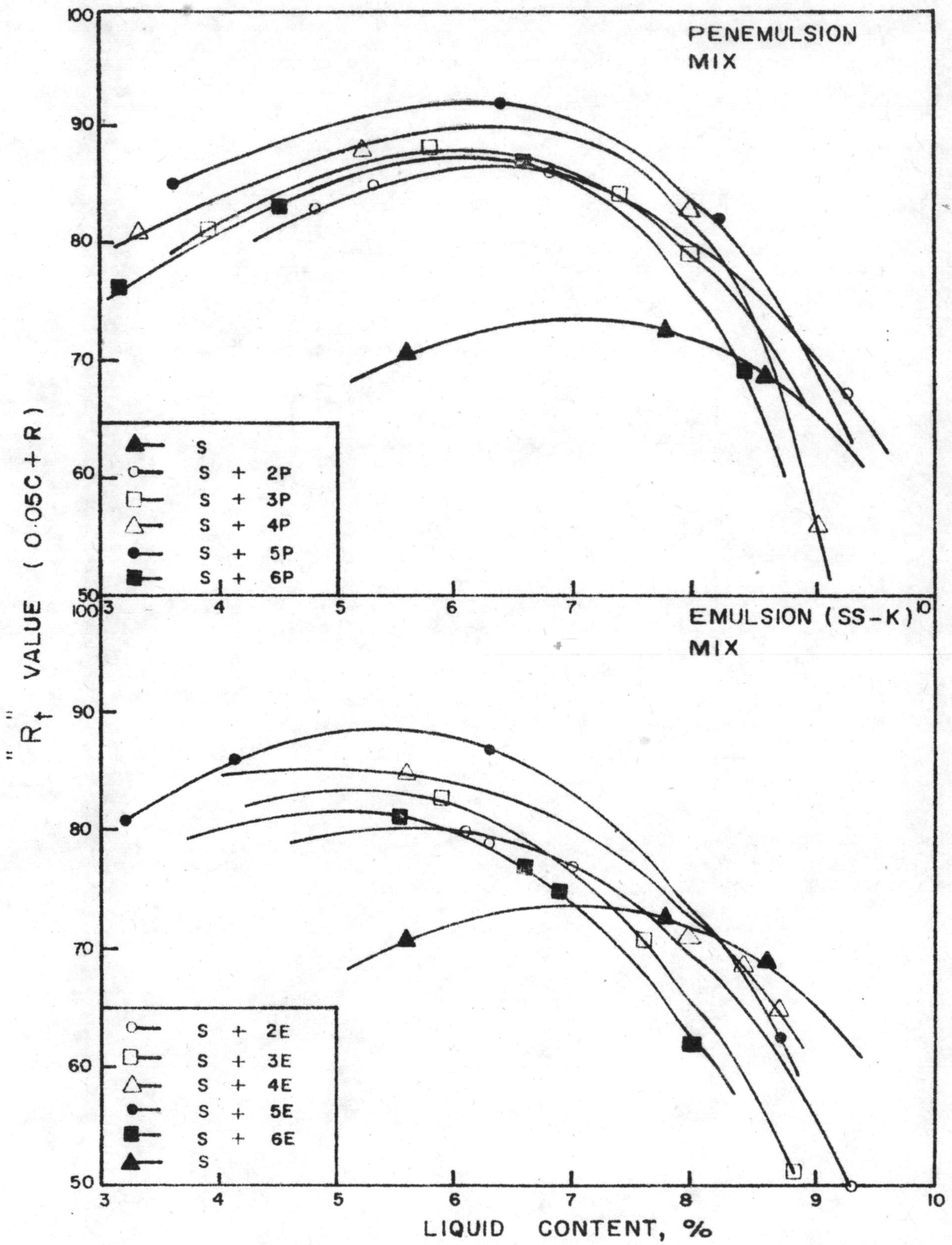

Figure 13. Comparison of "R_t" Value of Sitly Sand Stabilized with Penemulsion and Emulsion (SS-K) after Moisture Vapor Susceptibility (MVS).

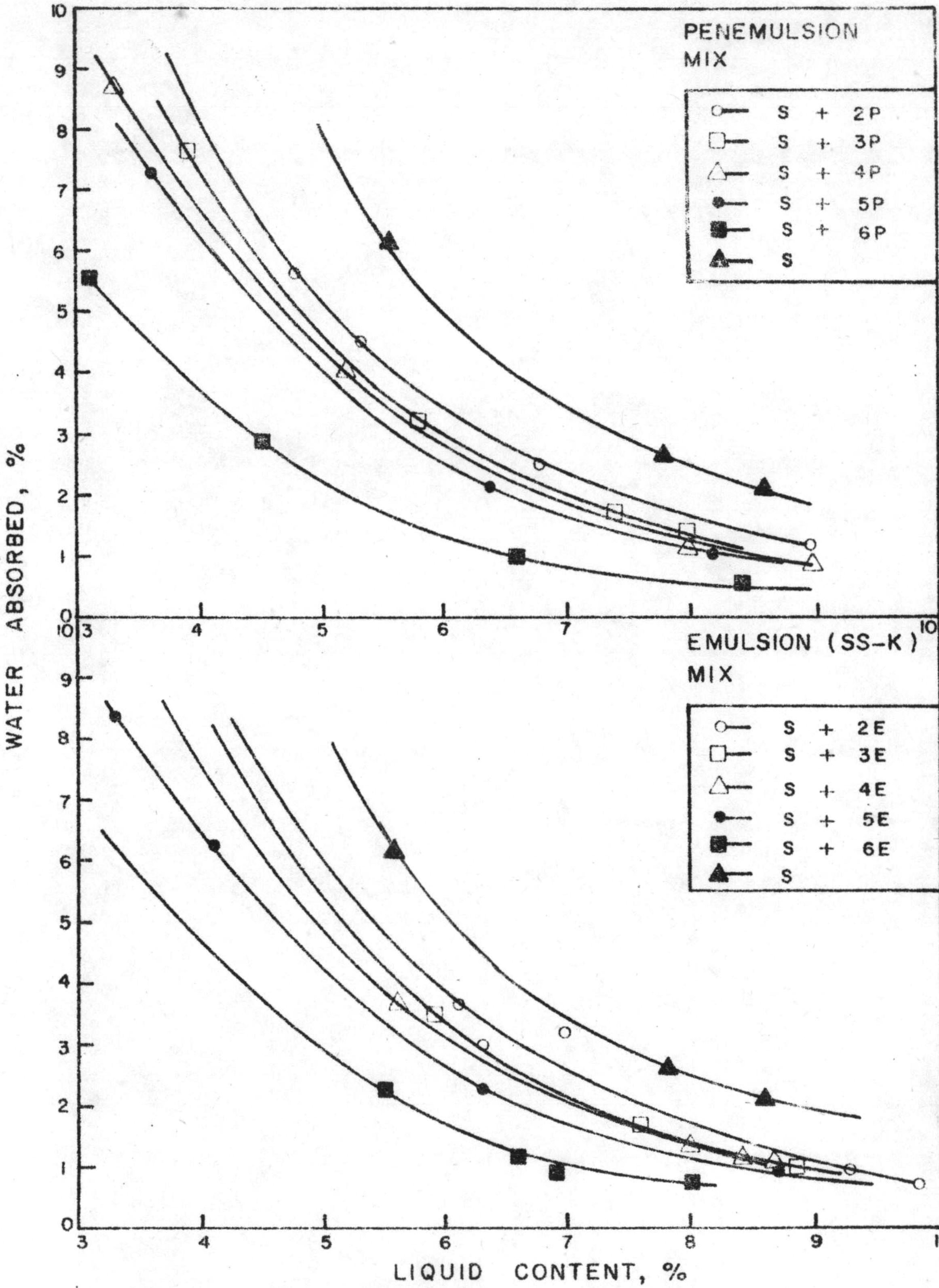

Figure 14. Water Absorbed of Silty Sand Stabilized with Penemulsion or Emulsion (SS-K) after Moisture Vapor Susceptibility (MVS).

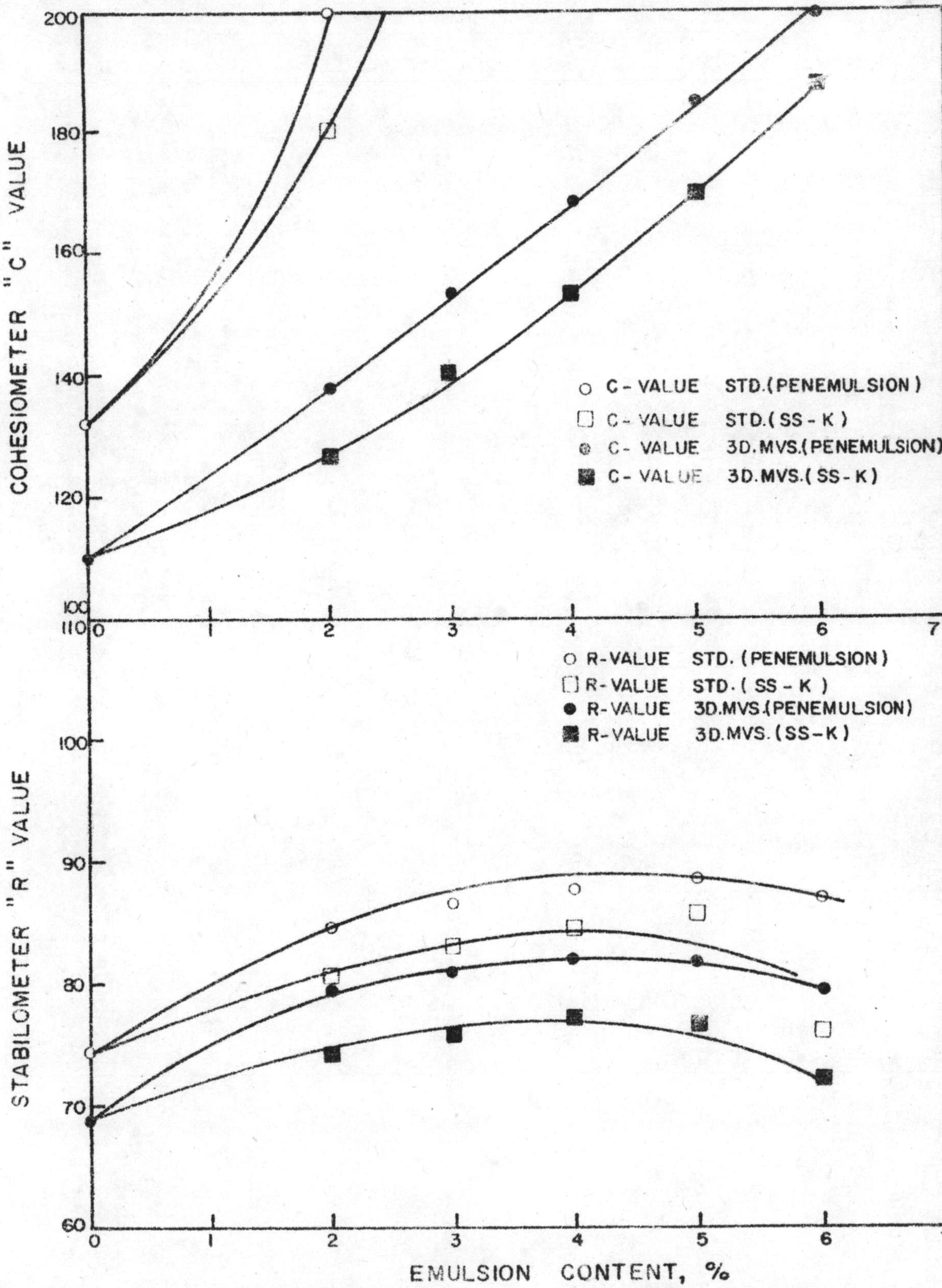

Figure 15 Comparison of Strength Characteristics of Silty Sand with Various Percentages of Penemulsion and SS-K Emulsion at Standard Condition and after Moisture Vapor Susceptibility.

