

Use of Lime in Improving Bases and Subgrades

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In these days of high costs and concurrent demands for more miles of surfaced roads, highway engineers are in need of means to improve subgrade and base materials. Use of a thin surface-treatment means that the subgrade must be fairly stable in order for the surface not to shove and rut under the action of traffic. The softening effect of water and the action of frost and subsequent softening are factors which are ever in the mind of the highway engineer.

Frequently attempts are made to improve the carrying capacity of the subgrade by introducing a base course of granular material—sand or gravel. However, the mere addition of a base course is not a cure-all. The materials must be carefully selected; or, if there is no selection, the limitations of the available materials must be realized. Gravels may be too granular with too little binder, or they may be too plastic. Yoder and Woods (1)* have shown that a given gravel has an optimum binder content. Similarly, clean sands with no binder are likely to compact under the vibration caused by traffic and may lead to faulting in concrete pavements. Sands with too high a portion of binder soil will be unstable, and the finer portions will pump.

While there is no single cure for all these conditions, they are some of the factors that we have in mind when we talk of soil stabilization. Broadly speaking, when we think of stabilizing subgrades and bases, we mean increasing their strength and durability under traffic. Some of the factors which we seek to influence in order to bring about stabilization are: moisture content, plasticity, compaction, density, resistance to frost action, resistance to cycles of wetting and drying and of freezing and thawing, and grain-size distribution.

Various basic methods have been applied to the problem of stabilization. The mechanical method of controlling the grain-size distribution has developed from the work of Dr. Strahan (2) in Georgia. Stabiliza-

* Figures in parentheses refer to references in the Bibliography on page 91.

tion with bituminous materials and stabilization with portland cement have been developed, and each material has its range of usefulness. A large number of other additives have been tried in attempts to obtain stabilizing action on various soils. Among them have been calcium chloride, resins, sodium chloride, and hydrated lime. It is with lime that we are concerned here.

HISTORY OF LIME IN ROAD BUILDING

While lime is one of the oldest of construction materials—having been used, for instance, with great success by the Romans in such roads as the Appian Way—it has not received much attention from modern highway engineers until quite recently. The first report of the new ARBA Committee on Lime-Soil Stabilization (3) lists in its bibliography—presumably comprehensive—only 19 references, and many of these are but very brief treatments of the use of lime in roadbuilding.

The first important work with lime in modern days was done in Missouri in 1924 and 1925 under the direction of Dean McCaustland. This work was reported to the National Lime Association (4) and was followed by some experimental work in Iowa and South Dakota sponsored by the Bureau of Public Roads. These early attempts were on natural-earth surfaces, and the arrival of the era of paved highways put lime treatment out of mind.

There are other scattered references to the use of lime in engineering literature during the ensuing 20 years, including some field and laboratory experimentation in Texas (5). But it has not been until the post-war era that marked advances have been made in lime-soil stabilization, and research engineers of the Texas Highway Department have published several articles (6-10) in the past two or three years reporting successes that they have had stabilizing with both waste lime and commercial hydrated lime.

Hydrated lime is developing as a stabilizing agent for subgrades and base materials for low-cost roads. Its applicability to bases for high-type pavements is a fruitful field for experimentation. Its value in natural surface courses is still somewhat questionable.

Most recent construction work done with lime has been performed in Texas. The work has been directed toward improvement of base materials for flexible surfaces. Specification requirements for plasticity index and shrinkage were frequently met by adding lime to the soil. The roads which have been under traffic for two or three years are showing excellent performance.

Laboratory results reported by Texas include reductions in PI (plasticity index) of plastic clays from 52 to 12 and from 45 to 6 by

adding 8 and 9 percent of lime. Other poor subgrade materials, including gravels, have shown marked but less startling reductions. Bearing values and compressive strength have been increased several hundred percent by use of lime.

EXPERIMENTAL WORK AT PURDUE

The Engineering Experiment Station at Purdue has undertaken a laboratory research program to determine the types of soils to which lime may be added to improve their characteristics as base and subgrade materials. We have sampled a wide range of soil types—sand, silts, clays, and gravels. These samples represent soil areas in many states east of the Mississippi River as well as North Dakota, Texas, and Arkansas. The soils vary in origin from ice-deposited materials of both the Wisconsin and Illinoian glacial ages, water-deposited soils, and coastal plain



FIGURE 1. Source of soil samples used in lime-soil research.

materials to residual soils in bed-rock areas and wind-blown silts. Figure 1 shows the geographical location of the soil samples tested. Portions of these data were reported to the 28th Annual Meeting of the Highway Research Board (11).

