Experimental Lime Stabilization in Nebraska

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In 1956, the Nebraska Department of Roads constructed an experimental project using hydrated lime in the stabilization of plastic subgrade soils, and in the upgrading of inferior base course materials. A previous report (1) gave early details of this project. This paper reports and summarizes the tests and observations made since construction. From the 10-year study conducted on this experimental project it was concluded that hydrated lime is a suitable material to improve plastic subgrade soils and to use as an admixture to upgrade inferior base course materials.

•IN 1956, Nebraska became interested in hydrated lime for use in the stabilization of soils and base materials. As a result of laboratory studies, an experimental project, including a lime-treated subgrade soil section and a lime-treated base course section, was constructed that summer. The project, a part of US 136, is located west of Tecumseh, in Johnson County about 60 miles south and east of Lincoln.

In 1959, a paper was published (1) giving details of the preliminary field investigation, the laboratory study, design, location of the two test sites within each subdivision, preconstruction sampling, construction procedures, cost data, post-construction sampling and testing, and discussion of results.

Since construction the following observations have been made:

1. Field sampling and laboratory testing—intermittent basis.
2. Benkelman beam deflection tests—spring and fall of each year, 9-kip wheel load.
3. Cracking survey—fall of each year.
4. Wheel path depression survey—fall of each year. Measurements obtained by measuring the amount of space between a 7-ft metal straightedge and the surface of the asphaltic concrete on 1-ft intervals; final measurements were taken with a level.
5. General condition survey—fall of each year.

In this report, the results of this study are summarized in two main sections:

1. Lime-treated subgrade soil—design of the four 1500-ft subdivisions is given in Table 1. The treated subgrade soils were glacial clays having an AASHO soil classification range of A-6 (11) to A-7-6 (17).
2. Lime-treated base course—Table 1 gives the design of each subdivision. The granular material was a local coarse sand. Aftonian silt is an interglacial wind-blown layer deposited between the Nebraskan and Kansan glacial stages.

LIME-TREATED SUBGRADE SOIL

Laboratory Soils Tests on Field Samples

During the field investigation, the plan had been to run unconfined compressive strength and routine soil tests on undisturbed cores. However, attempts to obtain cores using diamond and carbide-tungsten tipped core barrels in combination with wet and dry drilling techniques proved unsuccessful. In the 3 percent lime-treated subdivision undisturbed samples were taken by pushing a 3- by 4-in. sampling tube

Paper sponsored by Committee on Lime and Lime-Fly Ash Stabilization and presented at the 48th Annual Meeting.

TABLE 1

DESIGN OF EXPERIMENTAL SECTIONS

Lime-Treated Subgrade Soil Section				
Subdivision Number	1	2	3	4
Station to station	1047 to 1062	1062 to 1077	1077 to 1092	1092 to 1107
AC surface course, in.	3	3	3	3
Soil-agg. base co., in.	4	4	4	4
Granular subbase co., in.	7	None	None	None
Subgrade treatment, in.	None	7	7	7
Lime, %	None	3	6	10
Remarks	Standard design	—	—	—

Lime-Treated Base Course Section				
Subdivision Number	5	6	7	8
Station to station	1048 to 1061	1161 to 1174	1174 to 1187	1187 to 1200
AC surface course, in.	3	3	3	3
Soil-agg. base co., in.	4	None	None	None
Lime-Aftonian silt base co., in.	None	6	6	6
Aftonian silt, %	None	15	20	20
Lime, %	None	2	4	7
Granular subbase co., in.	7	5	5	5
Remarks	Standard design	—	—	—

into the treated material. Since vertical cracks developed in the cores, unconfined compressive strength tests were not run. In the sections containing higher precentages of lime, the material was too hard to obtain samples in this manner; therefore, all testing was confined to disturbed samples.

The preliminary laboratory phase indicated that lime treatment apparently causes the agglomeration of some of the silt and clay-size particles with the net result that the soil is somewhat coarsened. However, it should be pointed out that the particles were weakly bonded and that by varying the mechanical mixer agitation period the results of the tests could be changed. For this reason, a standard 5-min agitation period was established. More than usual grinding and crushing was required during sample preparation because of the hardness of the field samples. This extra manipulation probably resulted in further breakdown of the particle bonds. Therefore, it is believed that the soil tests performed on the lime-treated samples should be considered only as approximations. Some observations of the hydrometer tests, on samples taken from the subgrade (Table 2), may include: (a) all testing periods show that the most