increase in C-value with little change in R-value. These show that addition of emulsion provides cohesive strength without undue interference with frictional resistance of silty sand. The stabilometer R-value of these two mixtures increases with increasing emulsion content up to a maximum and then decreased. The cohesiometer C-value contimuously increases as the emulsion content increases and do not oppear to be an optimum emulsion content.

The maximum R and C values of each percentage of both emulsions occur on the dry side of the optimum liquid content as shown in Figure 7 and 8. These can be explained from the fact that since there is less moisture on the dry side, soil particles are well coated by the asphalt and hence the strength is increased. On the wet side of the optimum, on the contrary, the water in the mixtures tend to separate the soil particles; thus decreasing the strength.

The Penemulsion mixture tend to give higher R and C values than the SS-K mixture. The maximum stabilometer R values for the Penemulsion sample and the SS-K sample were 88.5 and 85, respectively. This increase in strength is believed to due to the fact that Penemulsion has less impurity in the base asphalts; thus causing more stable bond between asphalt and soil particles. Therefore, Penemulsion mixtures tend to give higher strength than the SS-K mixtures. The optimum emulsion contents for both mixtures are the same at 5 percent.

As stated in Mix Design Criteria that a factor of 0.05 times the Cohesiometer Value (0.05XC-value) assigned to the tensile strength of the asphalt mix is reasonable. This 0.05 C-value was added to the R-value and reported as the Rt-value. Figure 9 shows the relationship between liquid content and Rt-value of the Penemulsion mixtures and the SS-K mixtures. The results show that Rt-value of both mixtures increase with decreasing liquid content and there is no peak value at each percentage of both emulsion contents. This is due to the effect of the C-value described above. The Penemulsion mixture gave higher Rt-value than the SS-K mixture to a certain amount.

After Mositure Vapor Susceptibility (M.V.S.), all strength properties of both emulsion mixtures by Standard method decrease as show in Figure 11, 12 and 13. This decrease in strength is due to the moisture absorption. The water tends to separate the soil particles; thus causing loss in strength. The specimens on the dry side of the optimum liquid content absorbed more water than on the wet side as shown in Figure 14. This is because of the greater water deficiency or lower degree of saturation of the sample on the dry side. The peak R-value for this case occurs near to the optimum liquid content. This is because the specimen at this liquid content has higher density and the strength loss due to water absorption is less compared with the increase in strength due to higher dry density.

Figure 11 shows the stabilometer R-value of the Penemulsion mixtures and the SS-K mixtures after M.V.S. test. The C-value of the Penemulsion mixture was still higher than the SS-K mixture for each percentage of the same emulsion content. The C-value increased with increasing emulsion contents. Figure 13 shows Rt-value of the both emulsion mixtures after M.V.S. test. The maximum Rt-values for Penemulsion mixtures and the SS-K mixtures were 92 and 88 respectively. The optimum emulsion contents are the same as 5 percent. The maximum Rt-value for the Penemulsion mixture and the SS-K mixture achieved at liquid content of 6 and 5.5 percent, respectively. This also near to the optimum liquid content. The percentage of water obsorbed for the Penemulsion mixture and the SS-K mixture were 2.5 and 3.5 percent respectively, shown in Figure 14. Figure 14 also indicated that water absorbed for both emulsion mixtures are not significantly different. The maximum Rt-values of the Penemulsion mixture and the SS-K mixture at 5 percent emulsion contents seem to indicate that both emulsions stabilized with silty sand in this study are good enough for subbase and base courses according to the criteria mentioned in Chevron Asphalt Company. Though less percentage of emulsion contents, Rt-values are within the limits but the percentage of water absorbed in Figure 14 shows that some are too high. Therefore, the selected optimum emulsion contents for the Penemulsion mixtures and the SS-K mixtures are the same as 5 percent by weight of oven dry soil at liquid contents of 6 and 5.5 percent respectively. These selected mixtures were next used to determine the comparative strength after curing periods of 3 days, 7 days, and 28 days by unconfined compressive strength test and study the strength envelope by triaxial test. Figure 15 shows the comparison of strength characteristics of silty sand with various percentages of Penemulsion and SS-K emulsion at Standard condition and after Moisture Vapor Susceptibility. The results show that addition of both emulsions to silty sand increased both R and C values of the mixtures. The stabilometer R-Value increased with increasing percentages of both emulsions up to 5 percent, then decreasing. The C-value of both mixtures continuously increased up to 6 percent of Penemulsion and SS-K emulsion. Both stabilometer R-value and C-value by Standard Method decrease after 3 days of Moisture Vapor Susceptibility. The stabilometer R-value and C-value of the Penemulsion mixtures gave higher value than the SS-K mixtures both standard and MVS. test.

These effects because Penemulsion had a more viscous base bitumen (lower penetration) than the SS-K emulsion. The more details about comparative strength are emphasized later in this study.

3. Hveem Test Results on Lateritic Soil Mixtures

Hveem test results for lateritic soil stabilized with Penemulsion and SS-K emulsion are shown in Tables 11 to 14 and Fignres 16 to 24

3.1 Density - Liquid Content Curves

The effects of both emulsions on liquid content-density relationships of lateritic soil are shown in Figure 16. Emulsion had the effect on an increase of dry density of lateritic soil mixtures in the same way as on silty sand mixtures as described before. Figure 16 shows that maximum dry density increases with the adding of emulsion but the optimum liquid content decreases. The liquid-density curves for the Penemulsion mixture and the SS-K mixture are not significantly different.

3.2 Stabilometer R-Value and C-Value V.S. Emulsion Contents

The addition of emulsion to lateritic soil has the effect on increasing the stabilometer R-value and C-value as shown in Fiqure 17 and 18. The maximum R and C values of each percentage of both emulsions occur on the dry side of the optimum liquid content. This can be explained in the similar manner as for silty sand mixtures as described previously. For this lateritic soil, after adding emulsion content up to 6 percent, stabilometer R-value and C-value still increase without showing an optimum emulsion content. For economic purpose, only 6 percentage of emulsion will be added in

Table 11 - Hveem Test Results for Jateritic Soil Stabilized with Penemulsion by Standard Method.

Sample	Liquid Content, %	Dry Density, lb/cu.ft	R-Value	C-Value	Rt-Value =R+0.05C
L+2P, 1	12.5	130.4	88	290	102
2	8.5	118.6	87	220	98
3	7.1	114.2	80	85.8	84.3
4	9.6	124.6	90.4	284.1	104.6
5	6.6	113.7	74	100	79
L+3P, 1	15.6	124.4	83	114.4	88.7
2	13.8	129.2	92.5	281.4	106.6
3	11.0	127.8	91.5	110.2	97.0
4	10.3	124.2	86	138.4	93.5
5	6.4	118.0	80	120.4	86.0
L+4P, 1	15.8	124.5	81.5	146.4	88.8
2	11.6	131.1	90.5	207.1	100.8
3	9.6	123.6	93.0	284.8	107.2
4	7.2	122.9	88.5	158.2	96.4
5	5.7	120.6	82.0	126.7	88.3
L+5P, 1	11.2	132	85	136.5	95
2	10.6	129.1	93.5	373.8	111.9
3	9.6	127.3	93.5	370.0	112.0
4	6.1	122.6	90	261.0	103
5	4.6	116.1	82.3	146.1	89.6
L+6P, 1	14.5	126.3	75	212.5	85.6
2	13.2	130	91	378.8	110
3	10.8	132.3	94	477.2	4117.9
4	7.0	119.8	92	316.2	107.8
5	4.6	118.7	84.2	150.8	91.8

Table 12 - Hveem Test Results for Lateritic Soil Stabilized with SS-K Emulsion by Standard Method.

Sample		Liquid Content %	Dry Density, lb/cu.ft	R-Value	C-Value	Rt-Value =R+0.05C
L+2E,	1	15.9	123.5	55	168.2	63.4
	2	13.4	129	80	286.2	94.3
	3	11.5	129.6	88.5	230	100
	4	9.7	122.4	90.0	205.4	100.3
	5	7.8	121.9	84.5	143.4	92
L+3E,,	1	14.5	129.2	60	96.4	64.8
	2	13.3	130.7	75	295.9	89.8
	3	11.6	126.9	89	296.3	103.8
	4	9.4	124.5	91.5	368.9	109.9
	5	7.3	119.5	84.3	147.8	91.7
L+4E,	1	15.5	128.05	68	297.3	82.8
	2	13.8	129.2	83	168.5	91.4
	3	12.6	131.1	87	352	105
	4	9.1	120.3	90.5	164.7	99
	5	7.7	113.7	87	113.9	93
L+5E,	1	13.4	130.4	85	216.7	96
	2	13.2	129.9	86	350.0	103.5
	3	9.6	126.8	91.6	360.6	109.8
	4	9.0	118.6	91	191.0	101
	5	7.5	112.6	85	113	91
L+6E,	1	14.0	126.7	53	186.9	62.4
	2	12.1	130.8	84	370.6	102.5
	3	11.7	131.3	86.5	366.2	104.8
	4	10.0	131.6	91.8	350	109
	5	6.6	121.2	87.4	177.26	96.2
L,	1	15.1	124	65	152.0	72.6
	2	13.0	128.5	79	203.9	89.2
	3	11.5	127.6	86	205.7	96.3
	4	9.0	120.2	84	201.3	94.07
	5	7.6	118.6	82	135.0	88.7

Table 13 - Hveem Test Results for Lateritic Soil Stabilized with Penemulsion after Moisture Vapor Susceptibility.

