CHAPTER IV

RESULTS AND DISCUSSION

4.1 Effect of Lime on Soil Plasticity

As shown in Table 2, the liquid limit of the soil tended to decrease but the plastic limit increased sharply when mixed with 2, 4, 6 and 8 percents of lime Fig. 1 and Fig. 2 were plotted to show the alterations in liquid limit and plastic limit relative to the age of mixing time respectively. A little decrease in liquid limit was observed as shown in Fig. 1. However the plastic limit of the soil-lime mixtures are increasing at the eariler days of age as shown in Fig. 2. As the number of days is increasing the plastic limit of the mixtures is slightly change. From the tested results the addition of 6 % of lime gives the maximum increase of the plastic limit of soil in one day from 14.36 % to about 38 %. And this mostly remained constant after one day age of mixing. At the lime content of 8 %, the plastic limit was raised to only about 29 - 31 %. This means that the amount of lime which caused the highest increasing of plastic limit of this type of soil or reaching lime fixation point is about 6 %.

The net effect was a decrease in the plasticity index of the soil as shown in Fig. 3, the plasticity index dropped sharply when the soil was mixed with 6 % lime and mostly remained constant with an increasing of age. This change in the plasticity can be attributed to the base-exchange reaction of soil and lime i.e. Ca^{++} replace the weaker univalent ion Na^{+} and H^{+}, and the increasing of calcium ions on the surface of the clay particle, resulting in flocculation. Consequently, the lime content of 6 % was selected for the preparation of lime-cement stabilization in the second phase of investigation.

Part of the scatter in the experimental values was probably due to the low accuracy of the plasticity tests. However, plasticity indices were ordinerily considered to be accurate and reproducible to within 2 or 3 percent.

Table 2 - Soil Plasticity and % Lime Content

Lime Content (%)	Time (days)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0	-	59.50	14.36	45.14
2	1	58.90	24.49	34.41
	2	58.30	25.42	32.88
	3	58.00	27.94	30.06
	4	57.90	32.43	25.47
	5	57.70	32.20	24.50
	6	57.80	33.62	24.18
	7	57.70	33.85	23.85
4	1	58.30	32.78	25.52
	2	58.00	33.28	24.72
	3	57.30	33.89	23.41
	4	57.60	34.62	22.98
	5	57.10	34.37	22.73
	6	56.80	34.78	22.02
	7	56.60	35.48	21.12
6	1	56.30	38.39	17.91
	2	55.80	38.14	17.66
	3	56.20	38.25	17.95
	4	55.90	38.26	17.64

Lime Content (%)	Time (days)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
	5	55.90	38.22	17.68
	6	55.80	38.20	17.60
	7	55.80	38.29	17.51
8	1	55.50	28.94	26.56
	2	55.20	29.28	25.92
	3	54.60	29.85	24.75
	4	54.20	30.43	23.77
	5	54.20	30.77	23.43
	6	54.20	31.30	22.90
	7	53.70	31.23	22.47

