Lime Stabilization Using Preconditioned Soils

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The scope of this investigation was to study the development of a new method of base construction using lime stabilization with a different concept than the conventionally accepted ones.

In this construction method, a first application of lime is used to condition the soil constituents; a second, to stabilize the conditioned material. This new method was adopted after a study of different soil-lime projects and their laboratory tests, the main objective being subsequent failures and their reasons. All tests, and field experience, led to the conclusion that to obtain the desired properties of stabilization with these types of soils they must be treated with lime before being stabilized and must be compacted within 48 to 72 hr after the second application of lime.

A further time study of the soil-lime reaction was made, based on information yielded by the soil characteristics tests. These tests revealed that lime has an initial reaction, taking place during the first 48 to 72 hr after mixing, and a secondary reaction, which starts after this period and continues indefinitely.

Also, an investigation of moisture-density relations of soils pointed out the effectiveness of conditioning before stabilization. Conditioned material produced higher densities at lower moisture contents after stabilization.

● THE SCARCITY of select material in Louisiana has imposed on the highway builder the necessity of finding an admix which would make possible the economical use of the local soil deposits for base construction. The use of soil-lime stabilization for this purpose was explored, and a number of roads were built with lime stabilized bases. The construction of these roads, however, produced various technical problems, which aroused questions in the minds of Louisiana engineers as to the value of lime stabilization. Therefore, the latter practice was abandoned for a period of three years pending further studies.

In 1957, a study was undertaken by Louisiana Department of Highways to evaluate the lime stabilized bases. The performance of these bases was investigated in relation to their construction methods, maintenance, traffic conditions and materials test results.

Date yielded by this study showed that the primary reasons for the failure of a lime stabilized base were poor mixing and delay in compaction after the completion of the mixing.

Based on the knowledge gained from this investigation, a base was designed in one of the problem areas of Louisiana; and a new construction method was developed.

The new procedure called for two applications of lime; the first, to condition the soil, and the second to serve as the actual stabilizing agent.

This paper summarizes results of the condition surveys of old bases and presents the new method of construction, its application, the end-product and test results.

Prior to this time, all soil-lime construction had been built under specifications which called for the soil to be scarified, pulverized and lime applied to it in one operation (1). Mixing was continued until such time as the pulverized soil, exclusive of gravel or stone, when tested by laboratory sieves, met the following gradation requirements:

Sieve	Percent Passing (by dry weight)
½-in.	100
No. 4	60

After this requirement was met, compaction operation was started. Projects constructed under these provisions can now be divided into two groups (Table 1).

Group One—projects in this group were constructed where the soil-lime base was compacted within 48 hr after mixing.

Group Two—projects in this group were constructed where the soil-lime base was compacted within 48 hr or more after mixing.

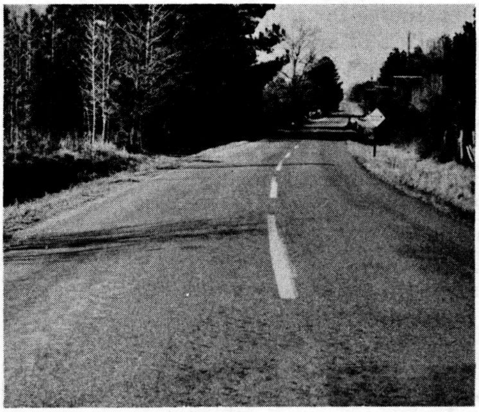

Figure 1. Condition of the Sykes-Grayson road after three years of service.

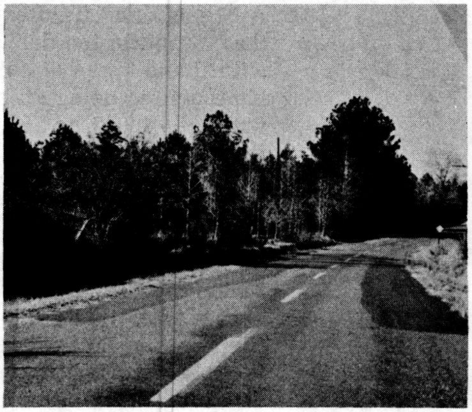

Figure 2. Surface failures and good maintenance work done on patching Sykes-Grayson road.