Sample	Before		After		Water absorbed %	R-Value	C-Value	Rt-Value =R+0.05C
	L/C, %	γ dry, lb/cu.ft	L/C,%	γ dry, lb/cu.ft				
L+2P, 1	12.5	130	15.24	129.6	2.7	64	200	74
2	11.8	129.8	15.4	129.3	3.6	68	190	77
3	8.8	118.3	17.0	118	8.2	50.3	128	57
4	7.5	116.3	19.2	116	11.7	50.0	90.0	54.3
5	5.2	114.6	19.2	114	14.0	42.0	86.3	46.3
L+3P, 1	12.4	130.3	14.7	130	2.3	78	215	88
2	10.5	126	15.75	125.4	5.2	68	200	78
3	9.6	122.3	18.7	122	9.1	48.6	164	57
4	6.0	116.3	17.01	116.1	11	56.5	94.7	61.2
5.	4.5	114.2	17.3	114	12.8	50.0	90.3	54.5
L+4P, 1	12.1	131.2	16.0	130.9	3.9	77.0	236	89
2	9.4	120.3	16.5	120.1	7.1	68.0	196	78
3	7.5	118.6	16.3	118.7	8.8	49.0	141.3	56.1
4	6.5	118.3	18.0	117.9	11.5	45.0	130.0	51.5
5	4.8	115	18.2	114.6	13.4	42.0	121.0	48.0
L+5P, 1	11.6	132.1	14.3	132	2.7	81	240	93
2	10.6	130.6	15.7	130.4	5.1	78	240	90
3	9.1	120.6	17.5	120	8.4	66	190	76
4	6.33	118.2	17.9	117.6	11.6	35.4	112.1	41.0
5	5.2	113.6	18.1	115	13.0	48.5	117.0	54.4
L+6P, 1	12.6	130	14.6	129.7	2.0	80	250	93
2	10.2	132.2	14.7	131.9	4.5	79	141.2	86
3	8.8	127.4	15.8	127	7.0	66	134.5	72
4	7.9	122	16.6	121.6	8.7	52.7	117.0	58.5
5	7.0	116.4	18.7	115.9	11.7	43.0	127.3	49.4

Table 14 - Hveem Test Results for Lateritic Soil Stabilized with SS-K Emulsion after Moisture Vapor Susceptibility.

Sample	Before		After		Water Absorbed %	R-Value	C-Value	Rt-Value =R+0.05C
	L/C %	γdry lb/cu.ft	L/C %	γdry lb/cu.ft				
L+2E, 1	16.8	122.3	17.6	121.9	0.8	52.5	277.9	66.4
2	14.3	127.1	14.7	127.3	0.4	66.0	186.1	75.3
3	10.2	124.8	15.3	123.6	5.1	54.0	148.9	61.4
4	8.9	118.3	17.4	117.9	8.5	35.0	121.3	41.1
5	7.1	113.4	18.4	112.6	11.3	32.0	97.8	36.9
L+3E, 1	17.4	122.8	17.8	122.4	0.4	40.0	208.2	50.4
2	14.6	128.3	15.4	127.6	0.8	70.0	228.3	81.1
3	11.1	128.2	14.1	128	3.0	70.0	221.0	81.46
4	9.0	118.6	17.6	117.8	8.6	40.0	119.2	46
5	6.8	116.3	18.3	116.2	11.5	34.0	121.7	40.1
L+4E, 1	17.2	126.3	18.2	126.3	1.0	42	137.7	49.0
2	13.8	129.2	15.1	129.2	1.3	73	232.6	84.6
3	9.9	125.4	14.9	125	5.0	65	173.3	73.7
4	7.7	118.6	17.0	118.4	9.3	46.4	117.6	52.3
5	5.6	116.3	18.4	116	12.8	46.6	116.3	52.4
L+5E, 1	14.9	126.4	16.3	126.8	1.4	65	220.2	76
2	13.0	130.9	15.6	130.6	2.6	74.0	235.0	85.7
3	11.8	131.2	16.4	131	4.6	77	240	89
4	8.6	119.6	16.0	118.9	7.4	52	180	61
5	6.4	114.6	16.1	114.3	9.7	42.0	129.2	48.5
L+6E, 1	14.7	125.3	15.5	125.1	0.8	34	181.6	43.1
2	11.6	132	14.41	131.6	2.8	78	254	91
3	10.3	132.2	14.2	131.3	3.9	74	244	86
4	8.2	125.3	14.7	125	6.5	50	180	59
5	6.5	116	16.5	117	10.0	45	120	51
L, 1	14.6	126	15.25	125.4	0.7	62.3	153	70
2	12.4	128.8	14.9	128.6	2.5	61.2	160.0	69.2
3	10.8	126.6	16.2	126.5	5.4	52.1	145.9	62.8
4	9.0	120.2	17.0	120.3	8.0	32.0	120.3	38

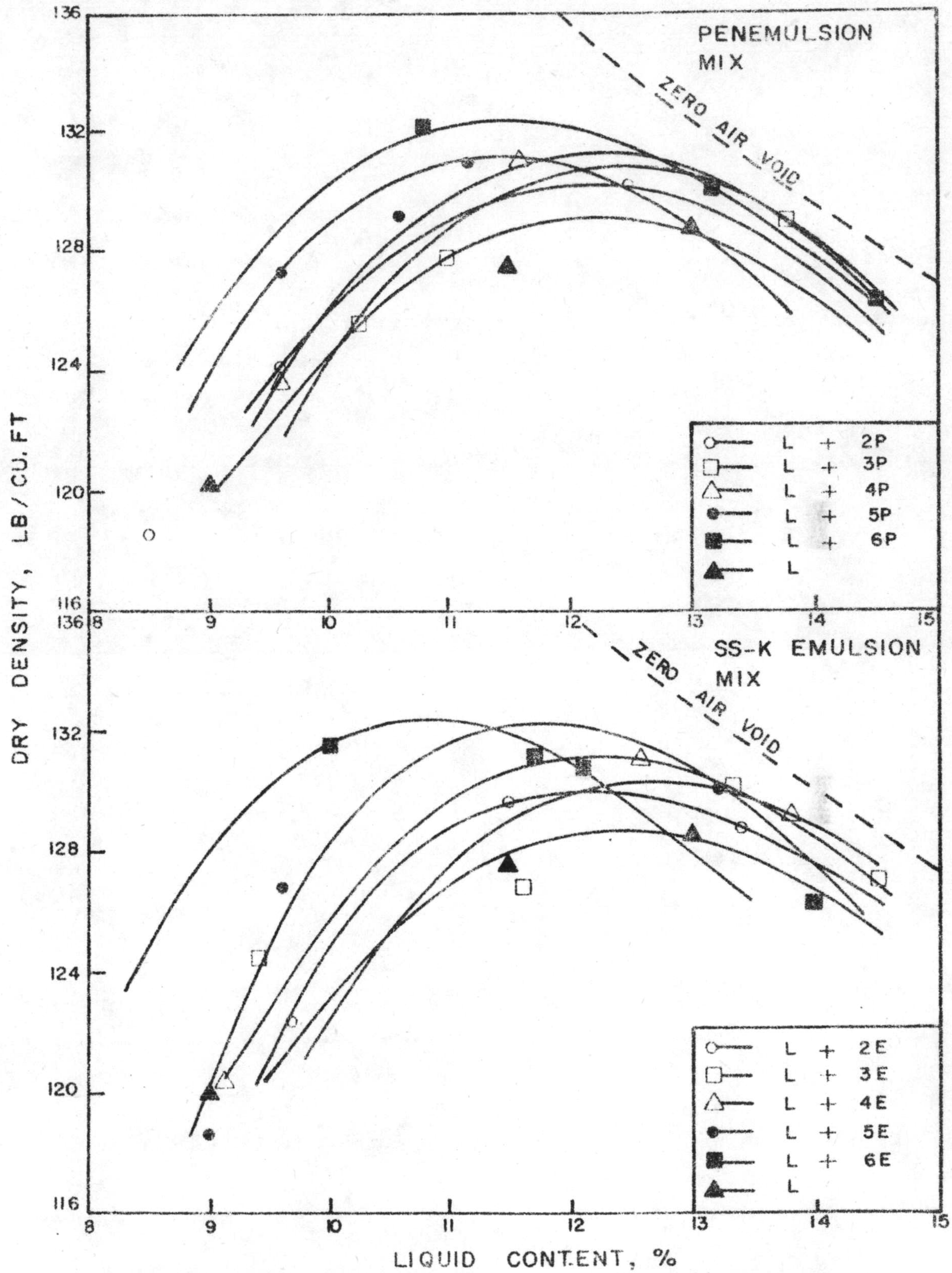

Figure 16 Comparison of Dry Density Curves of Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion by Standard Method.