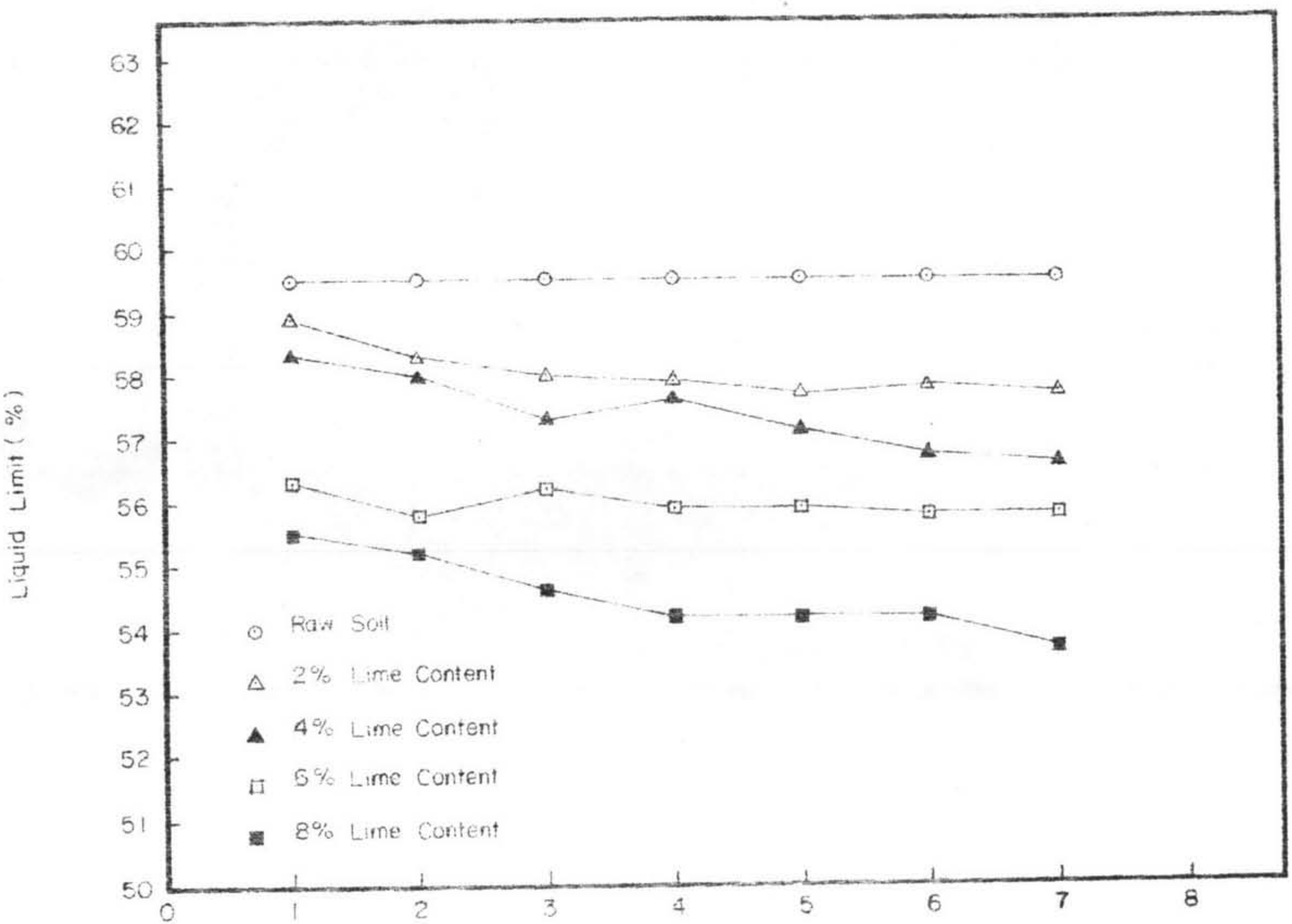

Fig I - Effect of Lime on Liquid Limit at Various Age of Mixing Time

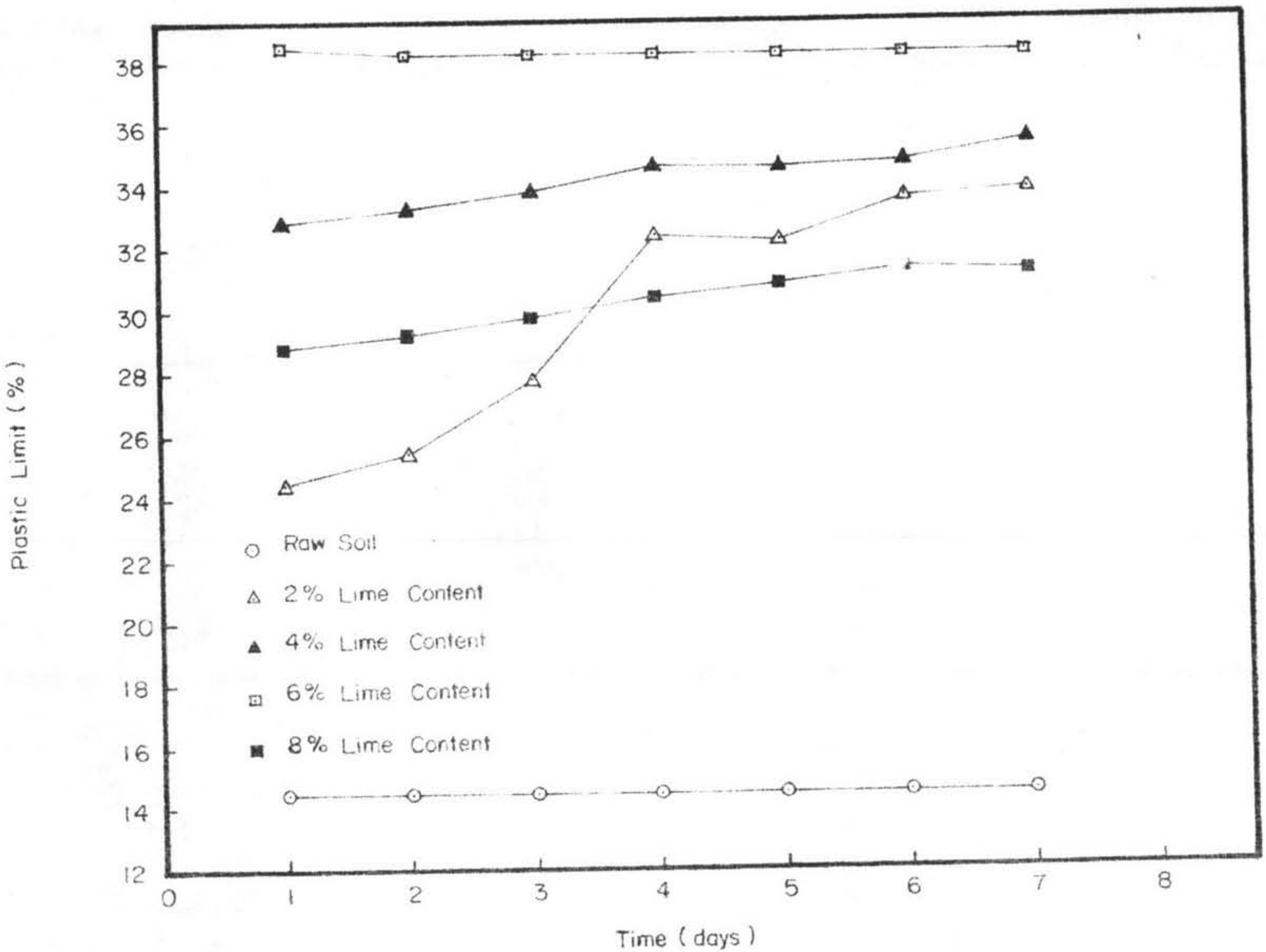

Fig. 2 — Effect of Lime on Plastic Limit at Various Age of Mixing Time

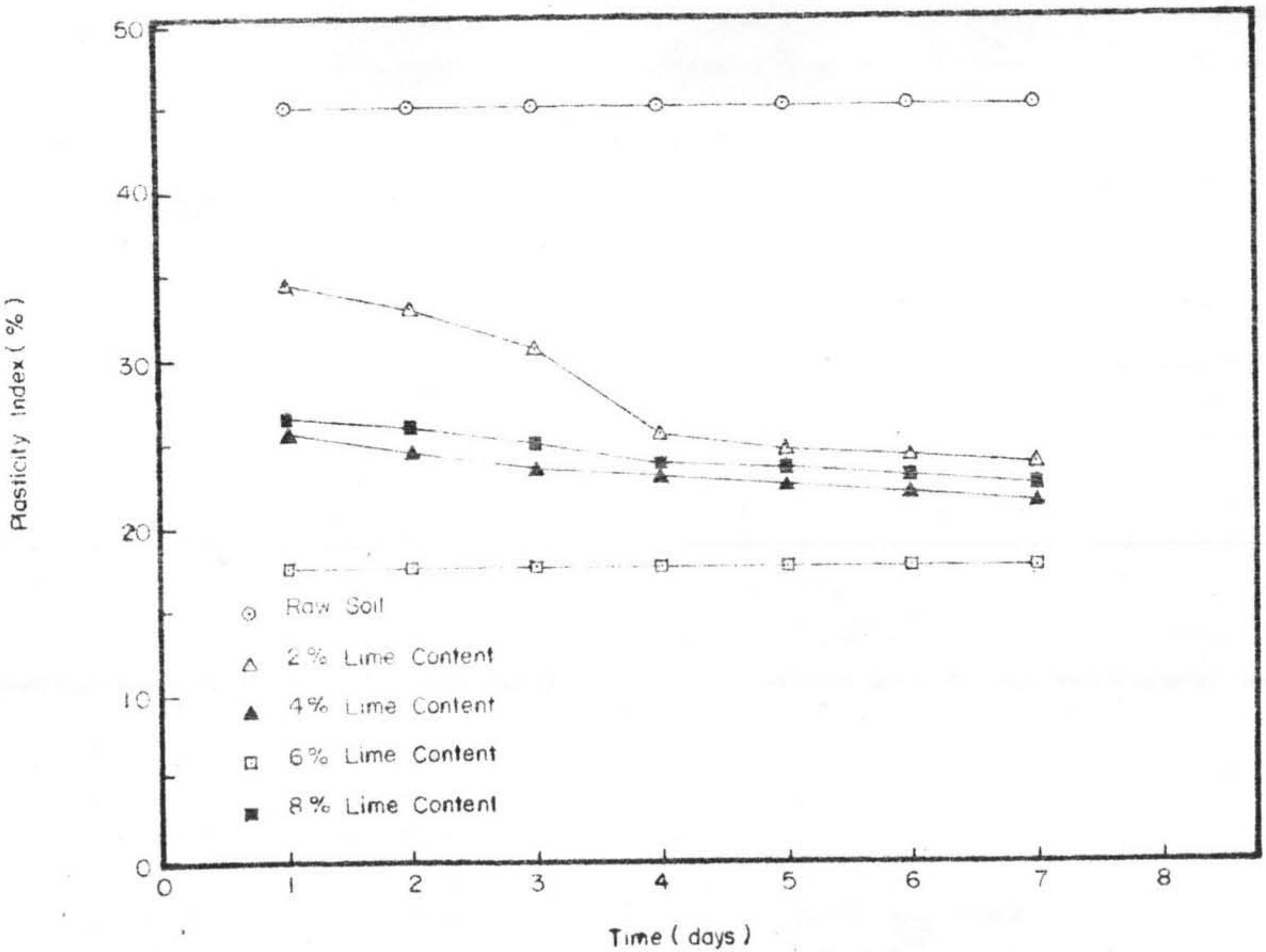

Fig. 3 – Effect of Lime on Plasticity Index at Various Age of Mixing Time

4.2 Lime - Cement Stabiliaation

4.2.1 Optimum Moisture Content and Compacted Dry Density

From the compaction curves, shown in Appendix, Fig. A 2, the lime-cement stabilized soils give the same type of moisture-density relationship as untreated soil. Table 3 illustrated the effect of the addition of lime and cement on the compaction characteristics of the soil. Fig. 4 and Fig. 5 were plotted to show the variation in the optimum moisture content and the maximum dry density of the soil due to effect of the stabilizers. Fig. 4 showed that the optimum moisture content increased from 28.2 % of raw soil to 29.4 % at 6 % lime with 5 % cement and then remained nearly constant when cement content was more than 5 %. Fig. 5 showed also that the maximum dry density decreased from 1.448 gm./cm.^{3} of raw soil to 1.430 gm/cm^3 at 6 % lime with 5 % cement. This indicated that when lime was added to the soil, at first it would increase the optimum moisture content and decrease the maximum dry density. The mixing of cement to the lime-soil mixture, would also cause the optimum moisture content to increase and the maximum dry density to decrease. This is observed until the cement content reached 5 %, the optimum moisture content and the maximum dry density seem to be nearly constant. These effects are attributed primarily to the increase in stability which is derived from the immediate cation exchange and to the flocculation and agglomeration reactions that further occured when cement was added to the lime-soil mixtures. Since the flocculation and agglomeration reactions reduce the specific surface of the mixtures and also the lime