TABLE 1

EVALUATION CHART

Name	Date Constructed	% Lime by Weight	Group 1	Group 2	Failures Surface	Failures Base	Remarks
McCall-White Castle	1957	3		X	X	X	Compacted 5 days after mixing,
Labadieville-Paincourtville	1957	3		X	X	X	roadway generally in fair condition. Localized base failures.
Sikes-Grayson	1956	3	X		X		Roadway in very good condition. (Figs. 1 & 2)
Milhaven-Swartz	1955	3	X		X	X	No shoulders, base failures. Failure areas do not have any lime as a result of poor mixing. (Fig. 3)
Oak Grove-Lake Providence	1957	3		X	X	X	Some of the base failures are attributed to poor subgrade condition. (Fig. 4)
Newellton Road	1957	3		X	X	X	No Shoulders, generally the road is in a good condition. (Fig. 5)

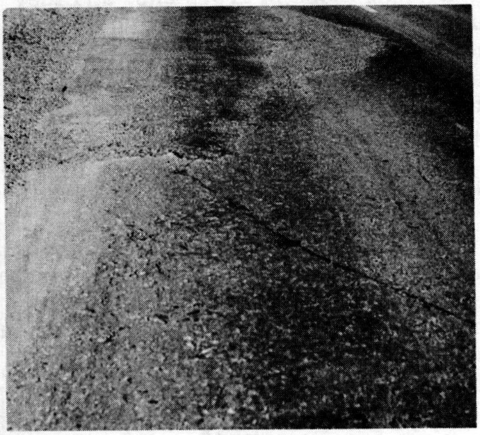

Figure 3. Base failure areas of Milhaven-Swartz road.

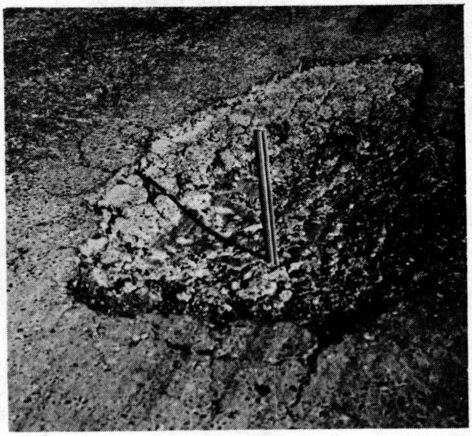

Figure 4. Base failure on Oak Grove-Lake Providence road.

Figure 5. Condition of the Newellton road after two years of service.

Figure 6. Condition of Highway 14 at Holmwood during the winter of 1958.

GROUP 1

Base material of the roads included in this group was pulverized, mixed and compacted immediately after the mixing. As of this date, these bases have been in service from 2 - 4 yr, yet they exhibit few surface failures and fewer base failures. Surface failures consist of shoving and subsequent cracking of the surface. Surface failures of well maintained roads have not affected the base.

Base failures have occurred where the full design depth was not stabilized, generally due to poor mixing.

GROUP 2

During the construction of these roads, lime was mixed with the base material, left open, but not compacted within 48 hr. In some cases it was compacted late because of the construction trend followed by the contractor, in others because of climatic limitations.

Surface failures in this group do not exceed in number those in group one, and they have the same characteristics. On the other hand, they have more base failures than those of group one. These failures are pronounced at the unsupported edges of those roads which have narrow shoulders. Base material is well packed, extremely crumbly, and friable; can be broken down to individual grains without any effort; and generally speaking, there was no cementation. Where the soil-lime stabilized material was confined and had full support on four sides, the bases have held up under traffic as well as those in the first group. It has exhibited the general characteristics of sand; if confined it makes a strong base, otherwise, it does not have any strength.

In conclusion, all of these projects point out the fact that if and when a soil-lime stabilized base is compacted within 48 hr after mixing, cementation takes place, and the whole base becomes a homogeneous slab, whereas, delayed compaction densifies the carbonated, friable material with no cementation (Fig. 7). Bases in the first group had the full advantage of both chemical and mechanical stabilization, while the latter group had only been stabilized mechanically, thus producing a relatively weaker base.

Sorting all of the information obtained from this investigation led to the necessity of working out a new method of construction, which would eliminate prolonged mixing and the curtailment of time before compaction.

PROJECT DOUBLE APPLICATION

About the time this study was completed, a familiar problem arose at Lake Charles, Louisiana. Approximately 18 mi southeast of Lake Charles, on State Route 14, two sections were let for construction with soil-cement stabilized bases. This construction required 210,000 cu yd of borrow material. Routine soil tests of the available borrow pits indicated that select material, which would be stabilized with portland cement, was insufficient, therefore, a change in the plans was deemed necessary.

Material from these pits was tested for suitability to stabilization with hydrated lime. Atterberg limit tests and Texas triaxial tests were run. There were four different types of soil; ranging from a sandy loam A-4 with a P.I. of 12 to a light silty A-6 with a P.I. of 27. The predominant material, a light silty clay, was tested triaxially. It produced a very high triaxial Class 1 material, with four percent lime by weight added and compacted with an effort of 13.26 ft lb per cu in.