TABLE 2

AVERAGE LABORATORY TEST RESULTS: LIME-TREATED SUBGRADE SOILS

No. Days Cure	No. of Tests	Hydrometer Tests: Sand +0.074 mm	Hydrometer Tests: Silt 0.074 to 0.005 mm	Hydrometer Tests: Clay -0.005 mm	Plasticity Tests: LL	Plasticity Tests: PI	Field Moisture Equiv.	Shrinkage Limit	Shrinkage Ratio	Volumetric Change	Lineal Shrinkage
(a) 3 Percent Lime-Treated Subgrade Soil											
Raw soil	2	23	42	35	45	24	24.40	12.47	1.85	22.07	6.4
16	6	44	45	11	38	9	30.99	21.35	1.58	15.23	4.6
600	4	39	55	6	38	8	34.00	21.80	1.57	19.15	5.7
2600	3	26	62	12	38	13	—	—	—	—	—
3850	6	22	55	23	38	14	33.70	17.70	1.71	27.36	7.8
(b) 6 Percent Lime-Treated Subgrade Soil											
Raw soil	2	16	56	28	42	23	23.45	15.34	1.78	14.44	4.4
16	6	52	47	1	NP	NP	36.46	25.53	1.45	15.85	4.8
600	4	59	40	1	NP	NP	38.25	27.51	1.41	15.14	4.6
2600	3	49	47	4	NP	NP	—	—	—	—	—
3850	6	39	51	10	NP	NP	35.35	28.23	1.41	10.04	3.1
(c) 10 Percent Lime-Treated Subgrade Soil											
Raw soil	2	13	55	32	43	22	23.35	14.49	1.80	15.95	4.8
16	6	42	58	0	NP	NP	39.46	26.44	1.37	18.08	5.4
600	4	57	42	1	NP	NP	41.30	29.60	1.32	15.44	4.7
2600	3	—	—	—	NP	NP	—	—	—	—	—
3850	6	39	51	10	NP	NP	36.27	26.58	1.45	14.05	4.3

pronounced effect of hydrated lime is the reduction of the percentage of clay-size particles and an increase in sand, (b) in all three lime-treated subdivisions (3, 6 and 10 percent) there appears to be a loss of the bonding effect of the lime with the passage of time, and (c) all tests seem to indicate that the effects of treatment with 6 and 10 percent lime are essentially the same.

One of the most publicized features of lime is its ability to reduce the plasticity index of soils. However, there has been much discussion concerning this phenomenon since some believe this reduction to be permanent while others feel that eventually there will be some increase in the plasticity index. Table 2 indicates that all tests in the 6 and 10 percent lime-treated subdivisions show the soils to be nonplastic following the lime treatment. The plasticity index of the soil treated with 3 percent hydrated lime was reduced from 24 to 9 in 16 days and to 8 in 600 days. However, the 2,600 and 3,850 day tests show that the plasticity index has increased to 13 and 14, respectively. This may indicate that when small percentages of lime are used in the treatment of glacial clays of the type and in the environment found on this project, early reduction in the plasticity index may be subject to a reversal with the passage of time.

The results of the field moisture equivalent and shrinkage tests are somewhat erratic (Table 2). Even though the trends are difficult to ascertain, it does appear that hydrated lime causes definite changes in the field moisture equivalent, shrinkage limit, and shrinkage ratio. However, the effect is not clear-cut on the volumetric change and lineal shrinkage characteristics.

Benkelman Beam Deflection Tests

On each test site (2 per subdivision) Benkelman beam deflection tests were made on the inside and outside wheelpaths during the spring and fall periods from December 1956 to October 1966. The seasonal Benkelman beam deflection tests fail to reveal a