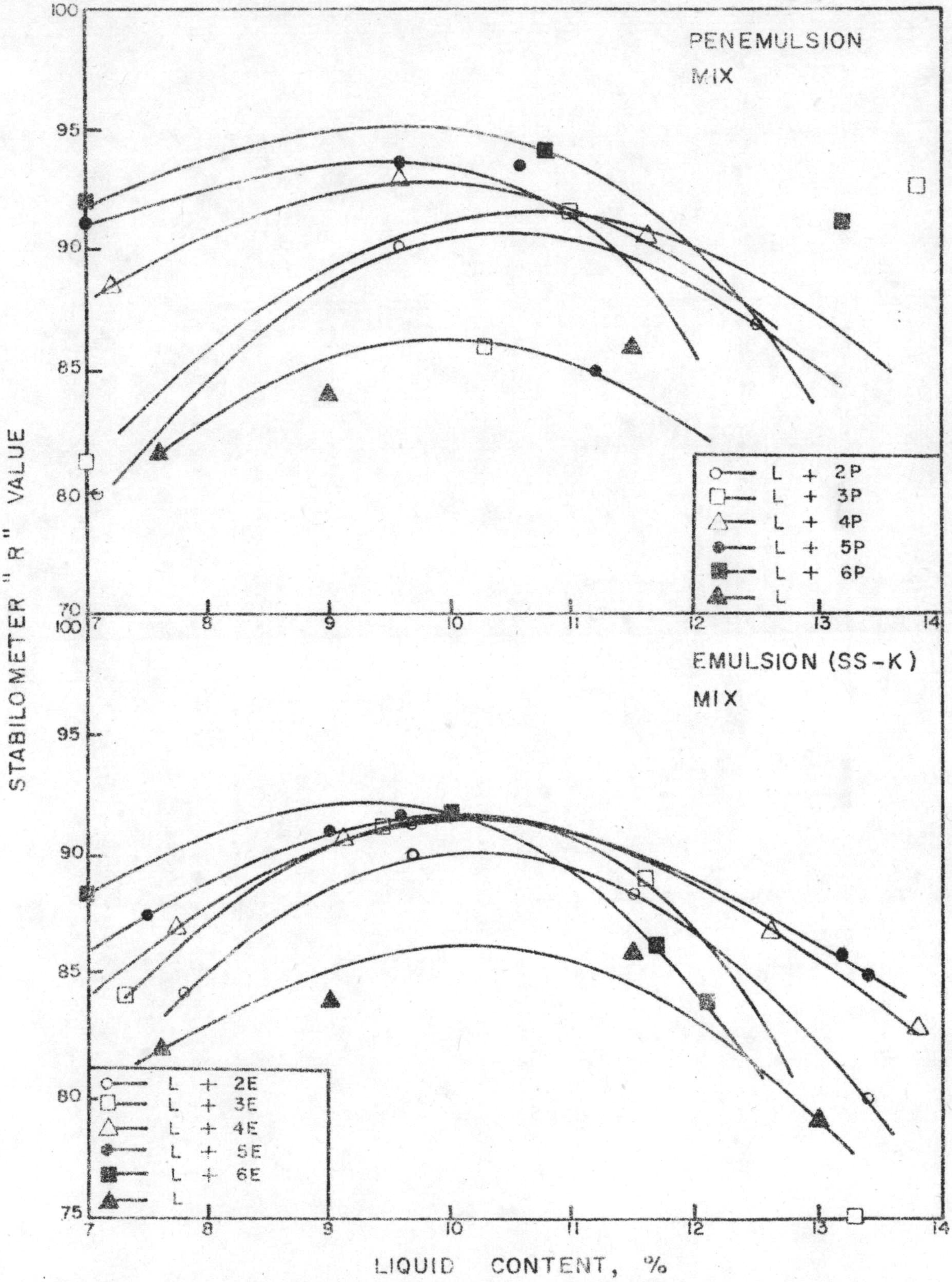

Figure 17 Comparison of Stabilometer "R" Value of Lateritic Soil Stabilized with Penemulsion and Emulsion (SS-K) by Standard Method.

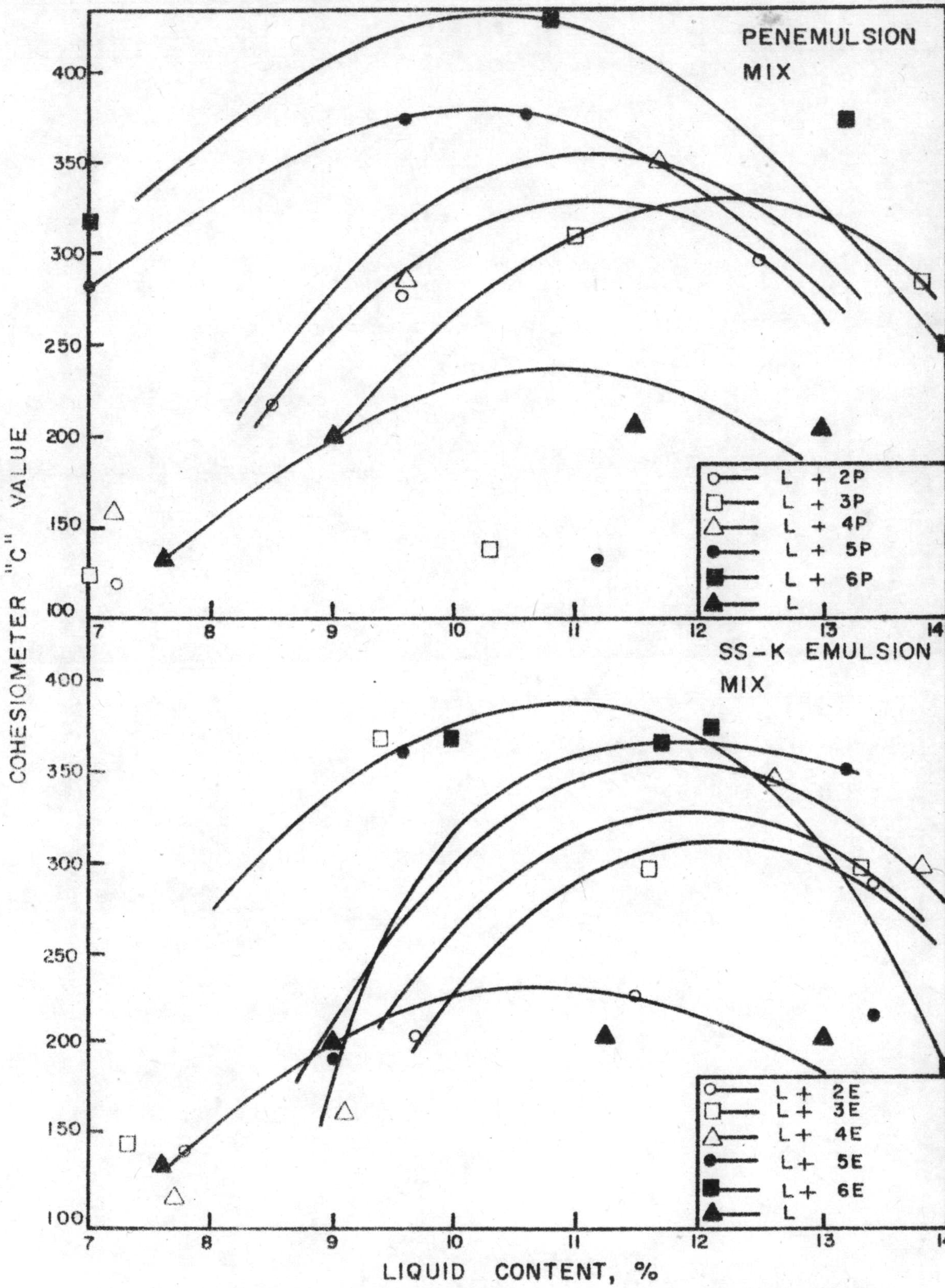

Figure 18 Comparison of Cohesiometer "C" Value of Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion by Standard Method.

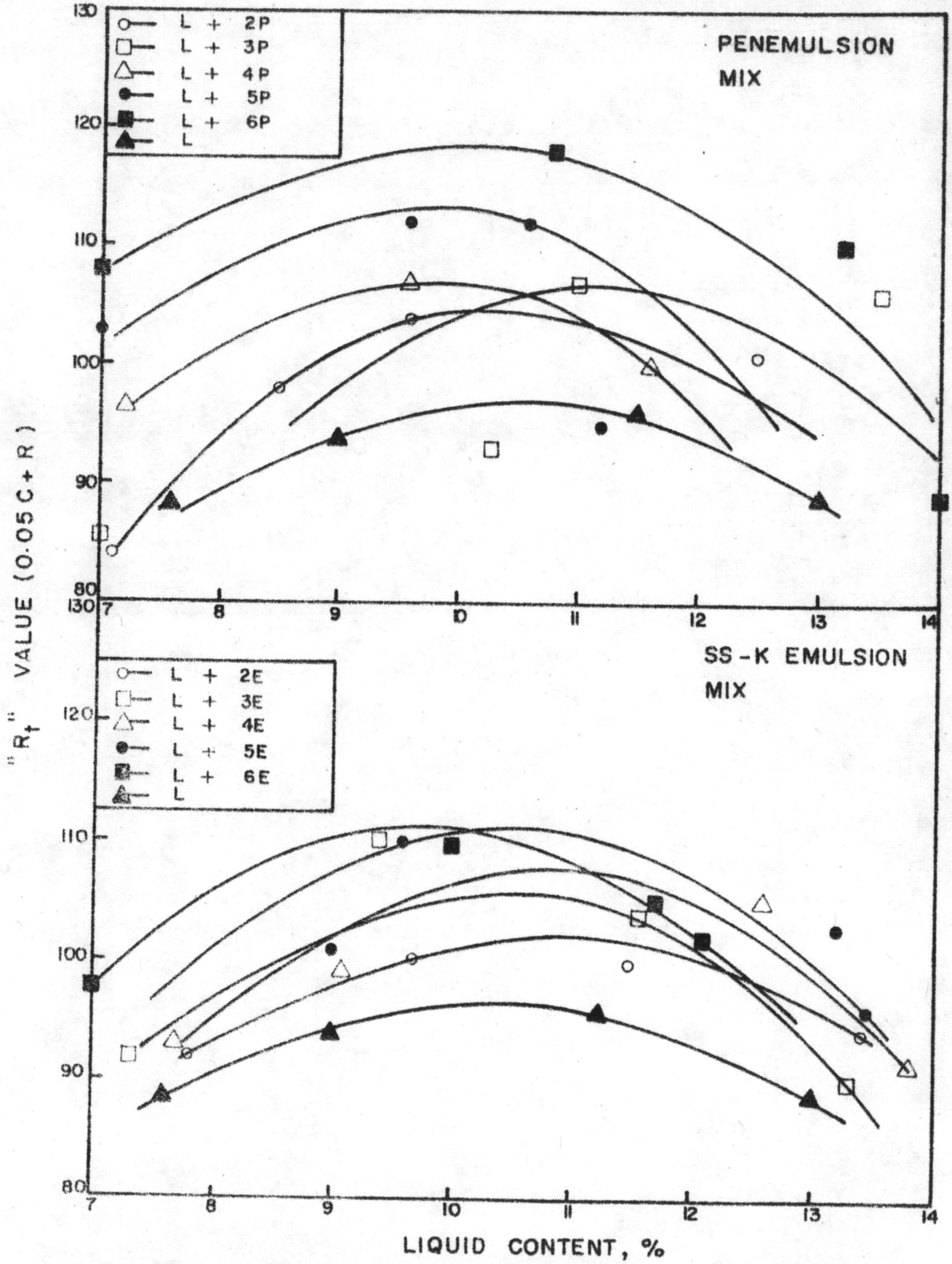

Figure 19 Comparison of "R_t" Value of Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion by Standard Method.