The effect of lime on liquid limit and plasticity index of these soils has been studied. Also studied has been the effect of lime upon the compaction, density, and strength of the fine-grained soils and the effect of lime upon the CBR (California Bearing Ratio) strength of the gravels. Two different curing procedures have given an indication of the effect of moisture and of drying upon the comparative strengths.

For the purposes of this paper, only the results of the tests on the Indiana samples will be reported. These data represent only a fraction of the data collected but are quite typical of the over-all results obtained. Soil No. 2148 is from the plastic Valparaiso moraine; while Soils 664, 666, 669, 2146, and 2147 represent some of the variations in the soils of the ground moraine deposited by the Wisconsin glacier. Sample 2149 is typical of the sandy soils of the old Kankakee lake bed. The silty soils of the Illinoian drift are represented by Soils 692 and 2150. Bedrock residual soils provided Samples 683, 712, 718, and 721.

PLASTICITY TESTS

Liquid-limit and plastic-limit tests were performed, using zero, two, and five percent of lime. These tests were performed in accordance with ASTM designations D423-39 and D424-39, and plasticity indexes were computed. These results are summarized in Table 1 with an

TABLE 1
SUMMARY OF CONSISTENCY TESTS ON 13 INDIANA SOILS

		0%	2%	5%	Percent Change with	
					2% Lime	5% Lime
		Lime	Lime	Lime		
Average of 5 Silty Soils PI 15	Liquid Limit	25.8	28.2	29.2	+ 9.3	+13.2
	Plastic Limit	16.2	17.6	18.4	+ 8.6	+13.6
	Plasticity Index	9.6	10.6	10.8	+10.4	+12.5
Average of 8 Clayey Soils PI 15	Liquid Limit	40.9	40.4	39.5	- 1.2	- 3.4
	Plastic Limit	20.9	25.4	26.4	+21.5	+26.3
	Plasticity Index	20.0	15.0	13.1	-25.0	-34.5

arbitrary division between soils whose natural PI is less than 15 and those with higher plasticity.

The less plastic soils showed little change or else a slight increase in plasticity index as a result of adding lime to the soil; whereas the more plastic soils consistently showed decreased plasticity when lime had been added. It may be noted that the larger part of this change was caused by an increase in the plastic limit with little change in the liquid limit. Generally speaking, it was noted the soils with high plasticity showed marked decreases in plasticity index with addition of lime. On the other hand, some soils with medium PI's may show sharp drops in that index when lime has been used. Accompanying the admixture of lime may also be noted improvements in the workability of the soil—it becomes much more friable in action and is much easier to handle, mix, and place.

COMPACTION TESTS

Figure 2 shows grain-size distribution curves for a number of fine-grained soils, including the five Indiana soils on which Proctor com-

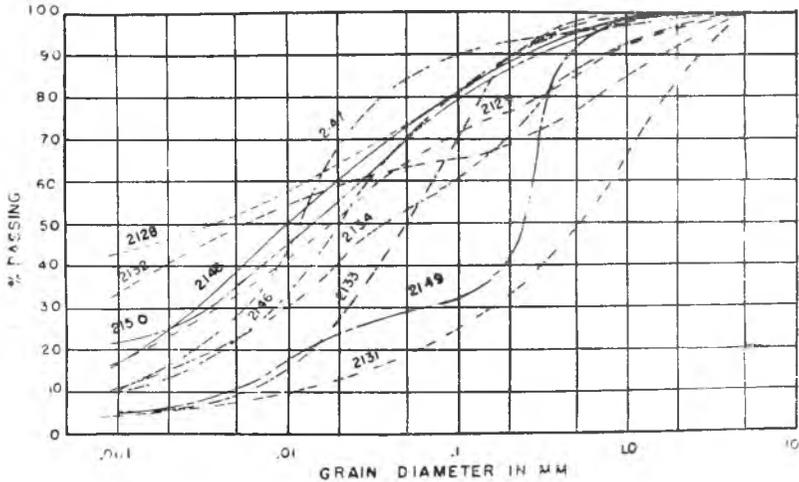


FIGURE 2. Grain-size distribution of eleven fine-grained soils.

paction tests were performed. The condensed results of the compaction tests are tabulated in Table 2. It will be seen from these data that