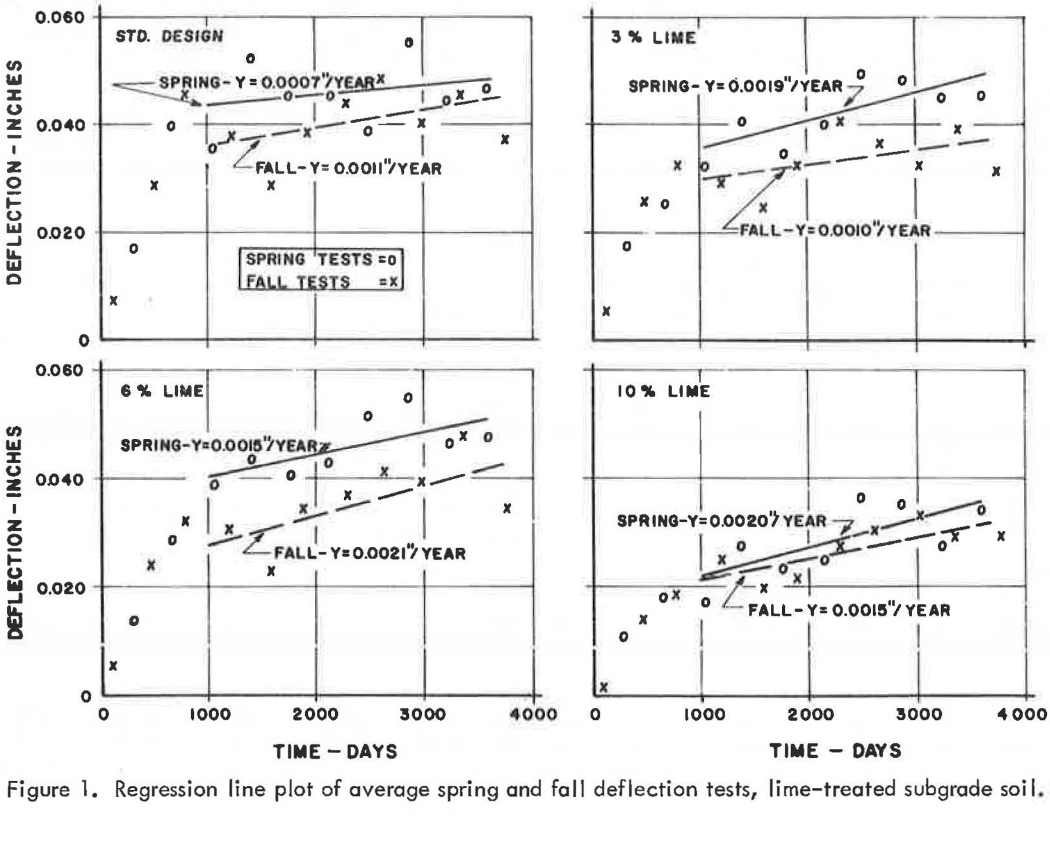

Figure 1. Regression line plot of average spring and fall deflection tests, lime-treated subgrade soil.

well-defined relationship between percentage of lime and deflection. However, the outer wheelpath (OWP) deflection values in the 10 percent lime-treated subdivision are lower than those of the other subdivisions.

To summarize the data for each design, a spring and fall deflection value was calculated, using an average value of the tests taken in both wheelpaths. Figure 1 shows that during the first five testing periods there was a decided increase in deflection. Tests taken after the fall of 1958 show a general increase but at a much slower rate. Since the subgrade was extremely dry at the time of construction, the change in slope of the deflection versus time trend may be due to the increase in the moisture content of the subgrade soil. Using the deflection values of the tests taken between spring 1959 and fall 1966, first degree polynomial curves were computed, using an IBM model 1620 computer. After study of the data (Fig. 1) some possible observations are:

1. The regression lines indicate that there is clearly an increase in deflection with the passage of time and the application of vehicular traffic for all four of the experimental subdivisions;
2. The spring regression line for the standard design subdivision (0 percent lime) is flatter than the corresponding lines developed for the lime-treated subdivisions;
3. The increase in the spring deflection values above the fall deflections for the 10 percent lime-treated subdivision is smaller than for the other subdivisions; and
4. The spring and fall regression lines for the 10 percent lime-treated subdivision plot below those developed for the other subdivisions; however, when the regression line slopes are compared, there appears to be no relation between slope and percent lime used.

Transverse and Longitudinal Cracking

During the 10 years that this project was under observation, a careful record as to the amount of yearly cracking was kept. An accumulative total of the data is shown in

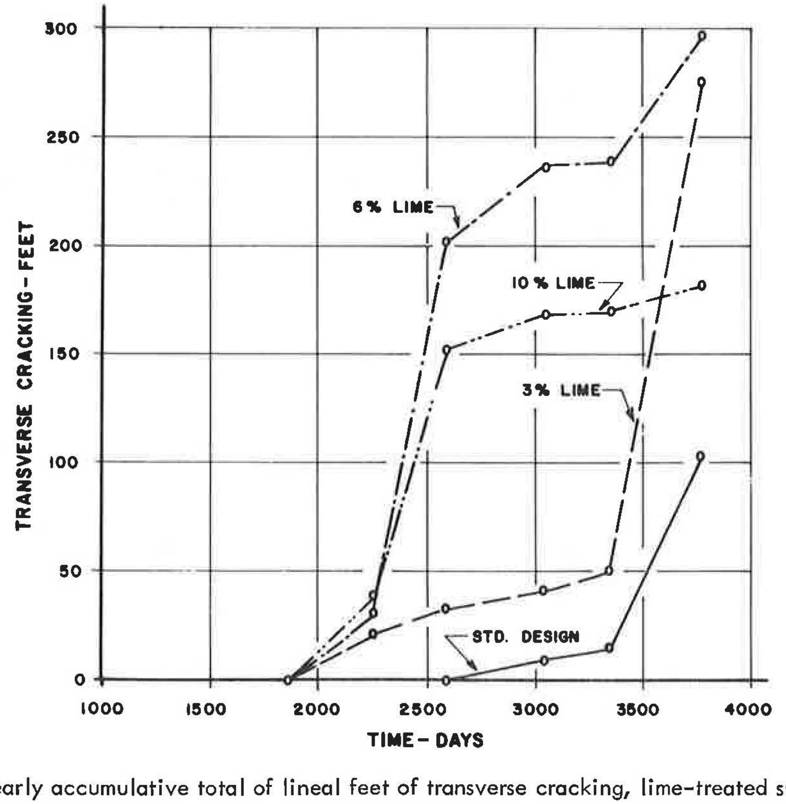

Figure 2. Yearly accumulative total of lineal feet of transverse cracking, lime-treated subgrade soil.