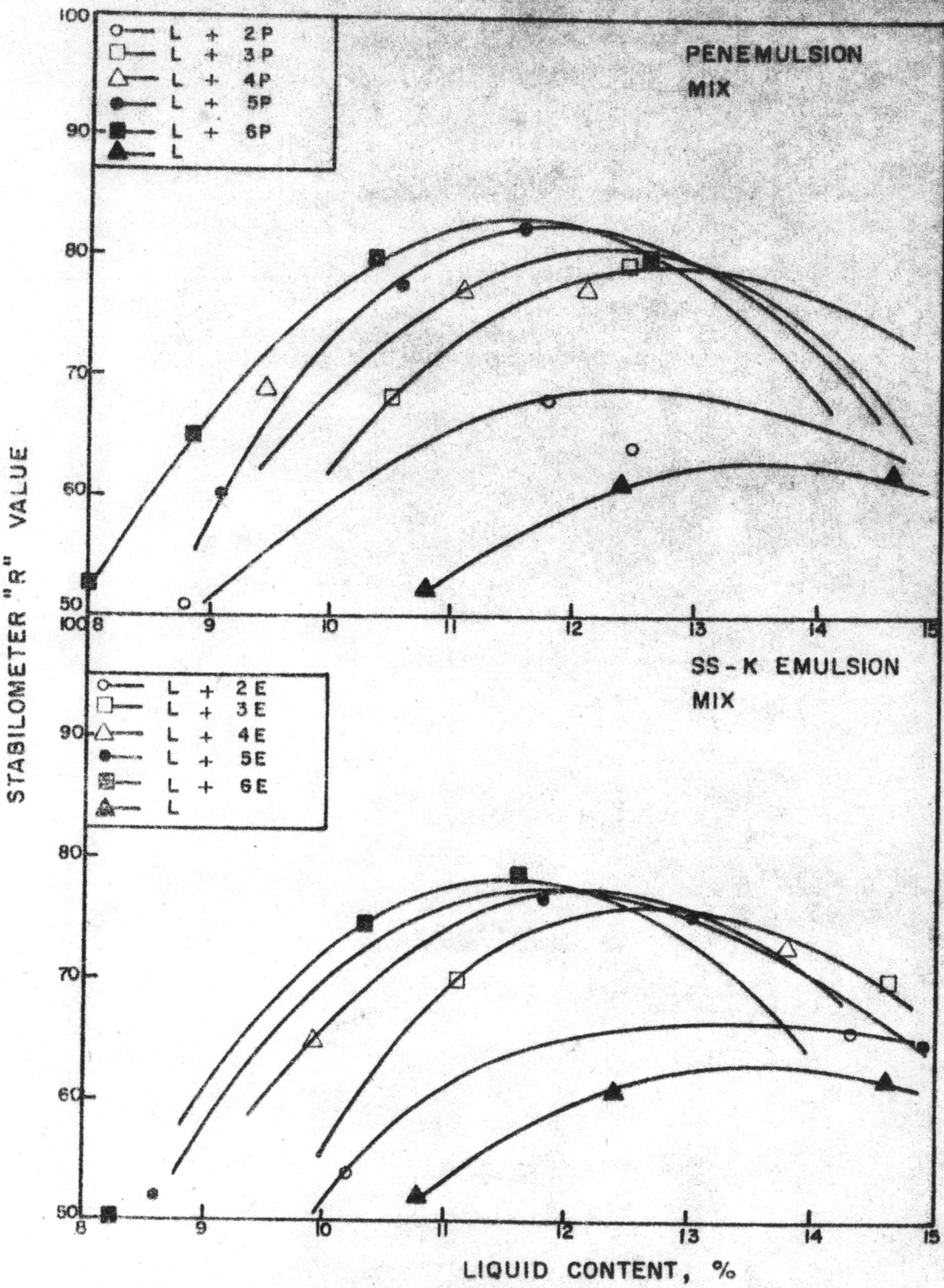

Figure 20 Comparison of Stabilometer "R" Value of Lateritic Soil Stabilized with Penemulsion and SS - K Emulsion after Moisture Vapor Susceptibility (MVS).

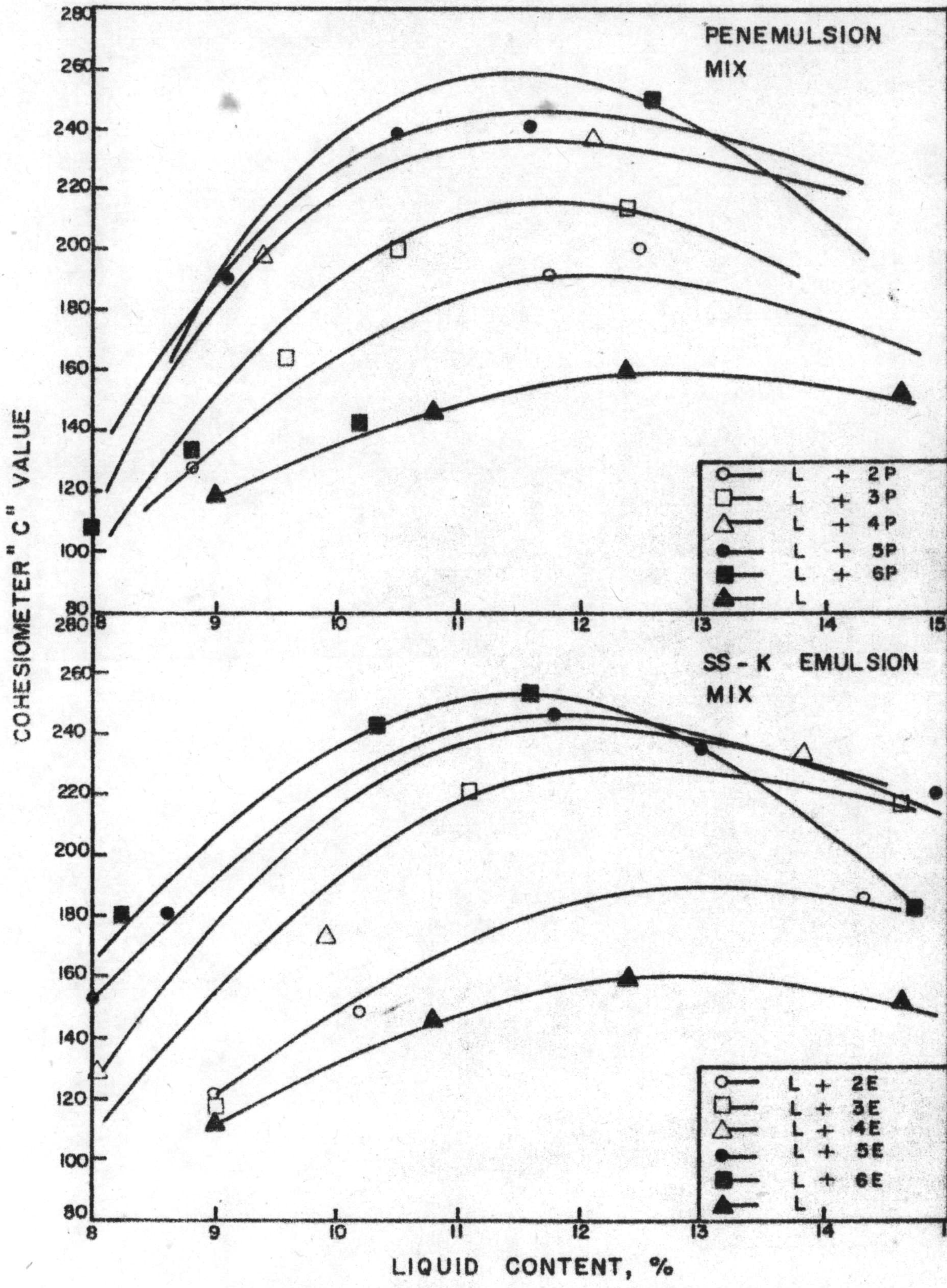

Figure 21 Comparison of Cohesiometer " C " Value of Lateritic Soil Stabilized with Penemulsion and SS - K Emulsion after Moisture Vapor Susceptibility (M V S)