TABLE 2

EFFECT OF LIME ON COMPACTION OF FIVE INDIANA SOILS

Soil			0% Lime		Dry Density, Lime Added		% Change in Dry Density	
			Optimum Moisture	Max. Dry Density	2% Lime	5% Lime	2% Lime	5% Lime
No.	Type	PI						
2146	Wisconsin Drift—Crosby	3	15.0	109.8	109.4	106.2	-0.4	-3.3
2147	Wisconsin Drift—Brookston	24	20.5	93.2	91.6	90.8	-1.7	-2.6
2148	Clay-Shale Moraine	12	16.0	110.0	107.7	107.2	-2.1	-2.5
2149	Lakebed Silty—Sand	10	14.7	111.8	107.7	107.2	-3.7	-4.1
2150	Illinoian Drift	16	16.5	109.2	107.1	105.4	-1.9	-3.5

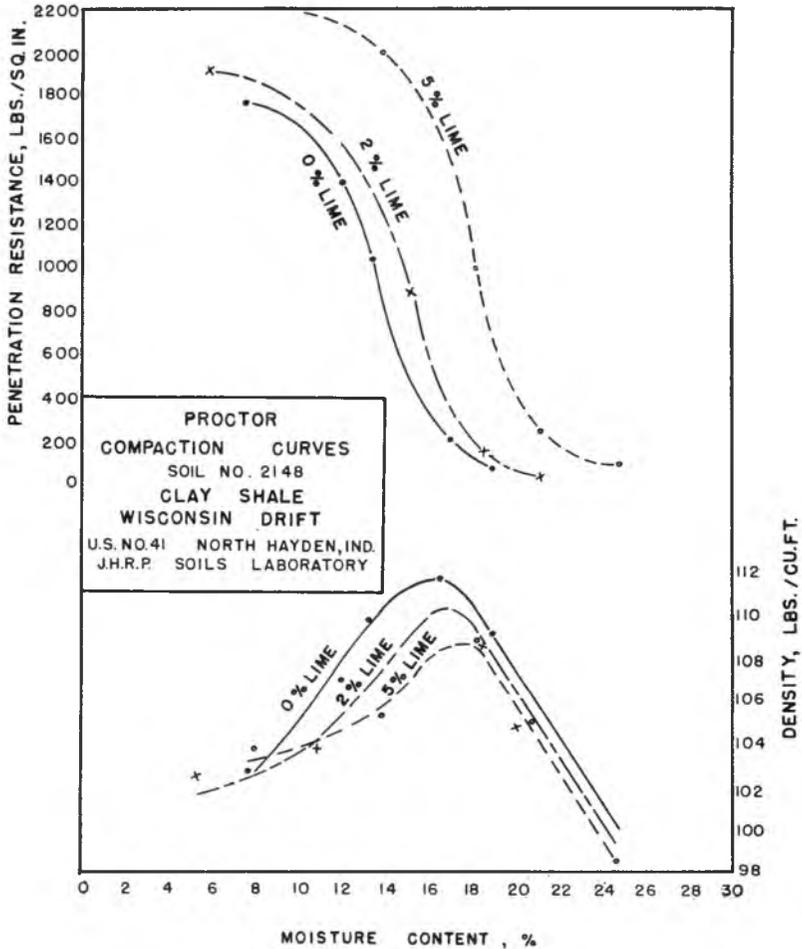


FIGURE 3. Proctor Compaction Curves, Soil No. 2148.

additions of lime have led to decreases in maximum density. Experience in compaction showed that the soils containing lime were much easier to work with, but that the degree of compaction diminished and a corresponding slight increase in optimum moisture content was observed when lime was used.

Figures 3, 4, and 5 are plots of the moisture-density relationships for three of the soils. It will be observed from these figures that the soil offers greater resistance to penetration at any given moisture content or at the corresponding optimum moisture contents when lime has been used. The penetration curves give some indication that, in spite of the