Table 3 - Optimum moisture Content and Dry Density of Raw Soil and Lime-Soil Mixture at Various Cement Content

Lime (%)	Cement (%)	Optimum Moisture Content (%)	Dry Density (gm/cm^3)
0	0	28.20	1.448
6	3	29.20	1.436
6	5	29.40	1.430
6	7	29.40	1.430
6	9	29.40	1.430

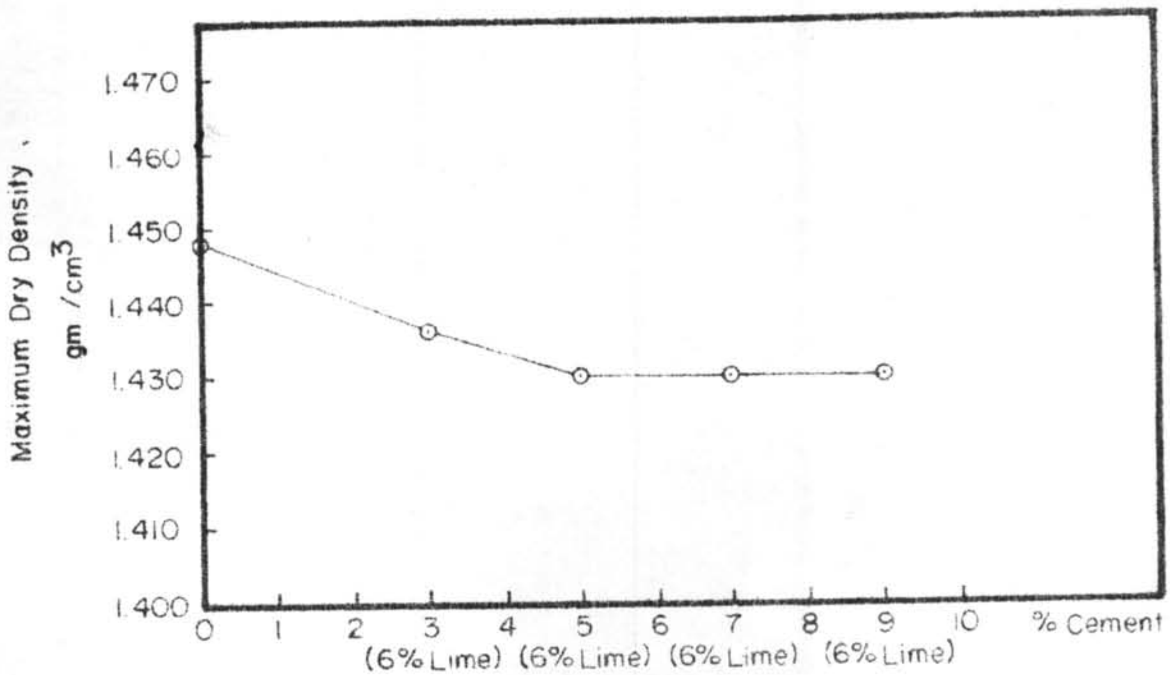

Fig 5 – Variation in Maximum Dry Density of Raw Soil and Lime-Soil Mixture at Various Cement Content

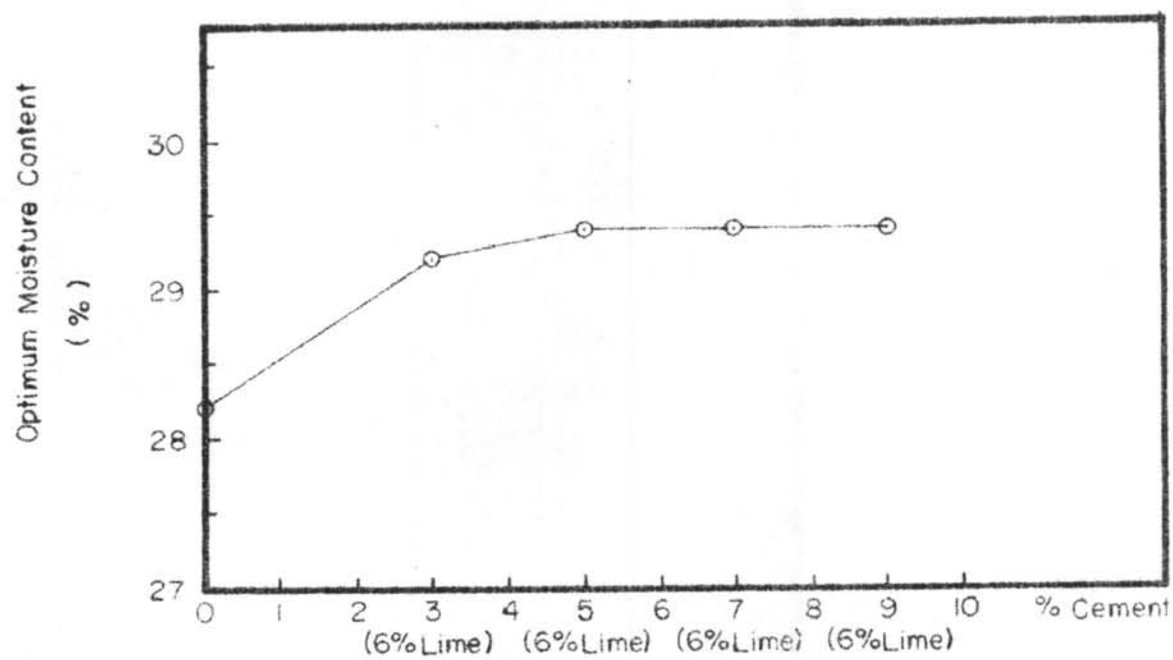

Fig 4 – Variation in Optimum Moisture Content of Raw Soil and Lime-Soil Mixture at Various Cement Content treated phase reduces the number of unbalanced charges of the soil, hence the amount of Ca^{++} required to replace in cation exchanging process when adding cement seems to have some optimum content. This optimum percentage of cement was observed to be 5 % for this case.

4.2.2 Strength

In general, lime and cement are beneficial stabilizers in the improvement of the soil properties including strength and stability. For the soil with high plasticity, lime is the most widely used to reduce the plasticity at first, and after that, cement is used to increase the strength of the mixtures. Base on this assumption the lime content as "lime fixation point" that will be used for Nong Ngoo Hao clay is 6 %. And the cement concentrations to increase the strength are 3 %, 5 %, 7 % and 9 % of the dry weight of the mixtures. The specimens are compacted at the various water contents and cured for the specified periods of time.