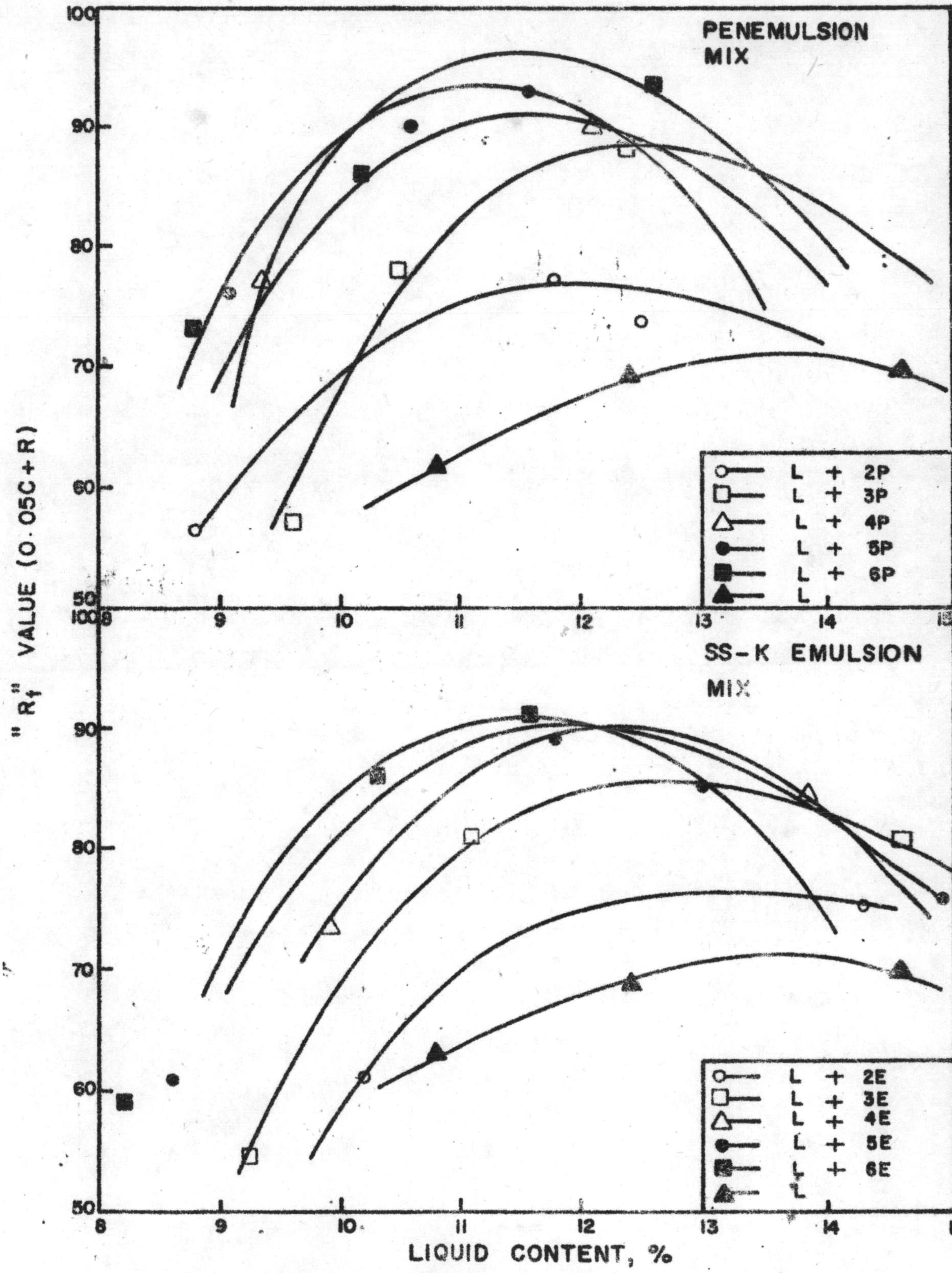

Figure 22 Comparison of "R_t" Value of Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion after Moisture Vapor Susceptibility (MVS).

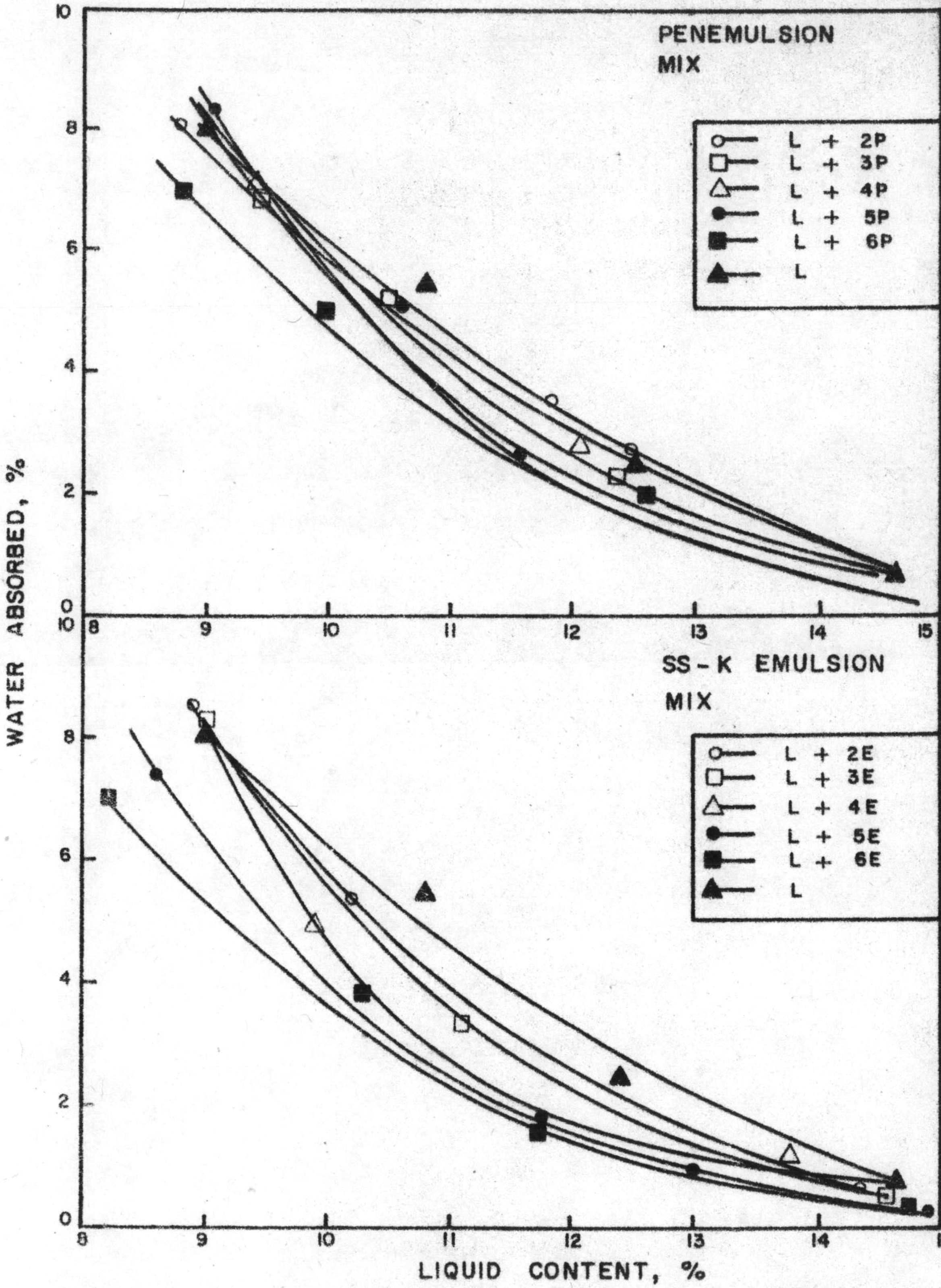

Figure 23 Water Absorbed of Lateritic Soil Stabilized with Penemulsion or Emulsion (SS - K) after Moisture Vapor Susceptibility (M.V.S.).

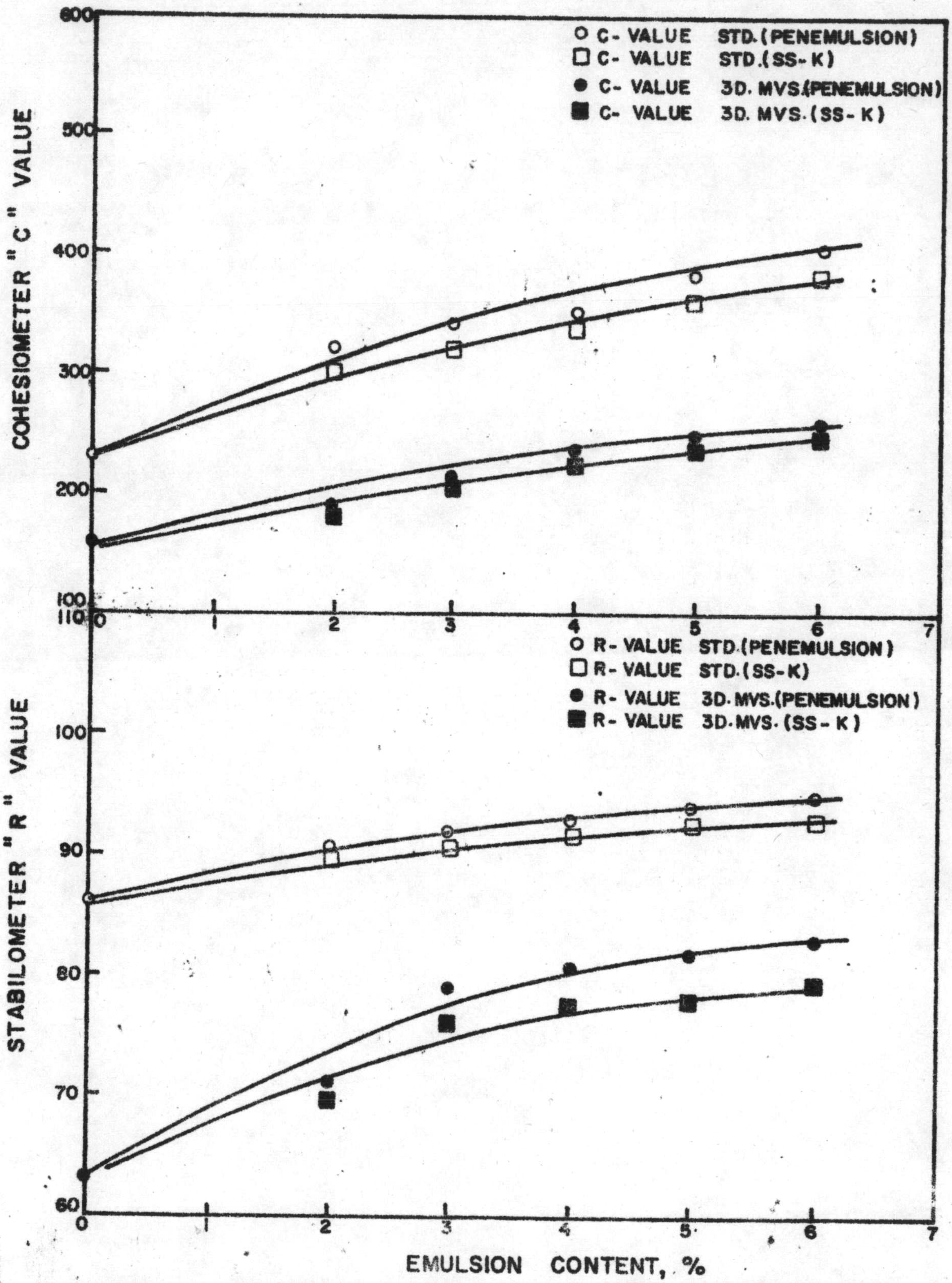

Figure 24 Comparison of Strength Characteristics of Lateritic Soil with Various Percentages of Penemulsion and SS-K Emulsion at Standard Condition and after Moisture Vapor Susceptibility.

in this study. The selected emulsion content was chosen at economic percentage of emulsion that giving the R-value and C-value within the designed criteria. The Penemulsion mixtures tend to give higher R and C values comparing with the SS-K mixtures. These effects might have been expected that Penemulsion has less impurity in the base asphalts as described in silty sand mixtures. Figure 19 shows the comparison of Rt-value of the Penemulsion mixtures and the SS-K mixtures. Again, the Penemulsion Mixtures gave higher Rt-value than the SS-K emulsion moisture at the same percentages of emulsion content.