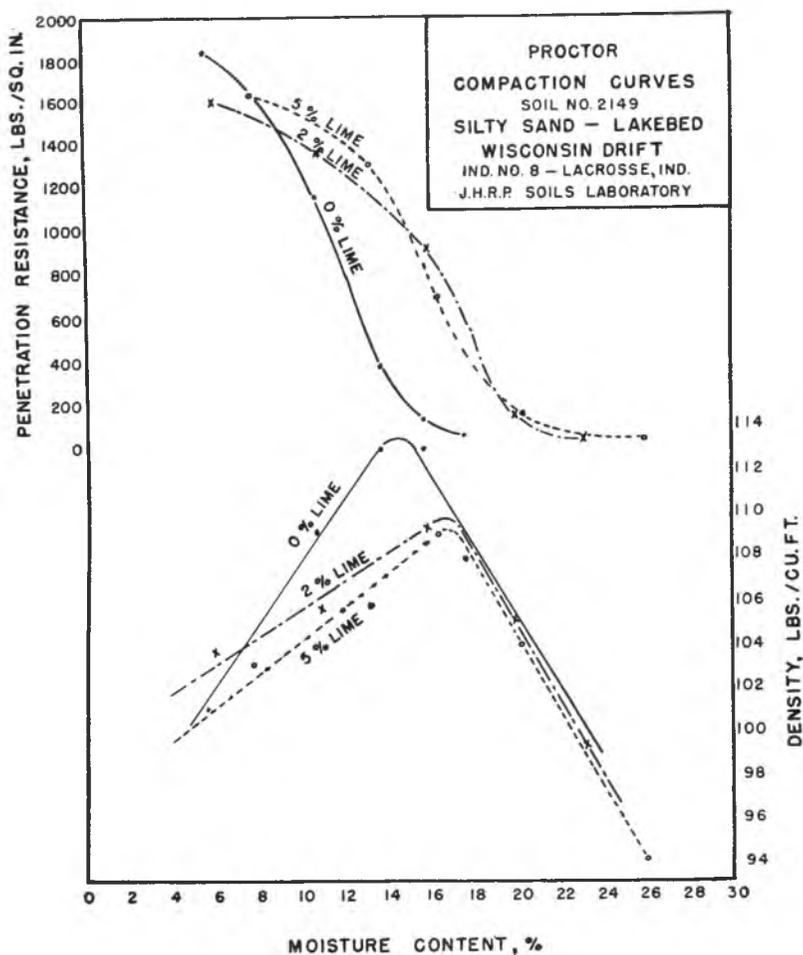


FIGURE 4. Proctor Compaction Curves, Soil No. 2149.

decreased density resulting from use of lime, the lime-soil mixture may be stronger and more stable.

STRENGTH TESTS ON FINE-GRAINED SOILS

The five Indiana soils for which compaction results are reported above were among the fine-grained soils which have been used in a series of unconfined compression tests to determine the effect of lime on strength of the soils. Specimens were formed in a Proctor-size split mold, using Proctor compaction procedure and at the optimum moisture content.

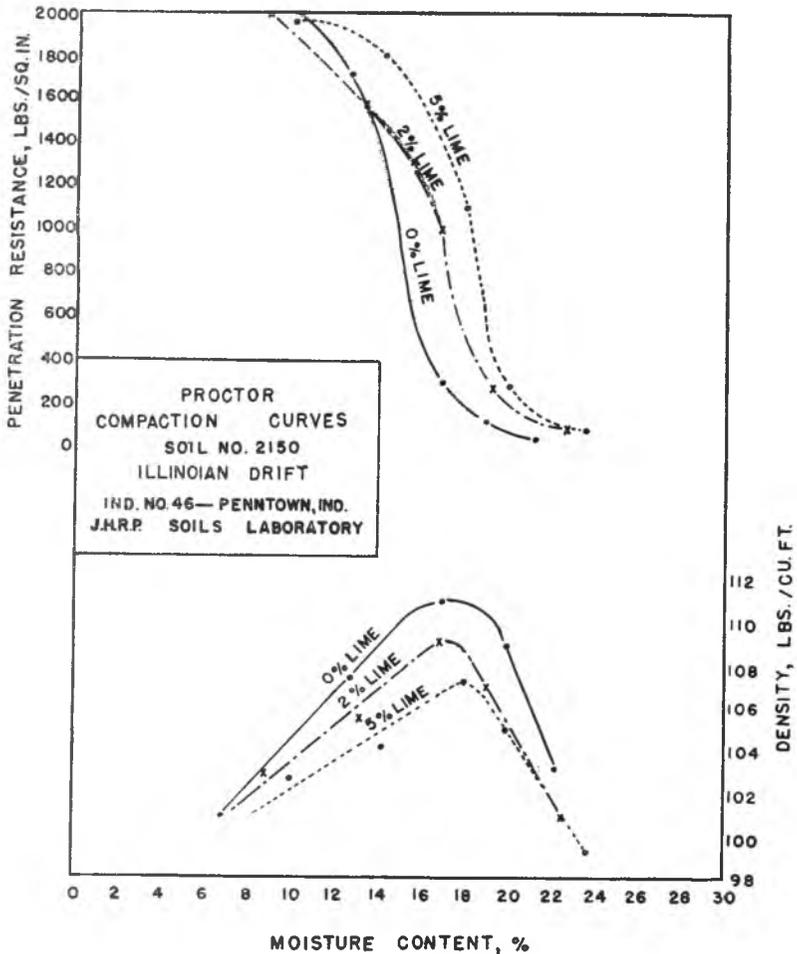


FIGURE 5. Proctor Compaction Curves, Soil No. 2150.