Figure 2. No longitudinal cracking was found in the top lift of the asphaltic concrete in any of the subdivisions.

Transverse cracking was first noted in all of the lime-treated subdivisions in the sixth year after construction. It was not until the eighth year that cracking began to occur in the standard design subdivision.

From Figure 2, some observations of the cracking pattern at the end of the 10-yr period may include:

1. There is less cracking in the standard design subdivision than in the lime-treated subdivisions;
2. Less cracking occurred in the 10 percent lime-treated subdivision than in either the 3 or 6 percent lime-treated subdivisions;
3. The accumulative total cracking in the 3 and 6 percent subdivisions is approximately the same; and
4. The crack survey data show no relationship between cracking and percent lime used.

Wheelpath Depression

To determine if rutting was in the consolidation or displacement of the asphaltic concrete, or in one of the underlying courses, or a combination of these, thickness measurements were made of each course, at 1-ft intervals, across the 22-ft surface at both test sites in each subdivision. Some difficulty was encountered in taking the measurements due to the inability to distinguish a marked difference at the contact between similar courses, e.g., soil aggregate base course and the granular subbase, lime-treated soils and untreated soils. From the average of these measurements and a surface survey a transverse cross section was plotted for each subdivision (Fig. 3). From this plot it will be noted: (a) for the standard design, some of the surface rutting is reflected in the soil aggregate base course and quite possibly in the granular

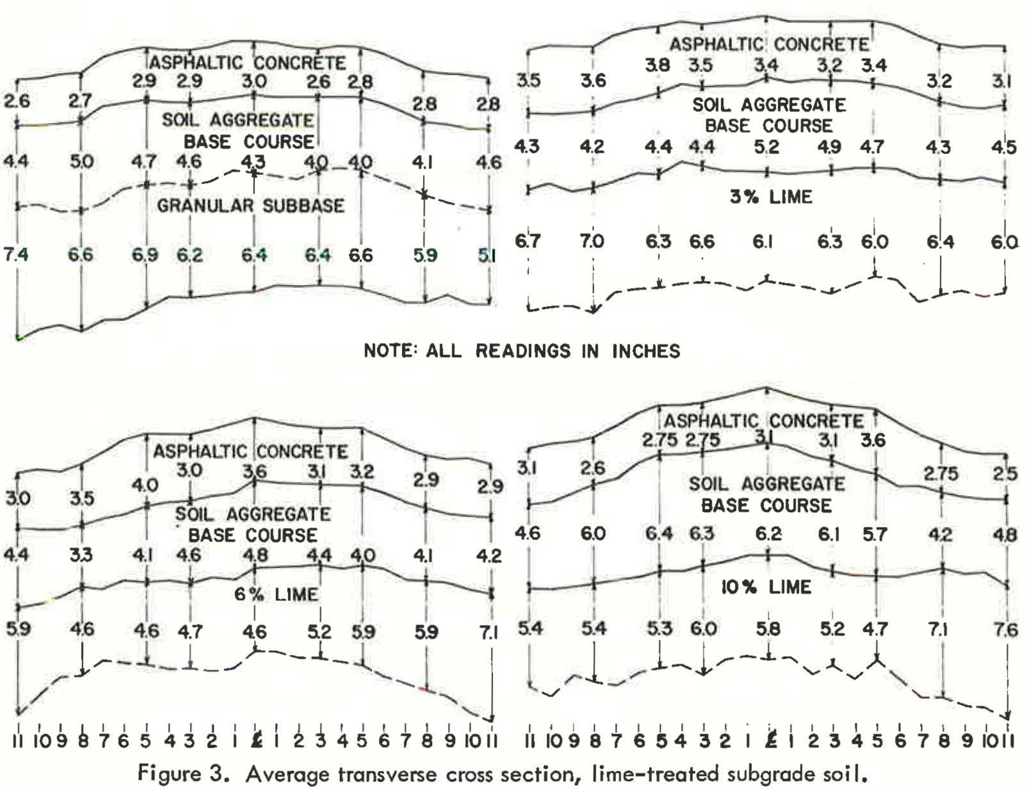

Figure 3. Average transverse cross section, lime-treated subgrade soil.

subbase; and (b) for the 3, 6 and 10 percent lime-treated soils, it appears that the surface rutting extends into the soil aggregate base course in all the lime-treated subdivisions. Since the original cross section of the lime-treated courses were not taken it is difficult to ascertain if rutting extends into this layer. However, from examination of the measured sections it appears that little if any rutting occurs in the lime-treated courses.