The results of these routine tests favored lime stabilization. Therefore, a soil-lime stabilized base was designed to take the place of the previous one. The design called for a base thickness of 8 in. stabilized with 18 percent hydrated lime by volume. In the construction provisions of this road (2), measures were taken to prevent carbonation to take place before cementation. Thus, it was specified that the base be compacted within 24 hr after the final mixing, and lime applied in two separate operations. The first application was to condition the soil; prepare it for an easy, fast and most of all, uniform mixing. Otherwise, it would have been practically impossible to get a uniform mixture from the combination of clayey soils and lime within 24 hr prior to compaction, while the second application would provide enough lime for stabilization.

To decide the rate of the first and second applications of lime, another set of Atterberg limit and Texas triaxial tests were run.

Samples representing the predominant types of soils were secured and mixed with different percentages of lime, and

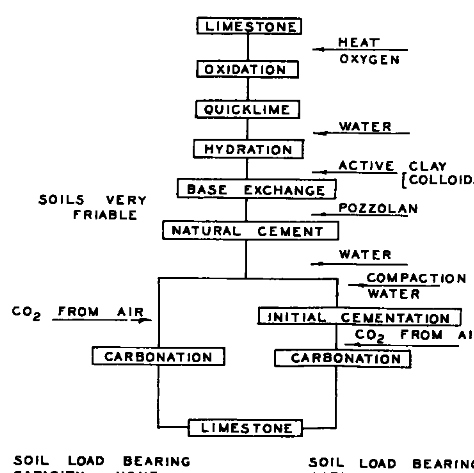

Figure 7. Flow diagram for lime stabilization.

water was added to bring the moisture content of the mix to the plastic limit of the raw soil. These specimens were put into covered pans and stored in the moist room for 72 hr. At the end of this period they were taken out of the moist room, dried at room temperature for 6 hr and broken down by hand, the only tool used being a 4-in. soft spatula.

The specimens tested represented a light silty clay A-6 with a P.I. of 27, and a sandy loam A-2 with a P.I. of 12.

In the discussion of the test results, two points were taken into consideration.

First, the amount of lime to be added during the first application should bring the plasticity index of this material down to a limit where pulverization and perfect mixing would be possible 24 hr after the second application. This limit was accepted as 10, based entirely on field experience. Second, this amount should condition the soil, but must not agglomerate all of the particles, leaving insufficient active clay for the cementation reaction to take place after the second application.

Test results indicated that the light silty clay would produce a P.I. of 8 by the addition of 9 percent lime by volume, and the sandy loam A-2 would produce the same if mixed with 6 percent lime by volume.

To confirm the base design, four sets of "double application" triaxial specimens were prepared (Table 2) using the foregoing percentages as guides, with four different types of soil, representing the entire project. All of these specimens produced a very high triaxial class 1 (Appendix).

From these test results, it was decided that both the first and the second application of lime would be 9 percent by volume.

CONSTRUCTION

The construction of this project was under the supervision of Lawrence Doucet, Project Engineer for the Louisiana Department of Highways, and the contract, dated June 17, 1957, was awarded to W.R. Aldrich and Company of Baton Rouge, La. Work was begun in July 1957, with the earthwork being started in April 1958. In January 1959, a special agreement was made between the Department and W.R. Aldrich and Company. This special agreement was made to substitute a soil-lime base course in place of a soil-cement base course as per original contract.

Treatment of the base was started in June 1959. It was decided to apply the first portion of lime throughout the entire length of the roadway and then apply the second portion of lime.

FIRST APPLICATION OF LIME

Prior to the application of lime, the roadway was graded and shaped to conform with the lines, grades and cross-section as set forth in the plans (Fig. 8). The roadway was then scarified to a depth of 4 in. and the first application of lime was applied. Bulk lime was spread uniformly on the scarified roadway for the full width of 22 ft. Preliminary mixing was done with a 30-in. disc which broke down the large clay lumps (Fig. 9) and mixed the soil-lime simultaneously. A Seaman Pulvimixer completed the mixing with water being added as necessary to obtain specified moisture contents. After a uniform mixture was obtained (Fig. 10) the base was re-shaped and sealed with a 5-ton rubber-tire roller to facilitate the operation of local traffic.

TABLE 2

TRIAXIAL TEST RESULTS

Triaxial Sample No.	Raw Soil Classification	Group	P.I.	% Lime—by Volume First Application	% Lime—by Volume Second Application	Triaxial Classification
TRX-1	Loam	A-4	15	9	9	1+
TRX-2	Sandy loam	A-2	12	6	12	1+
TRX-3	Clay loam	A-4	17	9	9	1+
TRX-4	Lt. silty clay	A-6	27	9	9	1+

Figure 8. Shrinkage cracks developed on the base before treatment with lime.

Figure 9. Condition of the soil after two passes of the disk.

Figure 10. Uniformly mixed and pulverized material after the first application of the lime.

Figure 11. Mixed and pulverized soil-lime before compaction after the second application.

SECOND APPLICATION OF LIME

The second application of lime, the actual stabilization of the base, started 30 days after the beginning of the initial "conditioning" operation. Prior to this operation, the base material had become highly friable, which made additional discing unnecessary.