After Misture Vapor Susceptibility (MVS.) all strength properties of both emulsion mixtures by Standard method decrease as shown in Figure 20, 21, and 22. This decrease in strength is due to the water absorption. The water tends to separate the soil particles; thus causing loss in strength of the mixtures. The mixtures on the dry side of the optimum liquid content absorb more water than on the wet side as shown in Figure 23. The peak R-value for this case occurs near to the optimum liquid content. These effects can be explained in the similar manner as for silty sand mixtures as described previously.

Figure 20 shows the comparison of the stabilometer R-value of these two mixtures after Moisture Vapor Susceptibility. The R-value of these two mixtures after M.V.S. still continuously increased up to 6 percent of both emulsion contents. The R-value of the Penemulsion mixes gave higher value than the SS-K mixes. But the percentage of water absorbed in Figure 23 shows considerable scatter and seems to no signiticantly different.

Figure 21 and 22 show the Cohesiometer C-value and Rt-value of the Penemulsion mixtures and the SS-K mixtures after Moisture Vapor Suceptibility. The C-value and Rt-value of the Penemulsion mixes also gave higher value than the SS-K mixes to a certain amount.

According to designed criteria for base course requirement from Chevron Asphalt Company (Table 1), minimum Rt-value after M.V.S. is not less than 78 and maximum water absorbed not more than 5 percent for heavy traffic. The selected economic Penemulsion and SS-K emulsion contents were 3 percent and optimum liquid content for both mixtures was 12.5 percent. The maximum Rt-value of 3 percent Penemulsion and SS-K mixtures were 88.5 and 85.5 repectively. The percentage of water absorbed after M.V.S. for both emulsion mixtures were about 2 percent. These selected mixtures were next used to determine the comparative strength after curing periods of 3 days, 7 days, 15 days, and 28 days by unconfined compressive strength test and study the comparative strength envelope by triaxial test.

Summary of the results are shown in Figure 24. Figure 24 shows the comparison of strength characteristics of lateritic soil with various percentages of Penemulsion and SS-K emulsion at Standard condition and after Moisture Vapor Susceptibility. The results show that addition of both emulsions to lateritic soil increased both R and C values of the mixtures. The R and C value continuously increase up to 6 percent of both emulsions. Both stabilometer R-value and C-value by standard method decrease after 3 day of Moisture Vapor Susceptibility. The stabilometer R-value and C-value of the Penemulsion mixtures tend to give higher value than the SS-K mixtures by both standard and MVS. test.

4. Unconfined Compressive Strength Test Results

From Hveem test results for silty sand stabilized with the Penemulsion and the SS-K emulsion, the selected mixtures for unconfined compressive test were carried out by using silty sand stabilized with 5 percent of Penemulsion and SS-K emulsion at the liquid contents of 6 and 5.5 percent respectively. From Hveem test results for lateritic soil stabilized with Penemulsion and SS-K emulsion; the selected mixtures were carried out by using lateritic soil with 3 percent of Penemulsion and SS-K emulsion at the same liquid content of 12.5 percent. Compacted specimens were cured under sealed conditions for periods of 3 days, 7 days 15 days and 28 days as stated in preparation of specimens. Their unconfined compressive test results are show in table 15 and Figure 25.

For silty sand mixtures result, the strengths of these specimens were found to be low comparing with the lateritic soil mixtures. Because the strength of silty sand is dominant with its frictional properties, and its strength is due to its porosity and the confining stresses to which it is subjected. The addition of emulsion as a binder has the effect on giving some cohesive strength, but, it also reduces the angle of shearing resistance. So the unconfined compressive strength of silty sand mixtures in this study was found to be low. Figure 25 shows that the strength of the mixtures increases as the curing time. increases, but the increase in strength is not significantly high. This result shows that both emulsions in this study develop strength at fast rate.The silty sand-Penemulsion mixtures gave slightly higher compressive strength than the SS-K emulsion mixtures as shown in Figure 25.

Table 15 Unconfined Compressive Strength Test Results for Silty Sand and Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion after Curing Time.

Sample		Unconfined Compressive Strength (lbs/in^2)				
		As-moulded	3-days	7-days	15-days	28days
S+5P[1],	1	36.51	37.48	38.39	41.56	43.10
	2	35.86	37.62	39.31	42.31	44.31
Avg		36.19	37.73	38.85	41.94	43.71
S+5E[2],	1	35.24	36.88	38.06	40.50	41.63
	2	33.04	37.01	37.95	40.41	41.09
Avg		34.14	36.95	38.0	40.46	41.36
L+3P[3],	1	69.40	75.04	76.85	77.35	80.06
	2	66.46	73.36	76.31	78.31	78.02
Avg		67.93	74.02	76.58	77.83	79.04
L+3E[4],	1	51.51	55.41	57.24	59.18	60.46
	2	49.73	53.20	56.57	57.80	61.31
Avg		50.62	54.31	56.91	58.49	60.89

1. Silty Sand + 5% Penemulsion at the optimum liquid content of 6 percent.
2. Silty Sand + 5% SS-K Emulsion at the optimum liquid content of 5.5 percent
3. Lateritic Soil + 3% Penemulsion at the optimum liquid content of 12.5 percent.
4. Lateritic Soil + 3% SS-K Emulsion at the optimum liquid content of 12.5 percent.

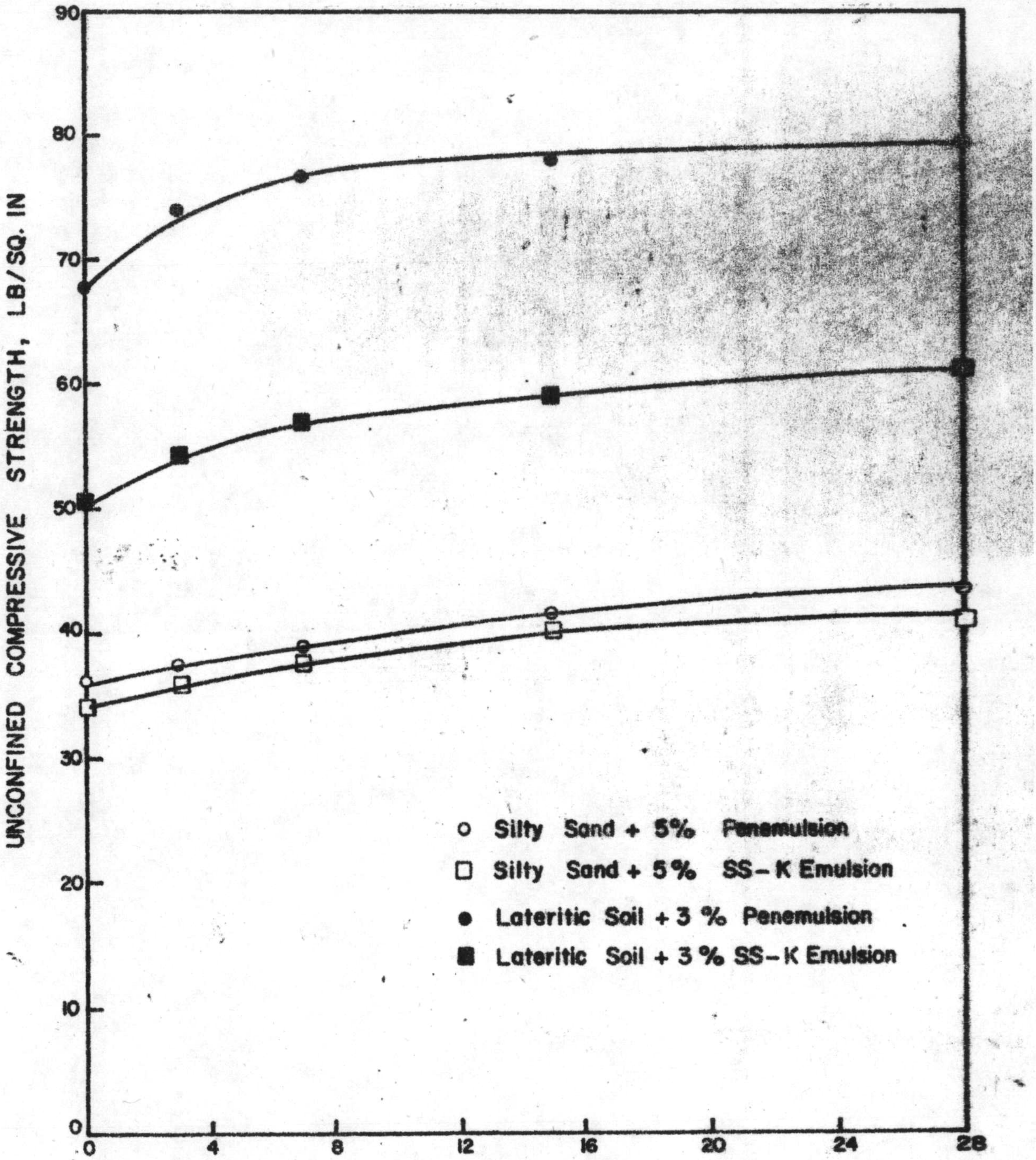

Figure 25 Comparison of Unconfined Compressive Strength of Silty Sand and Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion after Curing Time.

For lateritic soil mixtures result, the compressive strength of lateritic soil mixtures gave higher value than the silty sand mixtures even the lateritic soil mixtures contained less percentage of emulsion than the silty sand mixture. This was because the lateritic soil has more granular structure. The strength of lateritic soil mixtures sligthly increase as the curing time increases. The Penemulsion mixed with lateritic soil produced compressive strength higher than that obtained with the SS-K emulsion. The increase in compressive strength was about 30 percent at 7 days of curing period. From this result, it is expected that higher strength could be obtained by using better gradation aggregates.