General Surface Condition

During the years that this project was under observation, in addition to the transverse and longitudinal cracking record, notations were made of other types of surface failure, for example, map or alligator cracking, distortion, and raveling. From completion of construction in the fall of 1956 through November 1962 no failures occurred and no maintenance other than crack filling was required.

The following is a yearly resume of failures which occurred after 1962.

1963 Failures

1. Standard design subdivision: none.

2. Lime-treated (3 percent) subdivision: 50 ft of excessive rutting in the OWP of the right lane caused by displacement of the soil aggregate base course; no movement was detected in the lime-treated subgrade soil.

3. Lime-treated (6 percent) subdivision: two areas (90 and 75 ft) of excessive rutting were found in the OWP of the right lane. Wheelpath depression measurements showed as much as 1.8 in. of rutting in both areas. Deflection measurements in both failed areas were higher than the subdivision OWP average. In one of the failed areas, a transverse trench about 18 in. wide and 24 in. deep was dug to determine the cause of the excessive rutting. From measurements and visual inspection, it was found that the rutting was caused by movement and subsequent thinning (1.8 in.) of the soil aggregate base course. No depression or movement was detected in the lime-treated subgrade soil. Holes bored in the other failed area showed a definite thinning ($1\frac{3}{4}$ in.) of the soil aggregate base course. Again no movement in the lime-treated subgrade soil was detected.

4. Lime-treated (10 percent) subdivision: none.

1964 Failures

1. Standard design subdivision: none.

2. Lime-treated (3 percent) subdivision: short failure due to fill settlement over a culvert.

3. Lime-treated (6 percent) subgrade: none.

4. Lime-treated (10 percent) subgrade: none.

1965 Failures

1. Standard design subdivision: six areas of map cracking, ranging in length of from 10 to 74 ft, were found in the OWP of the left lane. Depression measurements showed that excessive rutting was occurring in all of these areas. Benkelman beam deflection tests, taken on each side of the map cracked areas, were higher than the subdivision average. Some displacement of both the soil aggregate base course and granular subbase was noted.

2. Lime-treated (3 percent) subdivision: none.

3. Lime-treated (6 percent) subdivision: none.

4. Lime-treated (10 percent) subdivision: none.

1966 Failures

1. Standard design subdivision: two short (8 and 13 ft in length) map-cracking areas were noted in the OWP of the left lane. Investigation of these areas indicated that there was some displacement of the underlying granular base courses.

TABLE 3

UNCONFINED COMPRESSIVE STRENGTH LIME-TREATED BASE COURSE

Number Days Cure	Unconfined Compressive Strength (psi)								
	2% Lime-Treated Base			4% Lime-Treated Base			7% Lime-Treated Base		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
600[a]	—	—	165 (1)[b]	430	745	587 (2)	405	795	600 (2)
1380	—	—	—	—	—	—	870	2310	1590 (2)
2580	—	—	—	—	—	—	1690	2010	1850 (2)
3810	—	—	—	559	3065	2030 (6)	1432	3249	2080 (9)

[a]2- by 2-in. cube cut from 12-in. diameter core. [b]Number in parentheses is number of tests.

2. Lime-treated (3 percent) subdivision: four map-cracked areas, varying in length of from 6 to 51 ft, were noted. Investigation showed a thinning of the soil aggregate base course. There was no indication of movement in the lime-treated subgrade soil.
3. Lime-treated (6 percent) subdivision: none.
4. Lime-treated (10 percent) subdivision: none.

LIME-TREATED BASE COURSE

Laboratory Tests on Field Samples

Due to the cementing properties of hydrated lime, when added to Aftonian silt-course sand mixtures, it was planned that the principal laboratory test to be performed on field samples would be the unconfined compressive strength test. The most successful method found to take cores was that of using a 4-in. diameter diamond tipped core barrel and wet drilling. However, this technique met with only limited success (Table 3).

Table 3 gives the minimum, maximum and average unconfined compressive strengths of the cores tested. It will be noted that: (a) the difference in the average 10-yr strength between the 4 and 7 percent lime-treated subdivisions is insignificant; (b) the lime-treated base material in the 2 percent subdivision was not cemented strongly enough to obtain cores; and (c) in the 7 percent lime-treated subdivision the average unconfined compressive strength shows an increase with each testing period.

Benkelman Beam Deflection Tests

For the 10-yr observation period Benkelman beam deflection tests were made on the inner wheelpath (IWP) and outer wheelpath during the spring and fall of each year. The deflections taken between the fall of 1956 and the spring of 1959 show more abrupt increases in deflection than those taken after this period. This change in the slope of the deflection versus time trend may be due to the increase in the moisture content of the subgrade soil. The seasonal deflection values for both the IWP and OWP show the expected relationship between lime content and deflection, that is, highest deflection for the 2 percent lime, lower deflection for the 4 percent lime, and lowest deflection for the 7 percent lime. The deflection for the standard design subdivision is sometimes higher than the 2 percent subdivision but usually falls between the values of the 2 and 4 percent lime-treated subdivisions.