After the base was re-shaped and its edges marked by the grader, lime was spread over its entire width, scarified to a depth of 4 in., and mixed to the specified depth of 8 in. with a Seaman Pulvimixer. Regardless of the type of soil, a very uniform mixture was obtained and pulverization was such that 80 percent of the material passed the No. 4 screen; which was above the requirement of the specifications (Fig. 11). Following the dry pulverization, water was added and mixed uniformly with soil-lime mixture by the use of a Seaman Pulvimixer with a watering attachment, bringing the moisture content to the required optimum.

After the moisture content and depth of the base were checked, compaction operations were started, with a 35-in. diameter 10-ton sheepsfoot roller and a 5-ton rubber-tire roller.

The density control tests, however, indicated that even after the sheepsfoot roller had walked out completely, 100 percent of the laboratory density (Modified Proctor Density—50 blows) could not be obtained. Therefore, the original sheepsfoot roller was replaced with a 35-ton, 76-in. sheepsfoot roller, which increased the average density obtained to 102 percent of the laboratory density, with the lowest being 100 percent.

Figure 12. The finished road after it was covered with three-course bituminous treatment.

As the rolling was completed, the surface was swept and kept wet until sealed with emulsified asphalt (EA-4), applied at the rate of 0.30 gal. per sq yd. The application of emulsified asphalt was made in six shots, being applied over a period of five days. During this five-day curing period, through traffic was detoured. Only local traffic was permitted on the road, which was insignificant as far as repetition and weight were concerned. After the curing period, the three-application surface treatment was applied and the road (Fig. 12) was opened to traffic.

A crew from the District Laboratory in Lake Charles was assigned to this project for sampling and testing the material and to assist the project engineer. This project was only 18 mi from the District Laboratory at Lake Charles, therefore, samples were taken to the laboratory and tested immediately. Tests run during the construction consisted of Atterberg limits and moisture density tests.

ATTERBERG LIMIT TESTS

As a section of the base was prepared for the first application of lime, sampling of the material started. The sampling schedule was as follows: One sample, approximately 2 lb was obtained from every 500 ft of the base and at every soil change. The first sample was taken prior to the application of lime. Additional samples were taken at frequent intervals, ranging from two hours to 40 days from completion of mixing. Extreme care was exercised in obtaining a representative sample and also in taking them from the exact same spot of the road every time. These were transported to the laboratory in sealed cans and tests were started as soon as the material arrived at the laboratory.

Soil Preparation

The preparation of this material deviated from the standard AASHO method as follows: (1) A moisture specimen was taken from every can before the preparation started. (2) The material was transferred into an aluminum bowl and was broken down by a soft steel spatula until all of the material passed a No. 40 screen. Then the standard Atterberg limit tests were run. It was rather a tedious operation, but was found to be the only practical way which allowed immediate testing without spoiling the mix by overheating or grinding. In an effort to check the adequacy of this modified method, paralleled tests were run, using the same soil in a raw condition and the results were found satisfactory.

Figures 13 through 16 show the relationship of Atterberg limits—time from mixing to testing. It will be noted that a radical change took place in soil characteristics during the first three hours. Regardless of the soil type, all plasticity indices show a reduction. It will further be noted that, from three hours to the second application of lime, very little additional reduction is indicated in P.I. with the exception of the light silty clay. Because this material contained a higher percentage of clay a longer reaction time is noted.