Samples were molded using zero, two, and five percent of lime, and companion specimens were tested after three different curing procedures. One specimen with each percentage of lime was tested immediately after molding to furnish a standard for comparison. Another set of specimens was tested after being subjected to seven days of capillary saturation, capillary moisture being available only to the bottom of the specimens. The third set of specimens was tested after a 14-day combined curing cycle. These specimens, immediately after molding, were placed in an oven at 140°F and remained there seven days. The drying was followed by seven days of capillary saturation.

It was noted during the curing cycles that the specimens containing lime developed fewer shrinkage cracks during drying and appeared much more resistant to the softening effects of capillary water than did those specimens molded from the untreated soil. This effect is further reflected in the results of some of the strength tests, as in Soil No. 2148.

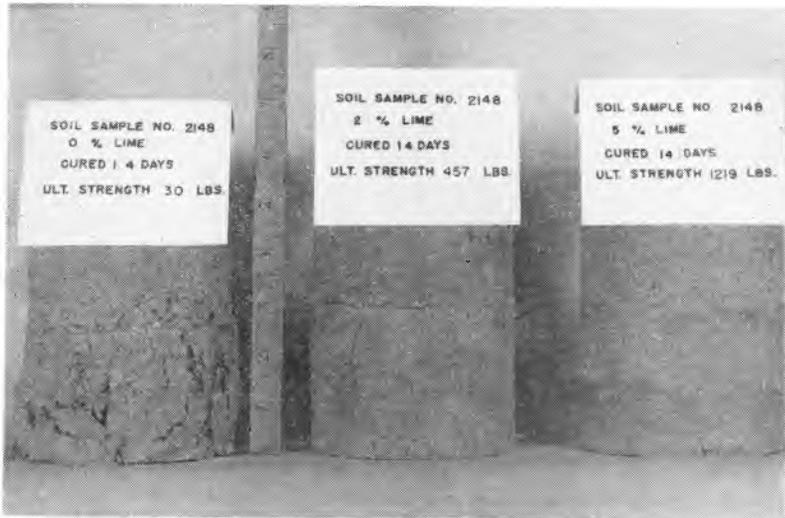


FIGURE 6. Picture of specimens of Soil No. 2148 after 14-days combined curing.

Figure 6 shows the difference in type of failure between that of the softened raw soil and the lime-soil specimens, which were much more resistant to the detrimental action of capillary moisture.

TABLE 3
RESULTS OF UNCONFINED COMPRESSION TESTS ON FIVE INDIANA SOILS

Soil No.	Ultimate Compressive Load, Pounds								
	As Molded			After 7-Day Cure			After 14-Day Cure		
	0% Lime	2% Lime	5% Lime	0% Lime	2% Lime	5% Lime	0% Lime	2% Lime	5% Lime
2146	398	486	472	60	135	98	178	282	466
2147	515	569	532	35	93	175	48	80	150
2148	461	550	588	30	266	450	30	457	1219
2149	167	161	169	200	272	405	60	454	701
2150	292	469	444	30	280	697	80	216	1025

Table 3 lists the results of unconfined compression tests performed on the specimens at the end of their respective curing periods. Results are reported as ultimate compressive load on the total area of the four-inch-diameter specimens. Those entries in the table which read 30 are approximate loads estimated when continued straining of the specimen beyond reasonable strain failure failed to produce an actual ultimate load.

Figures 7, 8, and 9 are bar graphs showing the results of the compression tests on three of the soils. It will be seen that, with all the soils except the Kankakee sand, the curing procedure produced much lower strengths with the raw soil than had been obtained in the specimens tested when molded. This is ample evidence that the curing procedures were rigorous. The Kankakee sand, on the other hand, was coarse enough not to be affected by capillary moisture, although the drying procedure lowered its strength.

Comparison of the strengths of any of the soils after either the 7-day curing or the 14-day combined curing shows the marked benefits to be gained by mixing lime with the soil. In all cases, the addition of two and five percent of lime resulted in marked increases—as much as several hundred percent—in the strength of the soil. In most cases, five percent of lime was even more beneficial than two percent had been.