The points in Figure 4 are averages of the IWP and OWP deflection values for the spring and fall. The plotted regression lines are first degree polynomial curves calculated from the tests taken between spring 1959 and fall 1966. Some observations of the data are (a) except for the spring regression lines in the standard design subdivision which show a slight downward trend, all regression lines indicate an increase in deflection with the passage of time; (b) the regression line slopes of the 2 and 4 percent lime-treated subdivisions are steeper than those of the standard design or 7 percent lime-treated subdivisions; (c) the standard design regression lines show the smallest yearly deflection increase of any of the subdivisions; (d) in the 7 percent lime-treated subdivision the fall regression lines plot above the spring lines (the yearly rate of deflection increase shows these lines to be parallel); and (e) the regression line plots do not

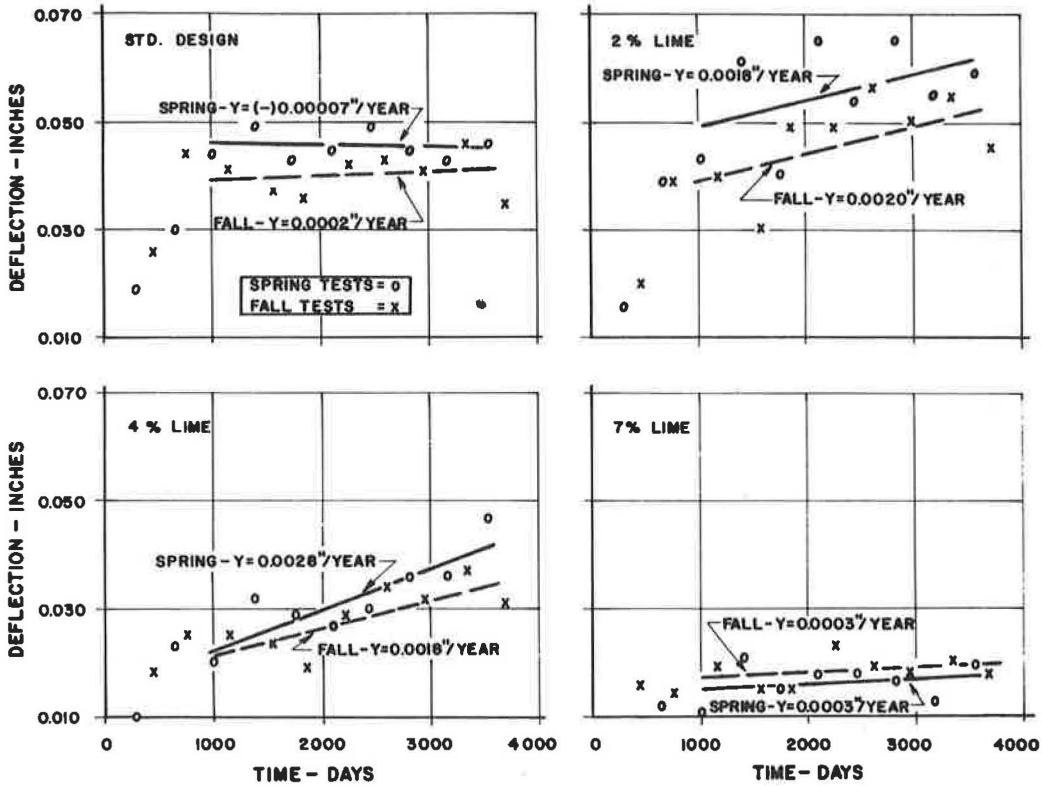

Figure 4. Regression line plot of average spring and fall deflection tests, lime-treated base course.

indicate a clear relationship between slope and percentage of lime used. However, when the 7 percent lime-treated base course deflection values and resultant regression line plots are compared with the same data obtained for the other lime-treated subdivisions a definite improvement in supporting capability is apparent.

Longitudinal and Transverse Cracking

During the 10-yr observation period only a small amount of longitudinal cracking was observed: 2 percent lime-treated base = (1961) 39 ft and (1962) 2 ft; 4 percent lime-treated base = (1961) 117 ft. In all cases the cracking occurred in the right traffic lane (eastbound), about 1 ft from the edge of the top lift of the asphaltic concrete. It is believed that the cracking which occurred in 1961 might have been due to unusually heavy loads hauled to a nearby Atlas missile site which was under construction.

The 10-yr cumulative transverse cracking total is plotted in Figure 5. Transverse cracking was first observed in the 4 percent lime-treated subdivision in 1959 and in the 2 and 7 percent subdivisions in 1961. It was not until 1966 that cracking was noted in the standard design subdivision and then only two cracks of 2 and 3 ft were found. It appears that all lime sections are equally susceptible to the cracking tendency. However, due to the more rigid nature of the lime-treated bases, it was not unexpected that more cracking occurred in them than in the standard design subdivisions.