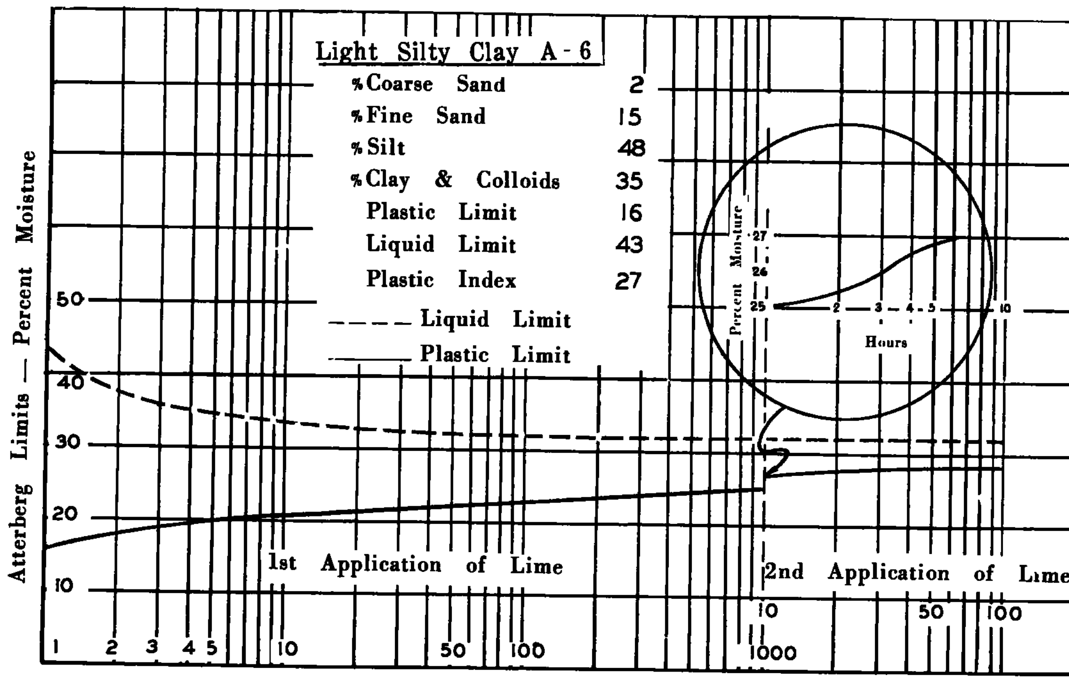

Figure 13. Time elapse between mixing and testing—hours.

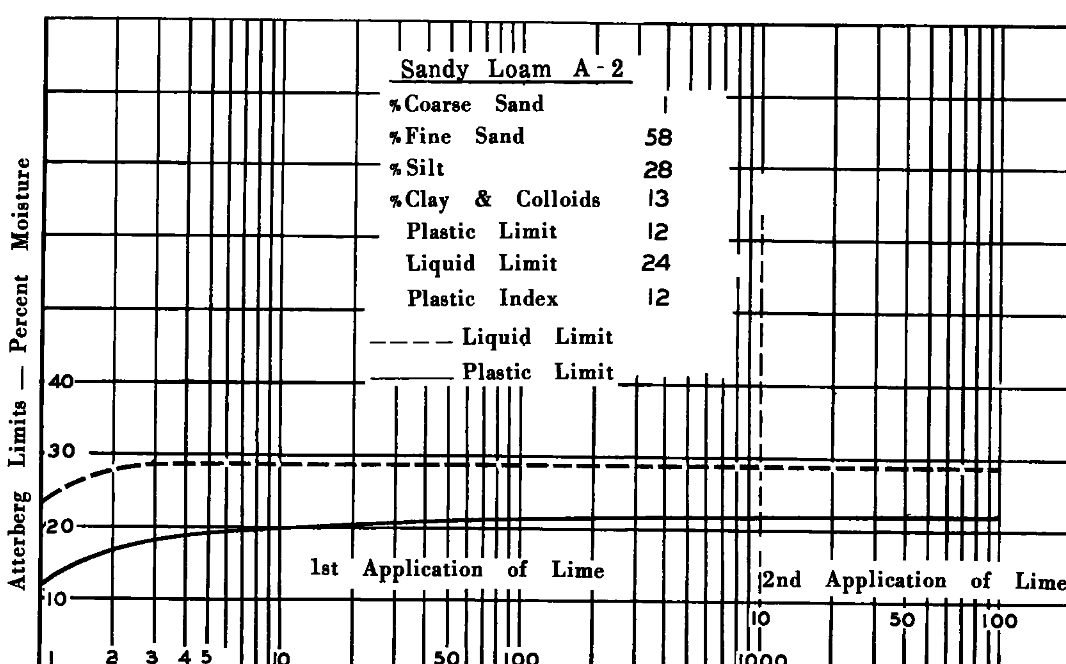

Figure 14. Time elapse between mixing and testing—hours.