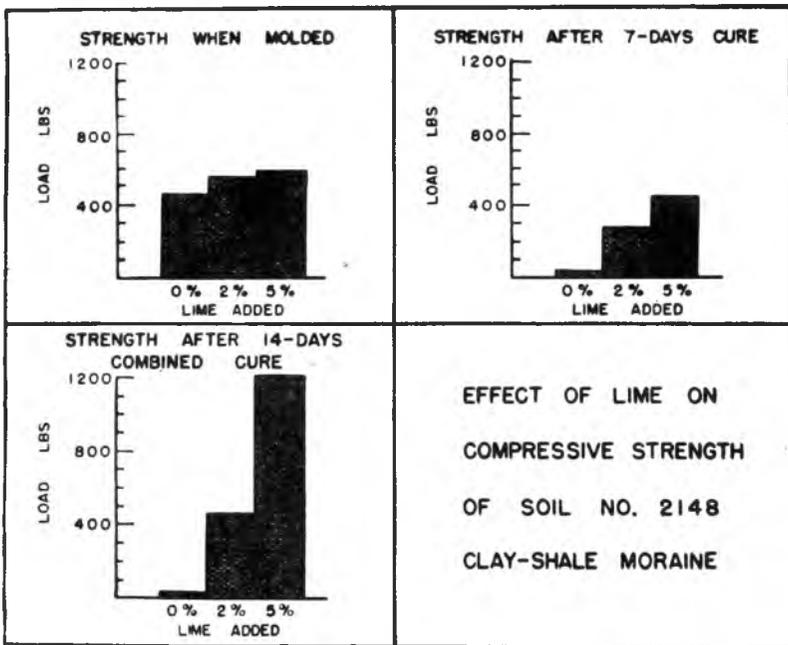


FIGURE 7. Effect of lime on compressive strength of Soil No. 2148.

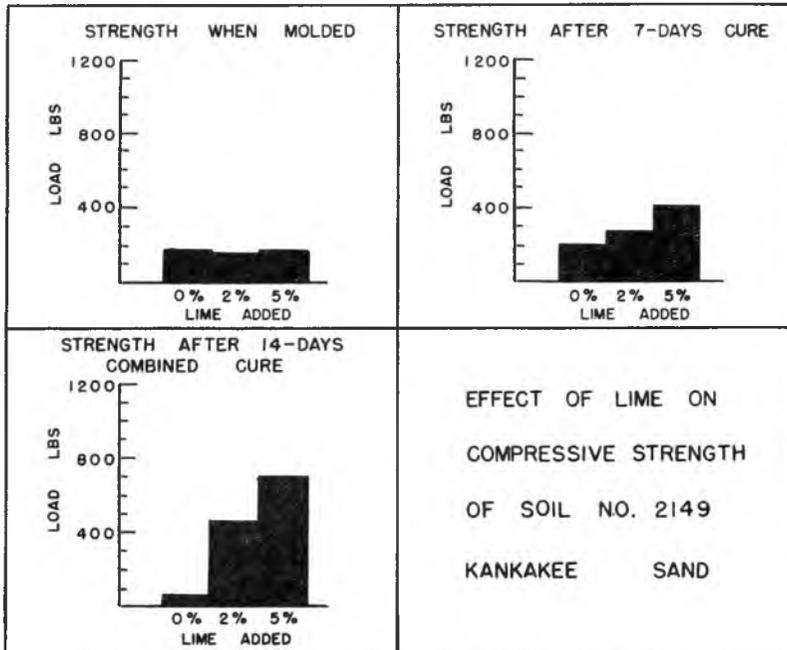


FIGURE 8. Effect of lime on compressive strength of Soil No. 2149.