The effect of cement content on the compressive strength at the same amount of lime is shown in Table 4. It is noted that as the cement increases the strength also increases. Usually the increasing of strength of cement-stabilized soils requires the adequate moisture in the mixtures during the specified curing period, and it depends not only on the amount of added cement but also depends on the properties of the soil. Fig. 6 showed the rate of strength development on the addition of various cement contents at the curing period of 7, 14 and 28 days. It showed that the strength increased with increasing percentage of cement and also increasing

Table 4 - Maximum Strength of Raw Soil and Lime-Soil Mixture at Various Cement Content after 7, 14 and 28 Days of Curing

Lime (%)	Cement (%)	Curing Time (days)	Maximum Strength (kg/cm^2)
0	0	-	3.95
6	3	7	5.00
		14	5.24
		28	5.92
6	5	7	6.85
		14	7.15
		28	8.15
6	7	7	9.20
		14	9.25
		28	14.70
6	9	7	12.30
		14	12.50
		28	17.22

Table 5 - Maximum Dry Density, Optimum Moisture Content and Molding Moisture Content at Maximum Strength after 7, 14, 28 Days of Curing

Lime % by wt.	Cement % by wt.	Max. Dry Density (gm/cm^3)	Optimum Moisture Content (%)	Molding Moisture Content at Max. Strength for Curing Period (%)			Maximum Unconfined Comp. Strength for Curing Period (kg/cm^2)		
				7-day	14-day	28-day	7-day	14-day	28-day
0	0	1.448	28.20	28.30			3.95		
6	3	1.436	29.20	29.00	29.00	29.20	5.00	5.24	5.92
6	5	1.430	29.40	28.80	29.00	29.20	6.85	7.15	8.51
6	7	1.430	29.40	28.60	28.80	29.10	9.20	9.25	14.70
6	9	1.430	29.40	28.60	29.00	29.20	12.30	12.50	17.22

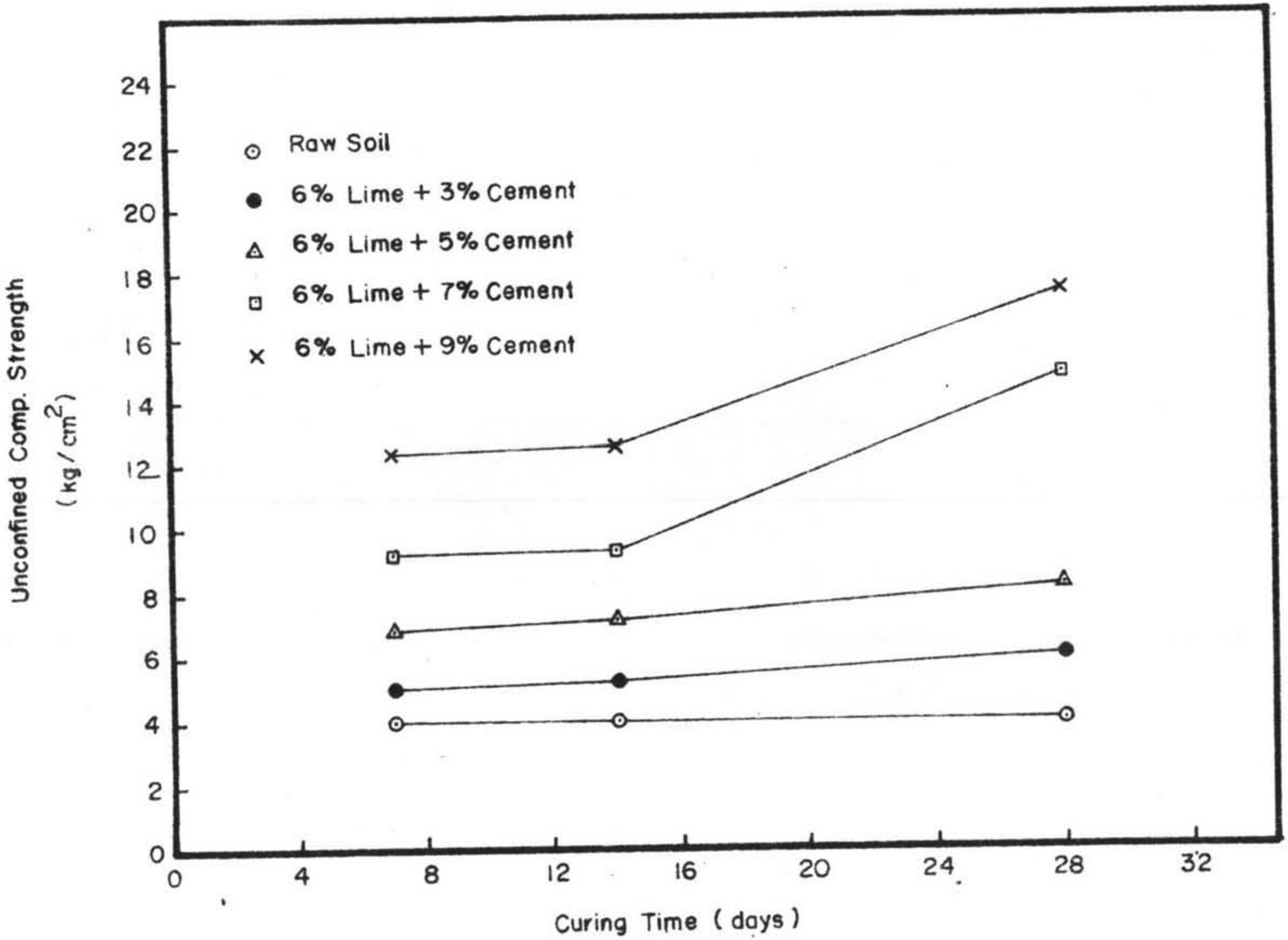

Fig.6 – Effect of Curing Time on Strength of Raw Soil and Stabilized Soils

of curing time. It is noted that the rate of strength development was higher and increased sharply after 14 days of curing for the mixture that contained 7% and 9% of cement. This may be explained by considering first the mechanism of **lime** and soil reaction. The reaction of lime and soil silica or alumina will result in immediately immobilized as insoluble silicate or aluminate. So, the addition of cement which is distributed between soil particles will form a cementitious silicate or aluminate gel that confined to a thin zone around each cement particle. With higher cement content, the zones of gel formations are expanded and later these zones will overlap each other result in the sharp increasing of strength. The amount of cement that causes thin zones of gel around each cement particle to expand and begin to overlap each other seem to be optimum content. For this case of study, the optimum percentage of cement was observed to be 5 %. Hence for the cement content of 7 % and 9 %, the excess cement in the mixtures will act like a filler that stimulate the pozzolanic reaction and then causes the strength development to increase sharply. This results in the overlapping of the zones of cementitious silicate or aluminate gel.

If 250 lb/in^2 (17 kg/cm^2) of compressive strength were used as a design criterion, the minimum period of time required to satisfy the specified strength would not be less than 28 days. And the minimum amount of cement required to stabilize this soil should not be less than 9 % for lime content of 6 %. Thus the most significant consideration in stabilizing this soil is the time required for specified strength. It should be also considered the effect of lime-cement from the other tests such as C.B.R. test and durability test.

The results from table 5 confirmed that the optimum moisture for the maximum dry density and the optimum moisture content for the maximum unconfined compressive strength were not the same. For raw soil, the moisture content for the maximum strength was slightly above the optimum moisture content for the maximum dry density or on the wet side. For stabilized soils, the moisture content for the maximum strength was slightly below the optimum moisture content for the maximum dry density or on the dry side.