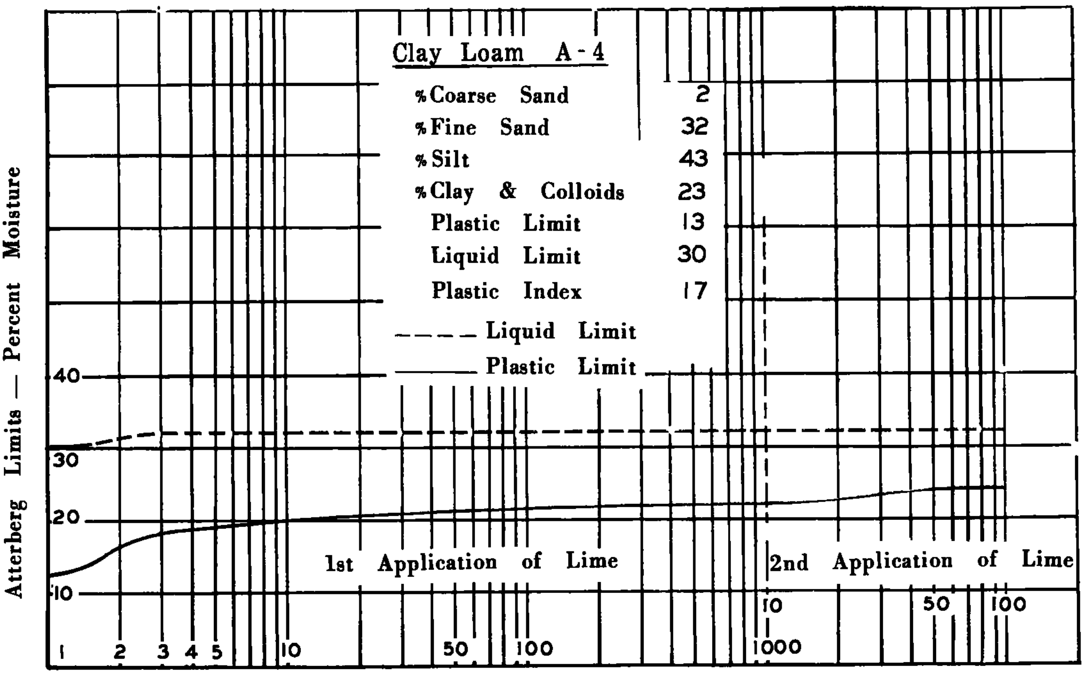

Figure 15. Time elapse between mixing and testing—hours.

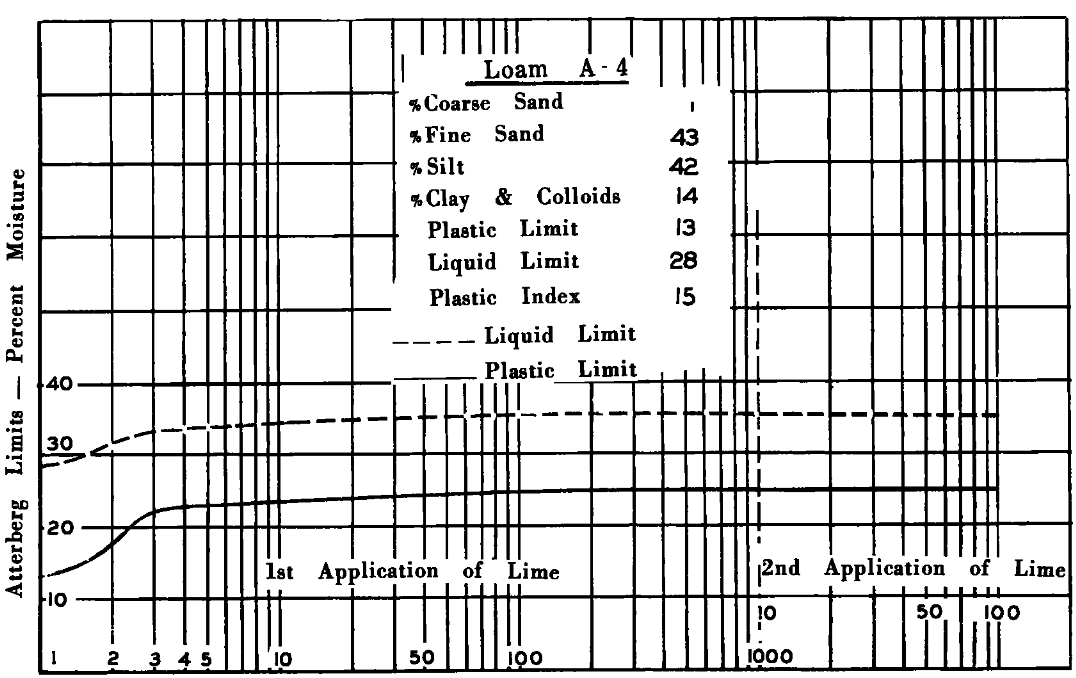

Figure 16. Time elapse between mixing and testing—hours.

The second application shows little change in liquid limit, with a moderate increase in plastic limit.

Results of the moisture-density tests are summarized in Figure 17. The optimum moisture content of each type of soil versus the maximum density obtained was plotted. Soils for the first three sets of moisture-density curves were prepared in the laboratory. The soils treated with the double application of lime (18 percent by volume) produced higher densities at lower moisture contents than those treated with a single application of lime. However, after construction was started, it was found that the curves prepared in the laboratory did not meet field conditions. Therefore, a fourth set of compaction curves were prepared where the soils were mixed with the actual construction equipment, cured in place and sampled four days prior to the second application of lime. The second application of lime was added in the laboratory. The results of these curves produced a lower density at a considerably higher moisture content than those of previous tests. Also, the results checked close to field conditions.