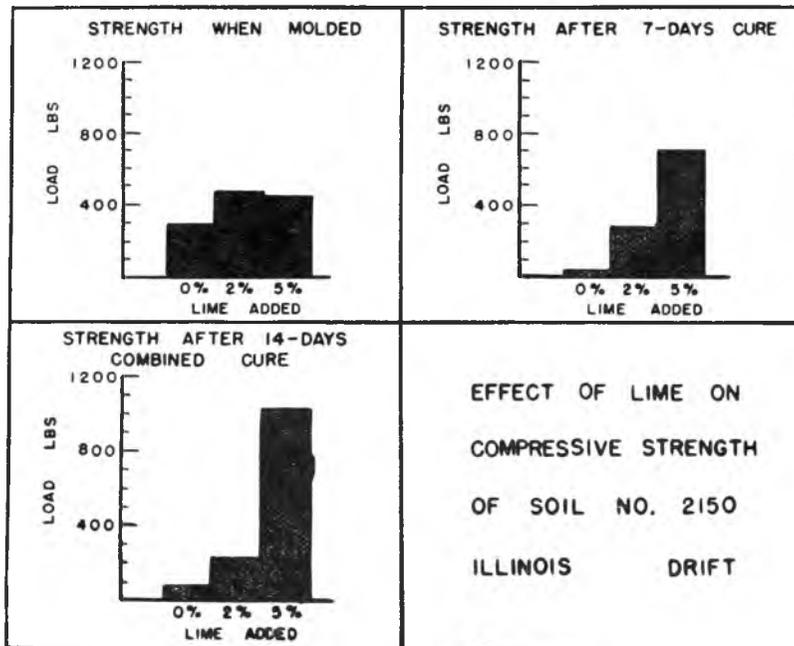


FIGURE 9. Effect of lime on compressive strength of Soil No. 2150.

STRENGTH TESTS ON GRAVELS

Among the tests which have been run on coarse-grained soils were tests with a Wabash River terrace gravel combined artificially with a binder soil to give combinations of two, five, and ten percent of material passing the No. 200 sieve. These coarse-grained base materials were molded and tested with zero, two, and five percent of lime using CBR procedures. Curing conditions were the same as followed with the coarse-grained soils except for a variation in the capillary saturation. The specimens were cured in the CBR molds, and again moisture was made available only to the bottom of the specimen. However, the head in the tank was held between an inch and two inches higher than the top of the specimen, the mold extending three inches above the top of the specimens.

TABLE 4
PARTIAL RESULTS IN POUNDS PER SQUARE INCH OF CBR TESTS
ON GRAVEL-BINDER MIXES

Soil	Percent Lime	Tested as Molded			Tested After 7-Day Soak			Tested After Drying and 7-Day Soak		
		0.1"	0.2"	0.5"	0.1"	0.2"	0.5"	0.1"	0.2"	0.5"
Gravel with 0% Binder	0	40	57	80	14	29	47	30	50	65
	2	100	110	113	37	94	90	184	219	178
	5	69	117	179	42	118	206	273	*	*
Gravel with 5% Binder	0	11	33	92	10	33	151	40	108	195
	2	22	74	213	27	94	a	93	246	a
	5	57	132	293	71	146	a	115	328	a
Gravel with 10% Binder	0	13	40	88	5	27	170	7	24	140
	2	20	65	236	26	111	*	84	240	*
	5	30	104	220	42	125	*	222	222	*

* Penetration not reached within capacity of machine, 335 psi.

Table 4 gives the results of these tests, expressing the strength in terms of pounds per square inch at penetrations of 0.1, 0.2, and 0.5 inch. Figures 10 and 11 show these results graphically for two of the gravel-binder combinations. The bars which are open at the top represent values which were not reached within the capacity of the testing machine.

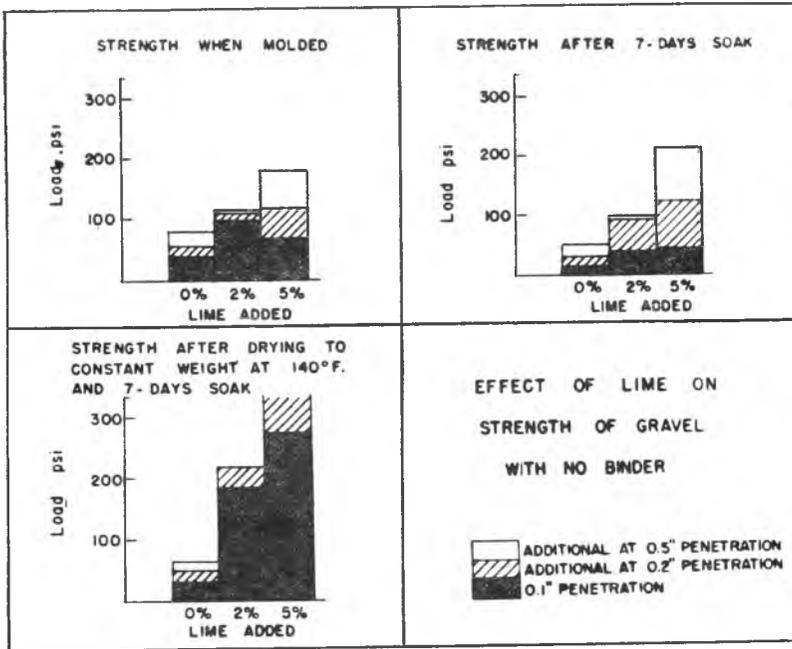


FIGURE 10. Effect of lime on strength of gravel with no binder.