4.2.3 Effect of Curing Time

When the soils are stabilized with lime and cement, the reactions between soil particles and stabilizers will take times. It is necessary that soil stabilized mixtures must be cured so that the hardening process can take place. This is the evidence that soil stabilized mixtures continue to gain strength with an increase in the duration of curing. Among the various factors affecting the rate of increasing in compressive strength, the most important things are the kinds and properties of soil and the concentration of cement. Fig. 6, Table 4 and Table 5 presented the data on lime-cement stabilization. It showed that; (i) the strength of lime-cement stabilized soil increases with curing time, (ii) the rate of strength development is less increase at 3 % and 5 % of cement content but more increase sharply at 7 % and 9 % of cement. This probable reason was explained in 4.2.2. Table 5 showed that the moisture content for the maximum unconfined compressive strength increased with prolonged curing periods. This may probably due to the required excess moisture to the reaction of pozzolanic reaction of lime and hydration of cement for long curing periods.

4.3 California Bearing Ratio Value

The specimens prepared for C.B.R. test in this study were compacted by Standard energy at the optimum moisture content and had been cured for 7 days prior to testing. The C.B.R. was investigated both unsoaked and soaked samples.

Fig. 7 and Fig. 8 showed the load penetration characteristics of untreated soil and lime-cement stabilized soils under unsoaked and soaked condition respectively. The C.B.R. values increased with further increase in the percentage of cement at the same lime content as shown in Fig. 9. It showed that the C.B.R. values of unsoaked condition were higher than that of soaked condition. The soaked C.B.R. value is generally the most widely used to determine the bearing resistance of the soils. Table 6 and Fig. 9 illustrated that there were large increased in the C.B.R. value development when the amount of cement were more than 7 % at the same lime content. At 9 % cement, the C.B.R. value was about 100 % of that 7 % cement at the same amount of lime. That is, the C.B.R. value

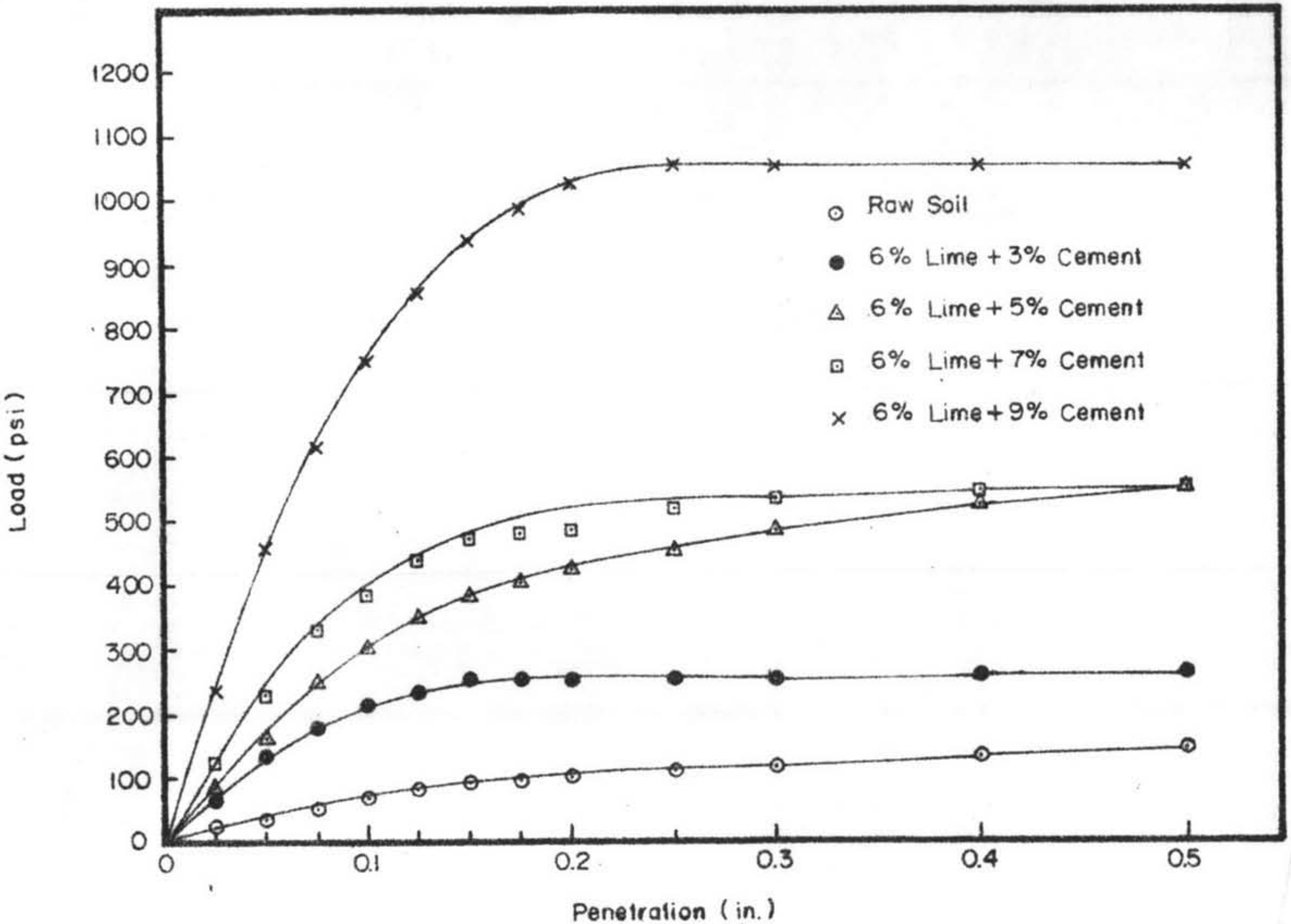

Fig. 7 – Resistance to Penetration of Raw Soil and Lime – Soil Mixture at Various Cement Content under Unsoaked Condition