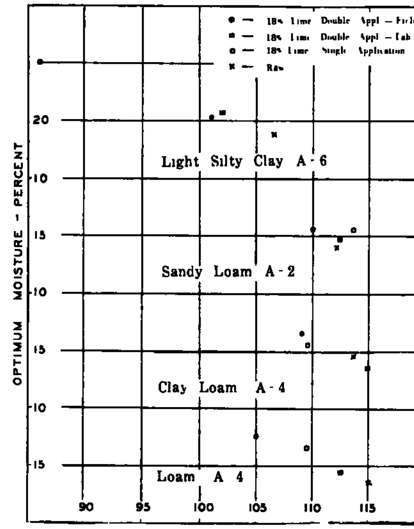

Figure 17. Maximum density (pcf).

CONCLUSIONS

1. Failures of soil-lime stabilized bases are caused by lack of cementation, which in turn is the result of one or all of the following deficiencies:

a. Poor mixing due to high clay content.
b. Insufficient depth and width.
c. Delayed compaction of soil-lime mixtures.

2. On the basis of observations made during and after the construction, "the double application method" proved itself capable of solving some of the more important problems in stabilization.

a. The first application of lime rendered the soil highly workable, changing its characteristics from worse to better.

b. Facilitated the operation of the mixing equipment, materializing a most uniform and accurate mixing with sufficient depth and width coverage.

c. Permitted immediate compaction following the mixing.

d. Brought out the fact that very heavy compaction equipment is necessary for this type of construction.

e. Eliminated surface cracks which were a problem in single application projects.

3. Information yielded by the test results indicated that:

a. There is a harsh initial reaction taking place immediately after the addition of the first portion of lime.

b. This reaction is fairly fast, rendering the soil friable within 3 to 25 hr after mixing.

c. These facts, combined with the results of the study of previous construction, reinforced the theory that soil-lime mixtures should be compacted within 24 hr after mixing in order to obtain cementation.

d. Equipment used for mixing, curing conditions, continuous changes of moisture and temperature in the field which cannot be duplicated exactly in a laboratory, created combined factors not present in the running of moisture-density curves for soil-lime stabilization in the laboratory; thus rendering the moisture-density curves run under the present conventional methods obsolete. A moisture-density curve prepared, using material mixed and cured in the field, is the only remedy found so far for this problem.

The construction method and test results reported herein should, by no means, be considered as a solution to all soil-lime stabilization problems, or as a complete picture of their general behavior. Further research in this field will produce better systems and methods which will warrant a more successful end-product.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Sidney B. Norris, Assistant District Engineer and Lawrence Doucet, Project Engineer for their help and cooperation; the assistance of District 07 Testing Laboratory Personnel, especially that of Abraham Fontenot, Jr., Laboratory Technician, is also gratefully acknowledged.

REFERENCES

1. "Soil Lime Base Course Specifications—CS-3 6/56." Louisiana Department of Highways.
2. Soil Lime Base Course—Special Provisions—Special Agreement State Project No. 196-02-04.

Appendix

TRIAXIAL TEST RESULTS

STATE OF LOUISIANA
DEPARTMENT OF HIGHWAYS

TESTING & RESEARCH SECTION

Date 9/18/59

Project No. 196-01-04 Lab. No. 11529

Material Loam A-4

Remarks TRX-1

Opt.Moisture 17.4 Opt. Density 105.0 Comp.Effort 13.26 Ft.Lb./cu. in.

TRI-AXIAL COMPRESSION TEST CLASS 1^+

20 YEAR ROAD REQUIRES ______ INCHES OF BETTER MATERIAL FOR ______ POUND WHEEL LOAD

10 YEAR ROAD REQUIRES ______ INCHES OF BETTER MATERIAL FOR ______ POUND WHEEL LOAD

MOLDING DATA			CURING DATA			TESTING DATA			
Cylinder No.	Moisture % Dry Wt.	Dry Den. Lbs.Per Cu.Ft.	Cap. Moist. Time Days	Moisture After Drying % Dry Wt.	Moisture After Cap. Absorption % Dry Wt.	Applied Lateral Pressure P.S.I.	Ulti. Comp. Strength	Strain at Ulti. %	Swell Volume %
20	16.3	107.7	10	14.0	16.9	0	101.00	0.911	0.13
21	16.3	107.4	10	14.0	16.9	5	144.52	1.609	0.11
3	16.3	107.4	10	13.9	16.8	10	169.94	1.856	0.09
30	16.1	108.0	10	14.1	16.3	15	172.50	1.901	0.10
7	16.2	107.3	10	13.8	16.2	20	177.79	2.105	0.11

Figure 18.