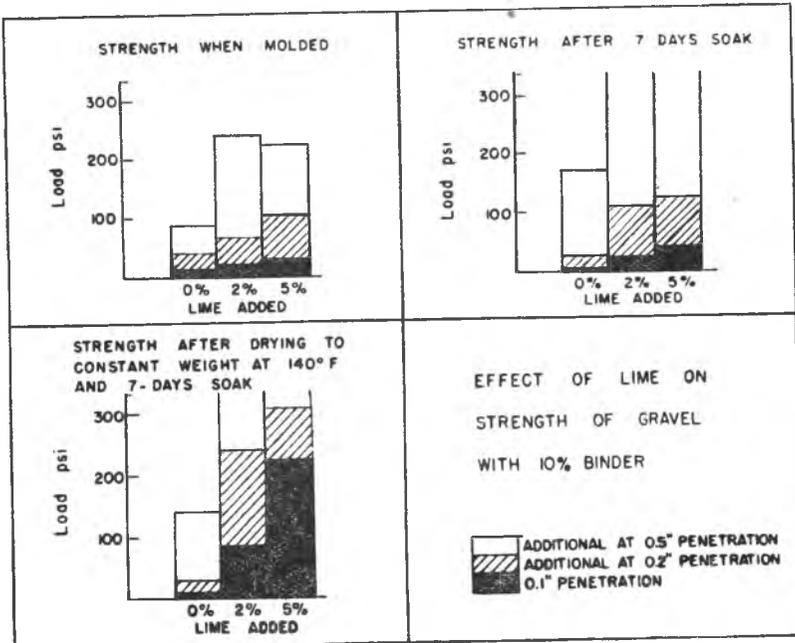


FIGURE 11. Effect of lime on strength of gravel with 10% binder.

Results here were comparable to those shown above for fine-grained soils. Even at the fresh-molded condition, the use of lime contributed to increases in strength. After the seven-day cure, and particularly after the 14-day combined cure, these increases in strength were much more marked. The greater increase in strength resulting from the combined curing cycle was much more prominent here than it was in the data on the fine-grained soils. It will be seen also that the decrease in strength of the raw soil resulting from curing was little evidenced for these gravel soils; whereas it had been notable with the fine-grained soils.

SUMMARY AND CONCLUSIONS

These results, which are borne out by results of similar tests on natural gravels and a wide variety of other soils from the eastern half of the United States (11), indicate several factors of interest to highway engineers. It may be seen that subgrade and base materials which are substandard in quality may possibly be improved by admixing small percentages of lime.

It may be possible to reduce materially the PI of particularly the more plastic soils and to make them much easier to handle and work. It is indicated that the strength and durability of most soils may be increased by using lime with them. Accompanying these benefits is the evident increased resistance to the detrimental effects of water.

Considerably more work needs to be done on studying the effects of weathering on lime-soil mixtures as resistance to alternate wetting and drying and to cycles of freezing and thawing. Field indications from Texas are that the lime-treated soils which they have used show much better supporting performance over a period of a few years than do the adjacent road sections built of raw soil.

Construction methods used to date have pretty much followed the established pattern—as used for soil-cement, for instance. Six inches of the subgrade or base material may be formed in two windrows and the lime deposited in proper amounts along on the windrows. The material in the windrows is then bladed out and thoroughly mixed, or the surface may be covered with the lime and scarified and mixed with blades. Compaction should take place at or slightly below the optimum and should be accomplished soon after the moisture has been added.

The Texas district engineers have followed the practice of keeping the surface damp for three days by sprinkling, although the question of proper curing procedures is one that needs to be explored at considerable length. The fine grading should not be delayed as the lime will set and

the job becomes much more difficult. The material which is scraped off during the final reshaping should be wasted rather than recombined in the roadway. The finished base will be much more waterproof than the raw soil would have been, but a thin bituminous surface will protect against abrasion as well as provide a surface seal.

In conclusion, it may be said that Indiana with its variety of poor subgrade soils, plastic drift and moraine, plastic residual soils, and poorly-graded granular soils may find that lime can provide at least part of the answer to the low-cost road problem. Experience indicates that the plasticity of the more plastic clays will be reduced by using lime and that most soils will be benefited in the realm of strength and of resistance to the leaching effects of water. It should be emphasized, however, that research with lime is still in the experimental stage, and any contemplated field project should be preceded by careful laboratory work on the actual soil in question.

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