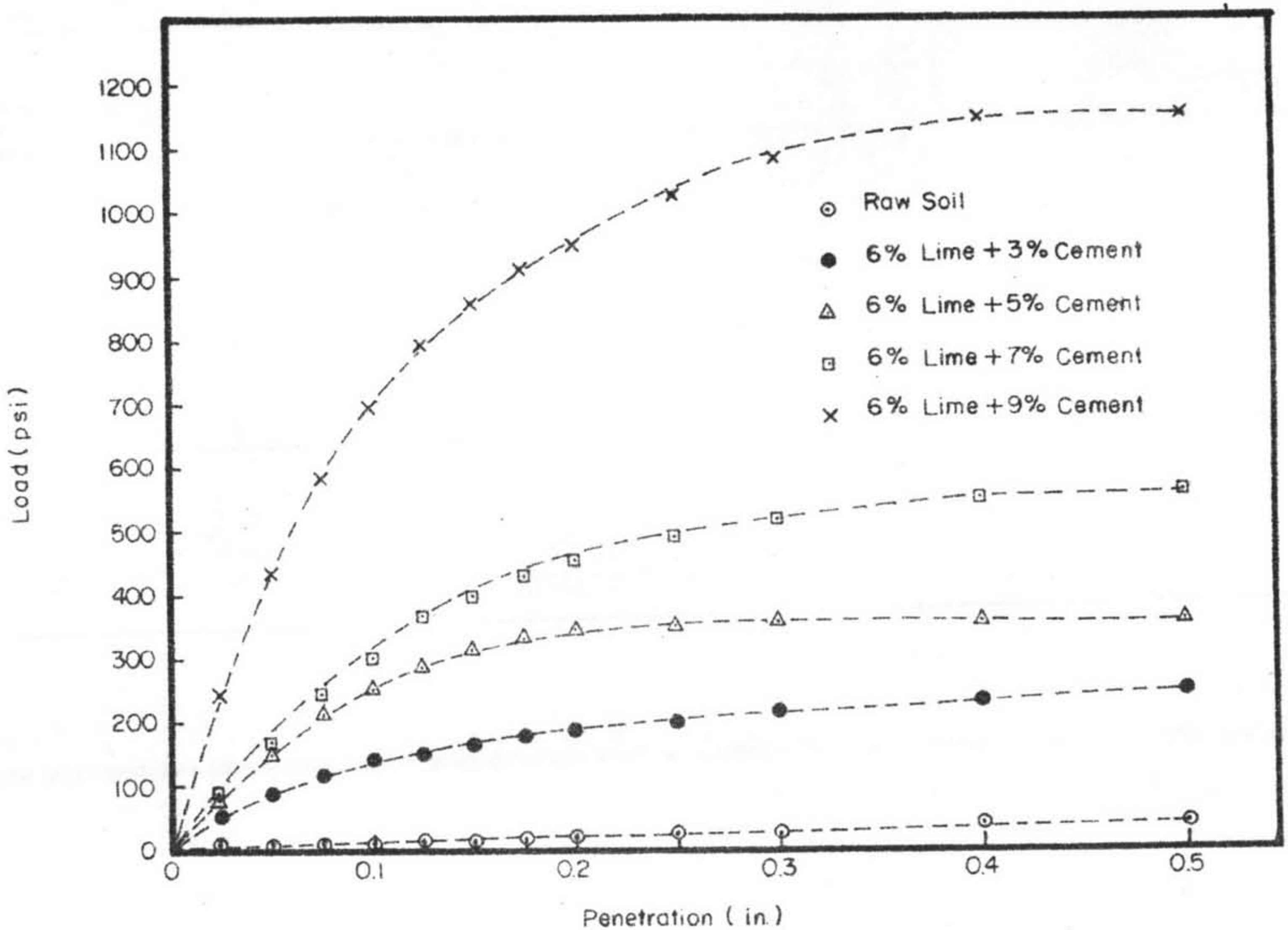

Fig. 8 – Resistance to Penetration of Raw Soil and Lime - Soil Mixture at Various Cement Content under Soaked Condition

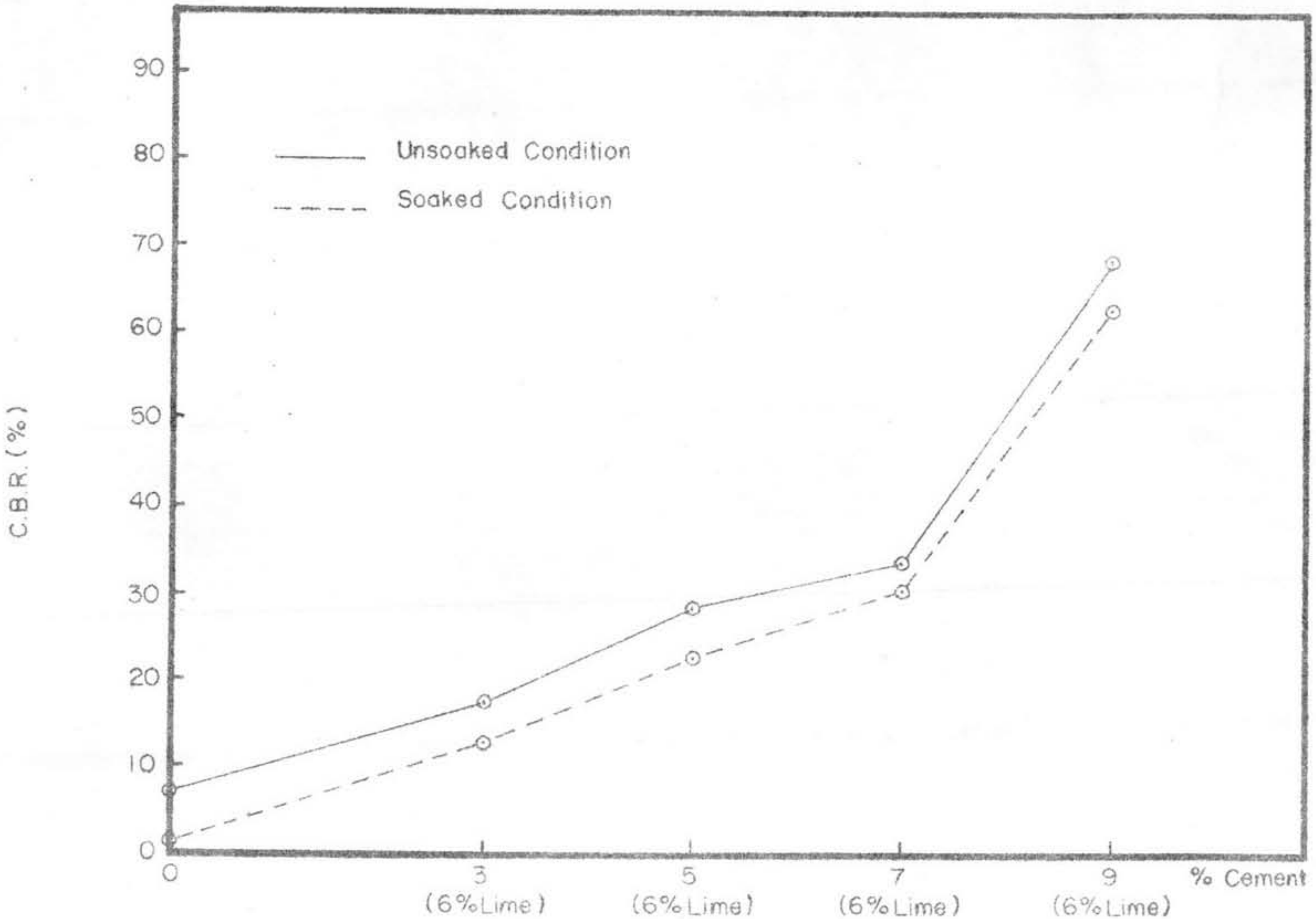

Fig. 9 — Effect of Lime-Cement Content on C.B.R. Value under Unsoaked and Soaked Condition