5. Triaxial Test Results.

The selected mixtures used in triaxial tests, both sitly sand and lalertic soil mixtures came from Hveem test results. The specimens were investigated by carrying out undrained triaxial tests. Varying cell pressures (between 0 and 80 psi) were applied to identical specimens so that the apparent cohesion, Cu, and the angle of shearing resistance, Øu, could be determined. All specimens were deformed at a constant rate of strain of 1 percent per minute. The specimens were given standard mixing and compaction as described in the preparation of specimen. All specimens were tested immediately after compaction as in Hveem stabilometer tests. The results are summarized in table 16

The shapes of the stress-strain curves were similar for all specimens in that the maximum deviator stress ($\sigma_1 - \sigma_3$) and the strain at failure increased with increasing cell pressure (in all cases). Typical Mohr circles for silty sand mixtures and lateritic soil

Table 16. Triaxial Test Results for Silty Sand and Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion

Sample	Strain, %	$\sigma_1-\sigma_3$, lb/in^2	σ_3, lb/in^2	σ_1, lb/in^2	Cu, lb/in^2	Øu, deg.
S+5P[1], 1	10.3	66.5	20	86.5	9.8	29
2	11.3	108	40	148		
3	13.5	184	80	264		
S+5E[2], 1	11.1	60.5	20	80.5	8	29
2	12.8	100	40	140		
3	13.2	176	80	256		
L+3P[3], 1	11.5	70	20	90	14	24
2	12.4	85	30	115		
3	14.2	97	40	137		
L+3E[4], 1	11.7	55	20	75	9.4	23.6
2	12.1	71	30	101		
3	12.4	84.5	40	124.5		

1. Silty Sand + 5% Penemulsion at liquid content of 6 percent.
2. Silty Sand + 5% SS-K Emulsion at liquid content of 5.5 percent.
3. Lateritic Soil + 3% Penemulsion at liquid content of 12.5 percent
4. Lateritic Soil + 3% SS-K Emulsion at liquid content of 12.5 percent

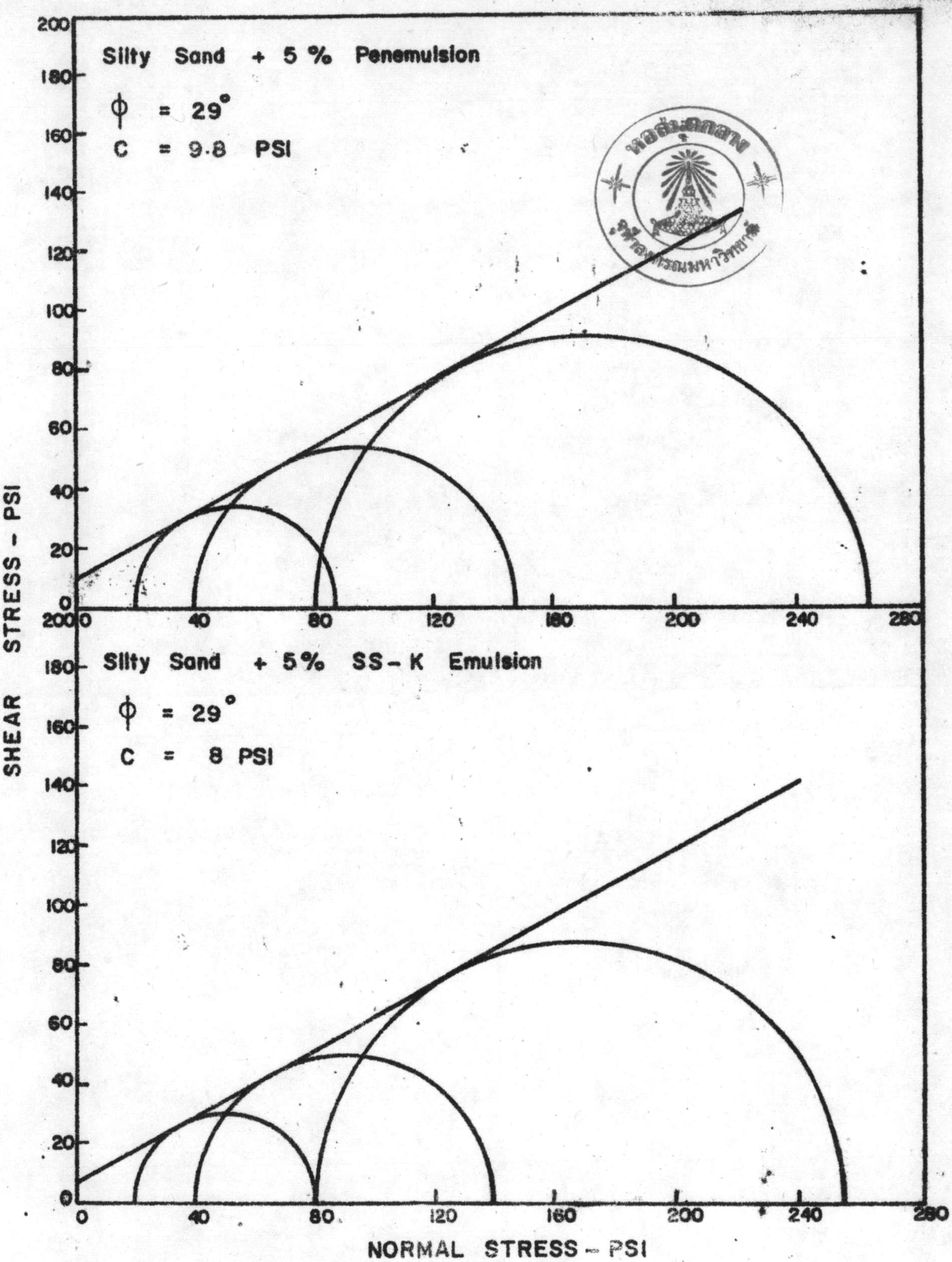

Figure 26 Comparison of Typical Mohr Circles for Silty Sand Stabilized with Penemulsion and SS-K Emulsion

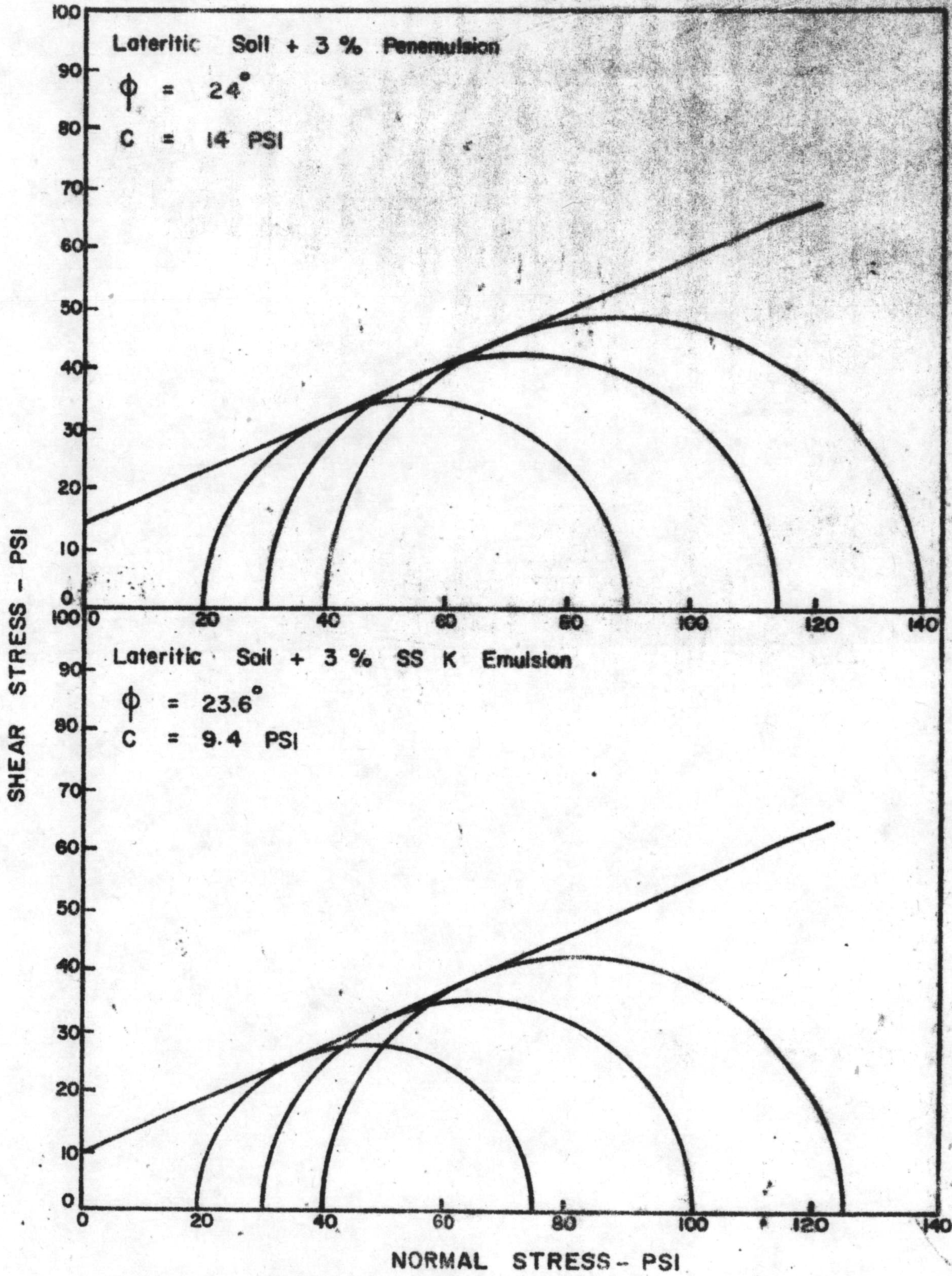

Figure 27 Comparison of Typical Mohr Circles for Lateritic Soil Stabilized with Penemulsion and SS-K Emulsion

mixtures are shown in Figure 26 and 27, respectively. The failure envelopes were very close to strainght lines, although they tended to be slightly concave downward. For the purpose of determining Cu and øu the straight line that best fitted the results was taken, as shown in Figure 26 and 27.

For the silty sand stabilized with Penemulsion and SS-K emulsion, the Penemulsion mixture resulted values of Cu and øu were 9.8 psi. and 29 dgree, respectively. The SS-K mixture resulted values of Cu and øu were 8 psi. and 29 degree, respectively.

These resulting values of Cu and øu are shown in Figure 26. The results show that the Penemulsion mixture yielded a higher cohesive strength than the SS-K emulsion mixture as one might have expected, but the angles of shearing resistance measured were the same. As described in the unconfined compressive strength test, the compressive strength of silty sand mixtures were found to be low comparing with the lateritic soil mixtures, because the strength is a function of the confined stresses to which it is subjected. From triaxial tests results, the silty sand mixture tend to give higher strength than the lateritic soil mixture when the cell pressures increased (see Figure 26 compared with Figure 27).

For the lateritic soil stabilized with Penemulsion and SS-K emulsion, the Penemulsion mixture resulted values of Cu and øu were 14 psi. and 24 degree, respectively. The SS-K emulsion mixture resulted values of Cu and øu were 9.4 psi. and 23.6 degree, respectively. These results are shown in Figure 27. The results also show that the Penemulsion mixture gave a higher cohesive strength than the SS-K emulsion mixture, but the angles of shearing resistance measured were apparently unaffected by the Penemulsion used.