At a number of locations in all three lime-treated subdivisions, cores were taken over the cracks. In every instance, in the 4 and 7 percent subdivisions, the cracks extended through the lime-treated base course. Since cores could not be taken in the 2 percent subdivision and examination of the core hole sides did not show any evidence of cracking it is not known if cracks extended through the base material.

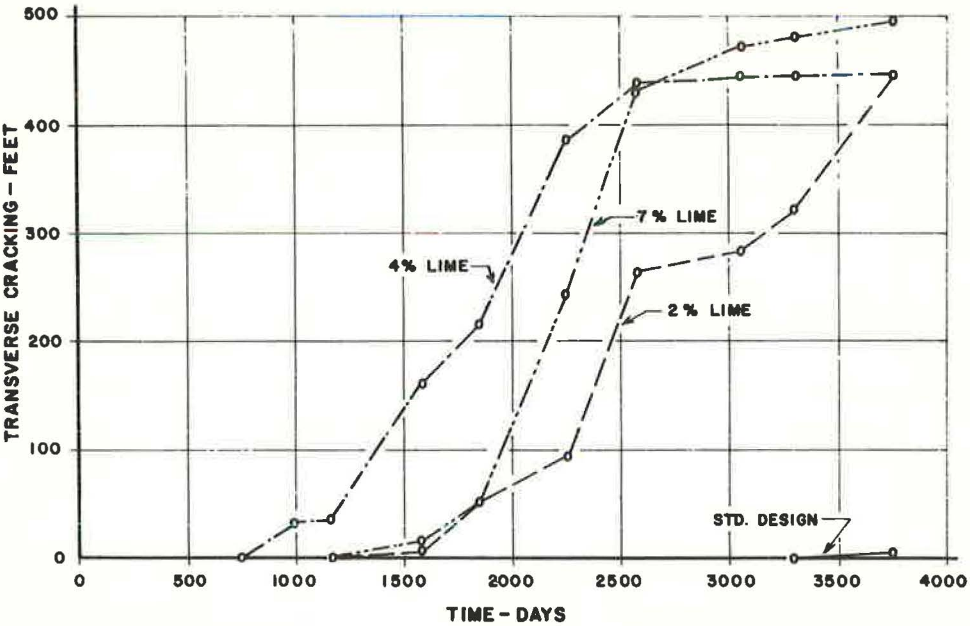

Figure 5. Yearly accumulative total of lineal feet of transverse cracking, lime-treated base course.

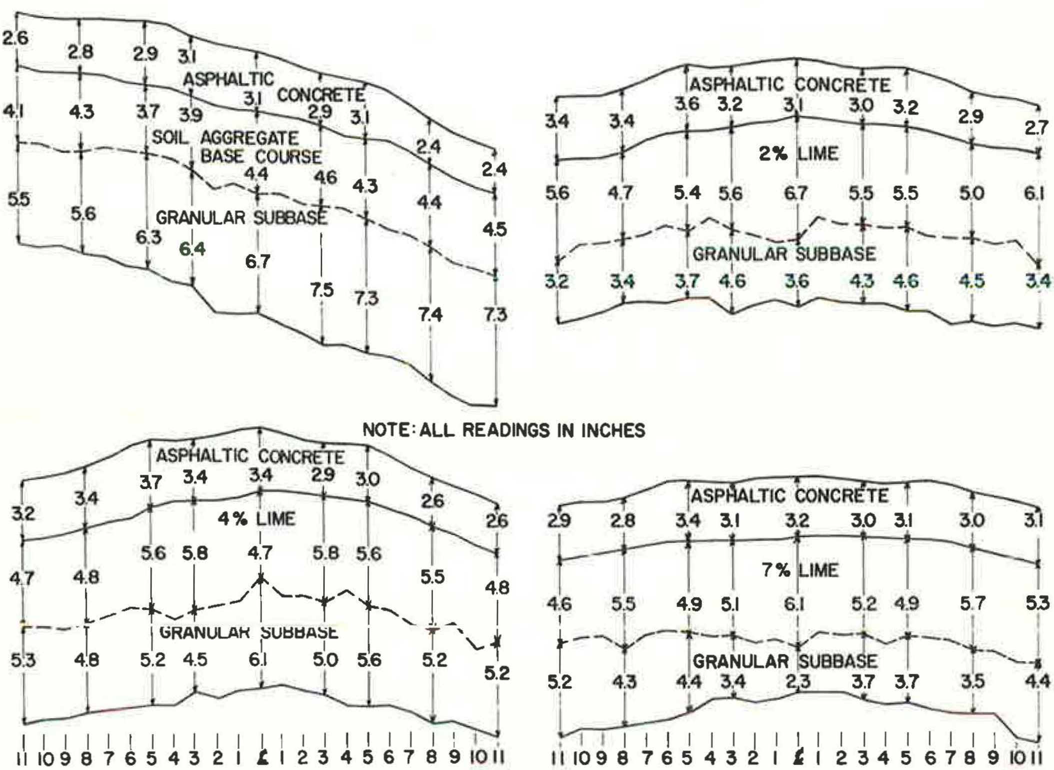

Figure 6. Avearage transverse cross section, lime-treated base course.