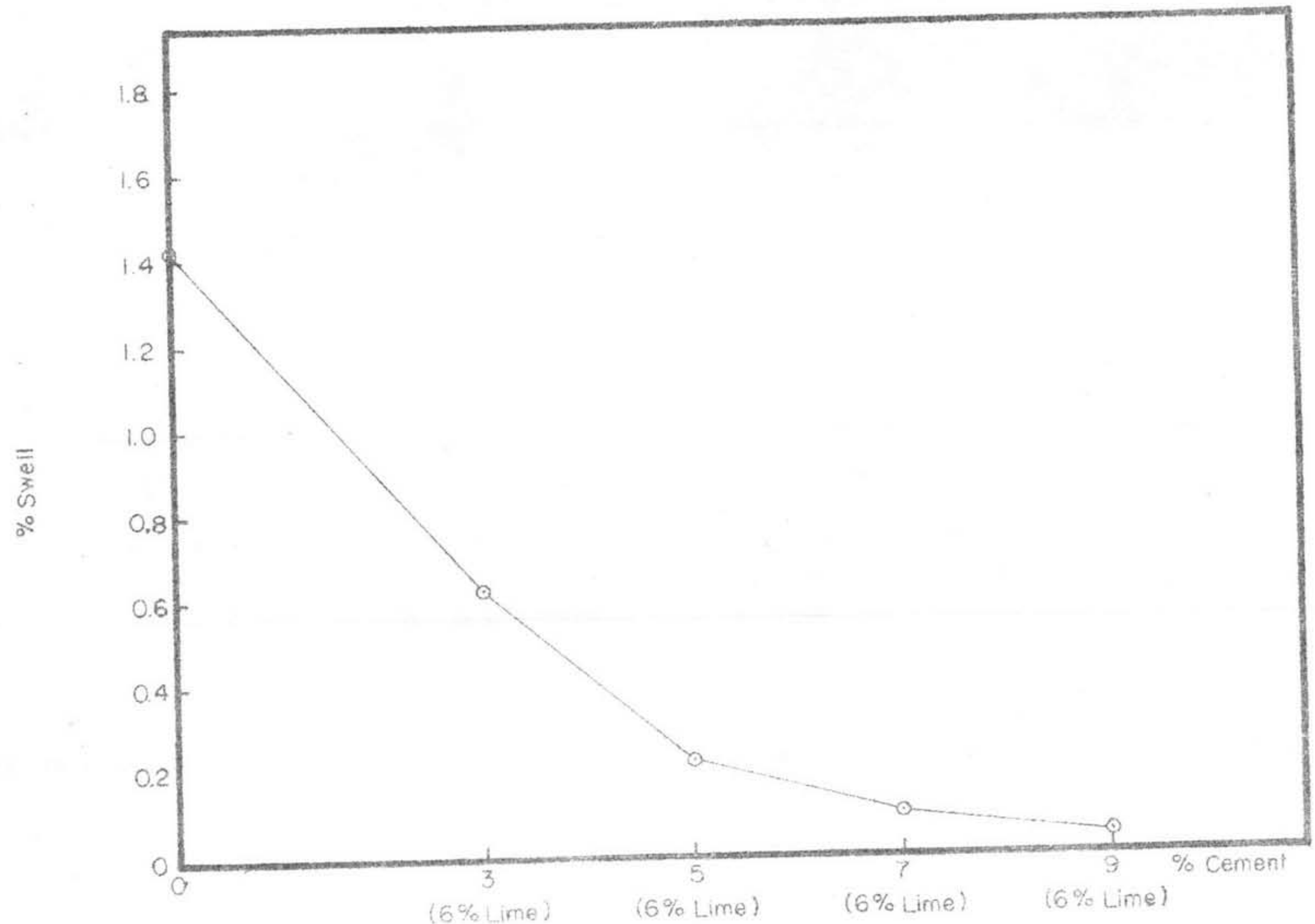

Fig. 10 - Effect of Lime-Cement Content on Swelling under Soaked Condition

Table 6 - Comparison of % C.B.R. under Unsoaked and Soaked Conditions, and Swelling of Raw Soil and Stabilized Soil

Lime %	Cement %	C.B.R. % Unsoaked	C.B.R. % soaked	Swell %
0	0	6.59	1.23	1.42
6	3	16.68	12.49	0.62
6	5	28.23	22.93	0.22
6	7	33.33	30.46	0.09
6	9	68.44	63.31	0.04

ranged from 30.46 % of 7 % cement to 63.31 % of 9 % cement.

As shown in Table 6 and Fig. 10, it is interesting to note that for soaked condition the swelling decreased sharply as the cement content increased at the same amount of lime under 10 lbs. surcharge weight. When 6 % lime and 3 % cement were added to the soil the swelling decreased from 1.42 % to 0.62 %, this is about 56 % in reduction. And the swelling decreased from 1.42 % of raw soil to 0.04 % of 9 % cement plus 6 % lime which is approximate 97 % in reduction. The results obtained from Table 6 indicate that the cement content has a significant effect on soil stabilization in the swelling reduction property.

In general constructions, the minimum C.B.R. value that has been used as a design criterion is 25 % for subbase. The results obtained from Talbe 6 indicates that the soil stabilized with 7 % and 9 % cement at 6 % lime content are satisfied. Consequently, the suitable cement content for stabilizing with 6 % lime is ranged from 7 % to 9 %

4.4 Durability Test

Most of cement - stabilized soils have sufficient stability to carry local traffic after being compacted to the maximum dry density at optimum moisture content. As hydration of the cement progresses, the stability of the cement-stabilized soil will increase. Accordingly, the durability test is designed to determine whether the soil-cement mixture can withstand the severe variations in moisture which often occur in field conditions. The effect of the durability testing on the height and volume, water content, and dry density was not significant for most of the mixtures tested. The significant one is the soil loss due to wetting and drying test which known to represent the durability of the mixtures.

As shown in Table 7, the total stabilized soil loss after 12 cycles of wetting and drying decreased with an increase of cement content at the same amount of lime. These results exhibit that the durability of the soils will increase with an increase of cement content.

Fig. 11 showed the effect of moisture content which related to the total soil loss after 12 cycles of wetting and drying. It is noted that the total soil loss on the dry side is higher than that of the wet side. The probable reason can be explained that at the dry side the water films around the particles of soil are small which result in the lower repulsive force between soil particles prior to testing compared to the wet side. During the test, the net increasing of repulsive force between soil particles is therefore greater on the dry side. This cause has an effect on loosen up the soil particles, hence at any cement content the total loss on the dry side is higher than the wet side. It is also observed that the difference in total loss is decreased as the cement contents

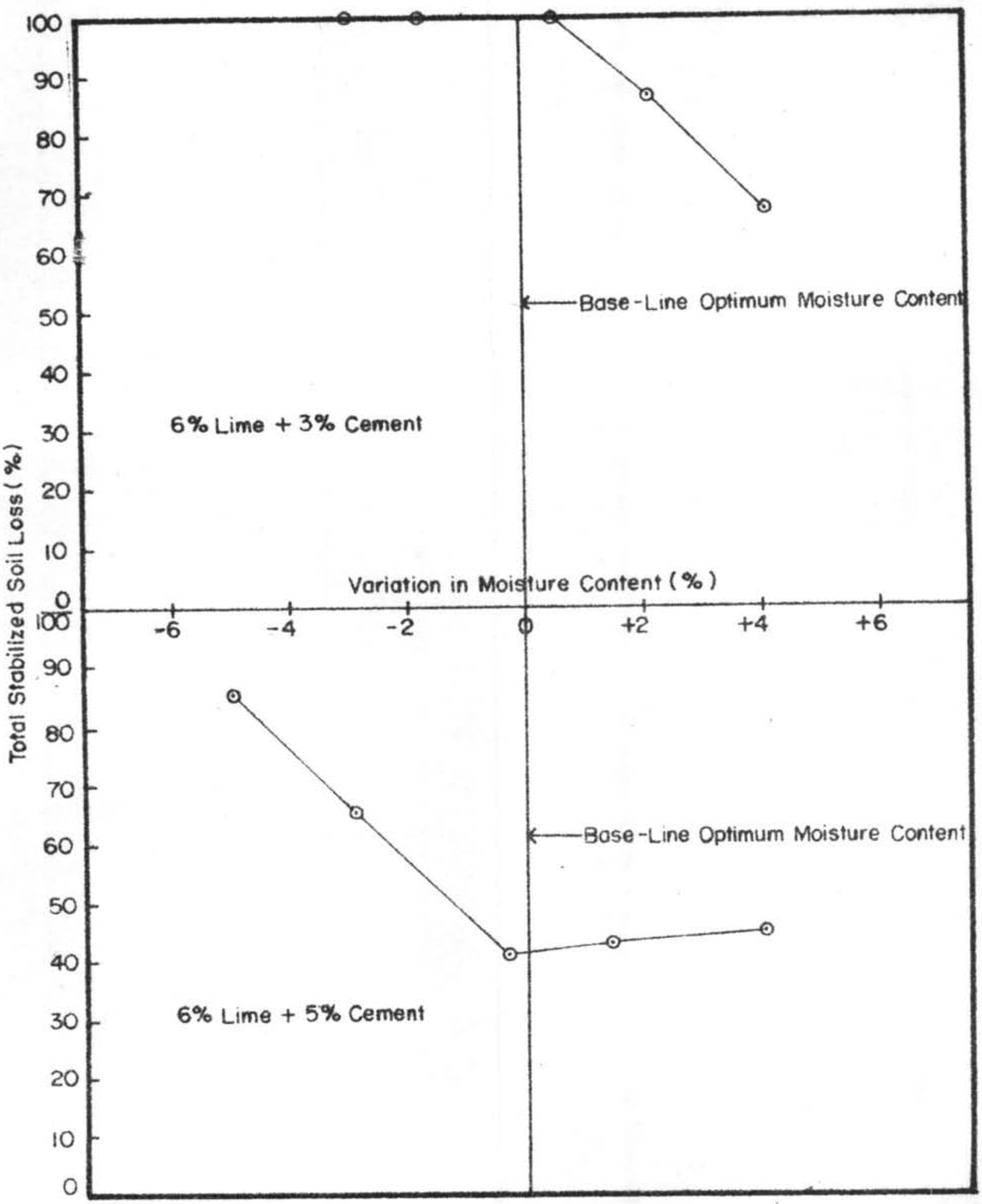

Fig.11 – Effect of Moisture Content on Stabilized Soil in the Wet – Dry Test

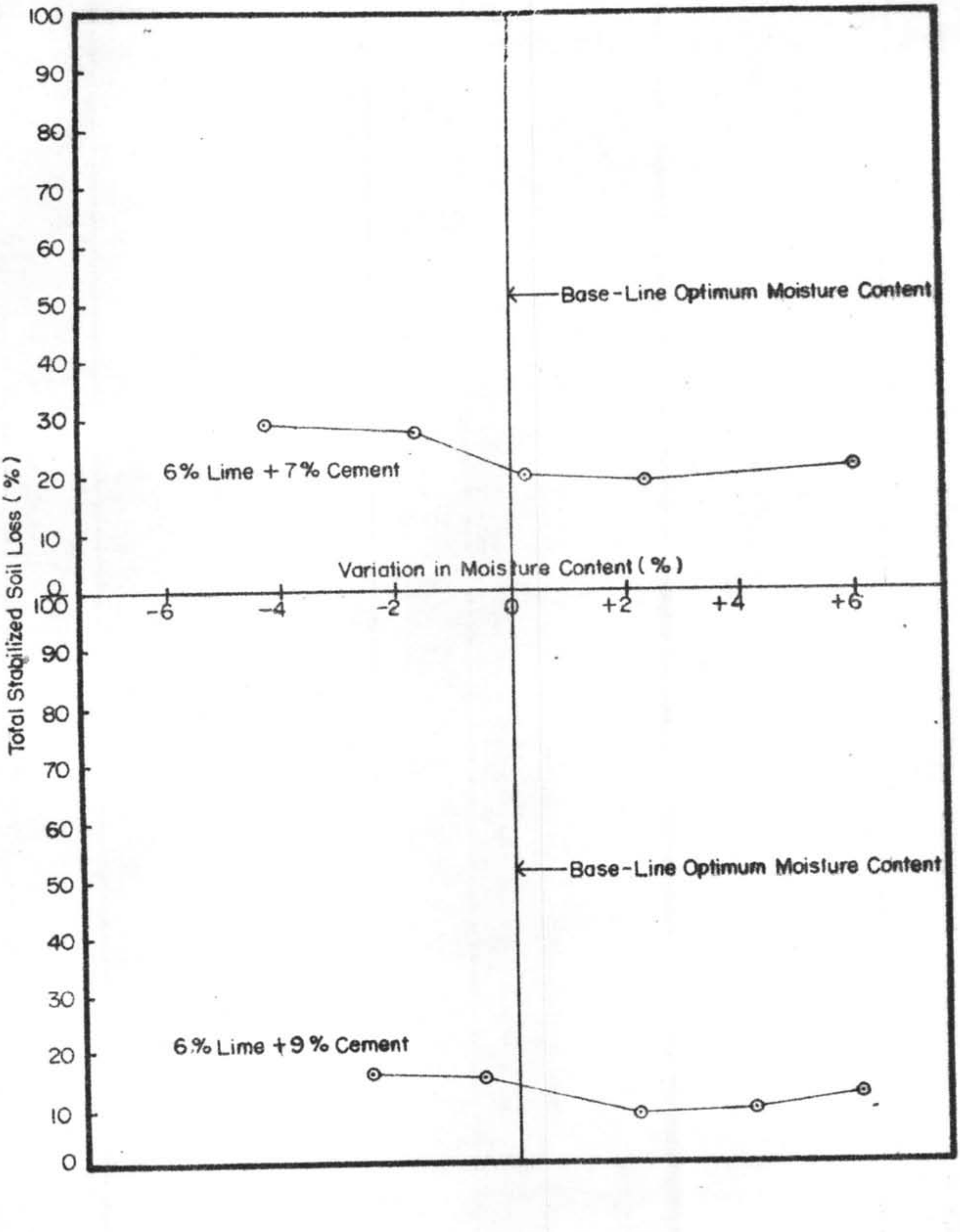

Fig. 11 – Effect of Moisture Content on Stabilized Soil in the Wet – Dry Test

Table 7 - Detailed Results from Wet-Dry Test

Lime by wt. (%)	Cement by wt. (%)	Optimum Moisture Content (%)	Initial Moisture Content (%)	Variation from opt. Moisture Content (%)	Initial Wet Weight (gm)	Initial Calculated Oven-Dry Weight (gm)	Final Oven-Dry Weight (gm)	Final Corrected Oven-Dry Weight (gm)	Soil Loss (%)
6	3	29.60	26.66	-2.94	1,708	1,348	-	-	100
	3		27.83	-1.77	1,741	1,362	-	-	100
	3		30.16	+0.56	1,784	1,370	-	-	100
	3		31.78	+2.18	1,773	1,345	195	188	86.02
	3		33.72	+4.12	1,747	1,306	440	425	67.46
6	5	30.00	25.04	-4.96	1,598	1,287	190	184	85.60
	5		27.13	-2.87	1,660	1,306	470	454	65.24
	5		29.69	-0.31	1,732	1,335	816	788	40.97
	5		31.37	+1.37	1,740	1,324	787	760	42.60
	5		34.06	+4.06	1,703	1,270	722	698	45.03
6	7	30.00	25.75	-4.25	1,610	1,280	937	905	29.30
	7		28.39	-1.61	1,702	1,326	999	965	27.22
	7		30.27	+0.27	1,743	1,338	1,109	1,072	19.88
	7		32.37	+2.37	1,731	1,308	1,100	1,063	18.73
	7		36.01	+6.01	1,679	1,231	999	965	21.60

Lime by wt. (%)	Cement by wt. (%)	Optimum Moisture Content (%)	Initial Moisture Content (%)	Variation from opt. Moisture Content (%)	Initial Wet Weight (gm)	Initial Calculated Oven-Dry Weight (gm)	Final Oven-Dry Weight (gm)	Final Corrected Oven-Dry Weight (gm)	Soil Loss (%)
6	9	30.20	27.65	-2.55	1,675	1,312	1,140	1,101	16.08
	9		29.53	-0.67	1,737	1,341	1,167	1,128	15.88
	9		32.28	+2.08	1,740	1,315	1,235	1,193	9.28
	9		34.37	+4.17	1,710	1,273	1,186	1,146	9.97
	9		36.20	+6.00	1,687	1,236	1,120	1,082	12.46

in the mixtures is increased. This is because of the mechanism of depressing of double layers water around soil particles. Furthermore, the total soil loss as shown in Fig. 11 is remarkably reduced when cement contents in the mixtures are increased. This is, because the additional stabilizers give more ion concentration to the soil water system hence reducing the repulsive force between particles.