Wheelpath Depression

To determine the extent of displacement in each layer, thickness measurements of the asphaltic concrete and underlying courses were made at 1-ft intervals. In all of the subdivisions, some difficulty was encountered in determining the contact between the base courses. A transverse cross section was plotted for each subdivision from the averages of these measurements and data obtained with a surveyor's level. From Figure 6, it will be noted:

1. Standard design: surface rutting extends into the soil aggregate base course; it is also believed that there may be some displacement in the granular subbase course.
2. Lime-treated (2 percent) base: some of the surface rutting is reflected in the underlying lime-treated base; it is doubtful if the granular subbase is displacing.
3. Lime-treated (4 percent) base: from study of the cross section, it appears that a slight amount of the rutting in the left lane may extend into the lime-treated course. In the right lane, it is doubtful if rutting extends into this course. It is not believed that the irregularities occurring in the granular subbase are the result of the surface ruts.
4. Lime-treated (7 percent) base: only a slight amount if any of the surface rutting is reflected in the lime-treated course.

General Surface Condition

Condition surveys were made on each subdivision at least once a year. A record was kept on the amount of map cracking, distortions or other types of failures. The results of the survey in each subdivision follows.

Standard Design

None, 1956 through 1966.

2 Percent Lime-Treated Base Course

None, 1956 through 1965.

In 1966, two map-cracked areas 8 and 10 ft in length were noted in the OWP of the left lane. Deflection tests taken adjacent to these areas were the same as the subdivision average (OWP—0.058 in.). Wheelpath depression measurements in these areas were about 0.1 in. deeper than the left lane, OWP average of 0.52 in. Measurements in holes bored in these areas did not indicate any noticeable thinning of the lime-treated base material.

4 Percent Lime-Treated Base Course

None, 1956 through 1964.

In 1965, eight feet of map cracking was found in the OWP of the right lane; the cause of this failure could not be attributed to the lime-treated base course.

None, 1966.

7 Percent Lime-Treated Base Course

None, 1956 through 1966.

CONCLUSIONS

The following conclusions are based on tests and observations made during the ten-year study.

Lime-Treated Subgrade Soil

1. The results of the soil tests are somewhat inconclusive. However, it appears that more long-range benefit may be gained when 6 to 10 percent lime is added than when smaller percentages are used.

2. The Benkelman beam deflection tests fail to reveal a well-defined relationship between percentage of lime and deflection; however, from the deflection tests and regression line plots the following summarizes the best performance rating of the four experimental subdivisions: (a) deflection magnitude, 10 percent lime; (b) rate of deflection increase, standard design; (c) relationship of spring to fall deflection, 10 percent lime; and (d) projected 15-yr deflection, 10 percent lime.

3. All lime-treated subdivisions were more susceptible to transverse cracking than the standard design subdivision.

4. In the lime-treated subdivisions no failure could be attributed to the inability of the lime-treated course to perform its function.

5. As a result of this project, it was concluded that hydrated lime is a suitable stabilizing agent to improve plastic subgrade soils.

Lime-Treated Base Course

1. The difference in the average 10-yr unconfined compressive strength between the 4 and 7 percent lime-treated base course material is insignificant.

2. When only 2 percent hydrated lime is added to the base material, it appears that little if any strength is gained through the cementing properties of the lime.

3. The seasonal deflection values are inversely proportional to the percentage of lime used. The deflections in the standard design subdivision usually fall between the values of the 2 and 4 percent lime-treated subdivisions. On the basis of the deflection tests and regression line plots the following summarizes the best performance rating of the four experimental subdivisions: (a) deflection magnitude, 7 percent lime; (b) rate of deflection increase, standard design; (c) relationship of spring to fall deflection, 7 percent lime; and (d) projected 15-yr deflection, 7 percent lime.

4. The lime-treated base courses appear to be more susceptible to cracking than the untreated base course.

5. Except for a slight amount of map cracking which developed in the OWP of the 2 and 4 percent lime-treated subdivisions, no failures occurred in any of the subdivisions.

6. It appears that hydrated lime is a suitable material to use as an admixture to improve the performance of inferior base course materials. Apparently more benefit is derived when 4 to 7 percent lime is added to the base material than when lesser amounts are used.

ACKNOWLEDGMENTS

This investigation was conducted by the Division of Materials and Tests, Nebraska Department of Roads, in cooperation with the United States Department of Transportation, Bureau of Public Roads. The work was performed as Project No. HPR-1, 63-10A, Part II, Research. The authors appreciate the opportunity to summarize and report the results of this cooperative effort.

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Bureau of Public Roads.

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