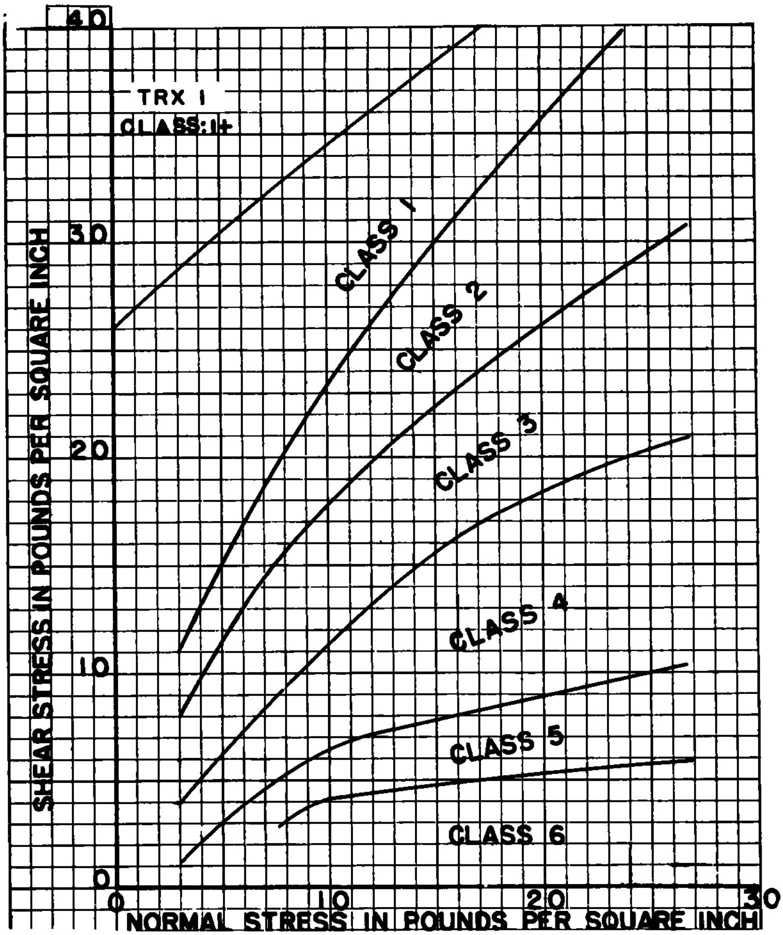

Figure 19.

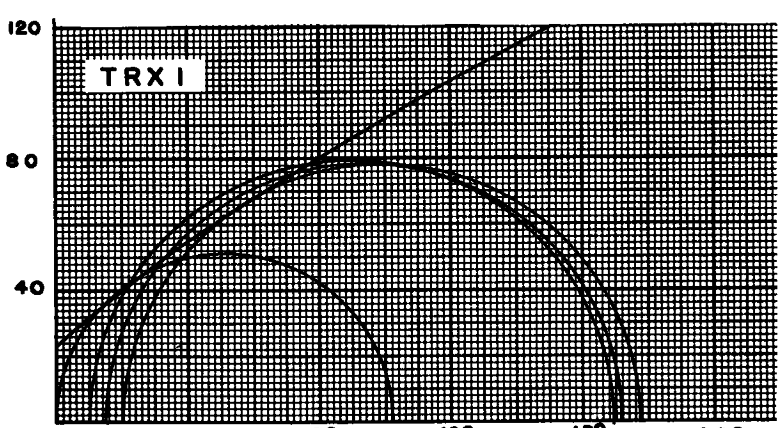

Figure 20.

STATE OF LOUISIANA
DEPARTMENT OF HIGHWAYS

TESTING & RESEARCH SECTION

Date 9/17/59

Project No. 196-01-04 Lab. No. 11530

Material Sandy Loam A-2

Remarks TRX-2

Opt.Moisture 15.6 Opt. Density 109.8 Comp.Effort 13.26 Ft.Lb./cu. in.

TRI-AXIAL COMPRESSION TEST CLASS 1+

20 YEAR ROAD REQUIRES ____ INCHES OF BETTER MATERIAL FOR ____ POUND WHEEL LOAD

10 YEAR ROAD REQUIRES ____ INCHES OF BETTER MATERIAL FOR ____ POUND WHEEL LOAD

MOLDING DATA			CURING DATA			TESTING DATA			
Cylinder No.	Moisture % Dry Wt.	Dry Den. Lbs.Per Cu.Ft.	Cap. Moist. Time Days	Moisture After Drying % Dry Wt.	Moisture After Cap. Absorption % Dry Wt.	Applied Lateral Pressure P.S.I.	Ulti. Comp. Strength	Strain at Ulti. %	Swell Volume %
2	14.09	110.7	10	10.26	16.18	0	109.94	0.582	0.03
39	14.05	111.0	10	10.34	16.17	3	140.28	.622	0.03
27	14.10	110.7	10	10.38	16.77	5	183.33	1.120	0.04
24	13.98	111.1	10	10.97	16.35	10	198.21	1.240	0.00
6	14.16	110.9	10	11.10	16.60	15	212.00	1.62	0.00
18	14.20	111.0	10	11.03	16.10	20	235.30	1.68	0.02

Figure 21.

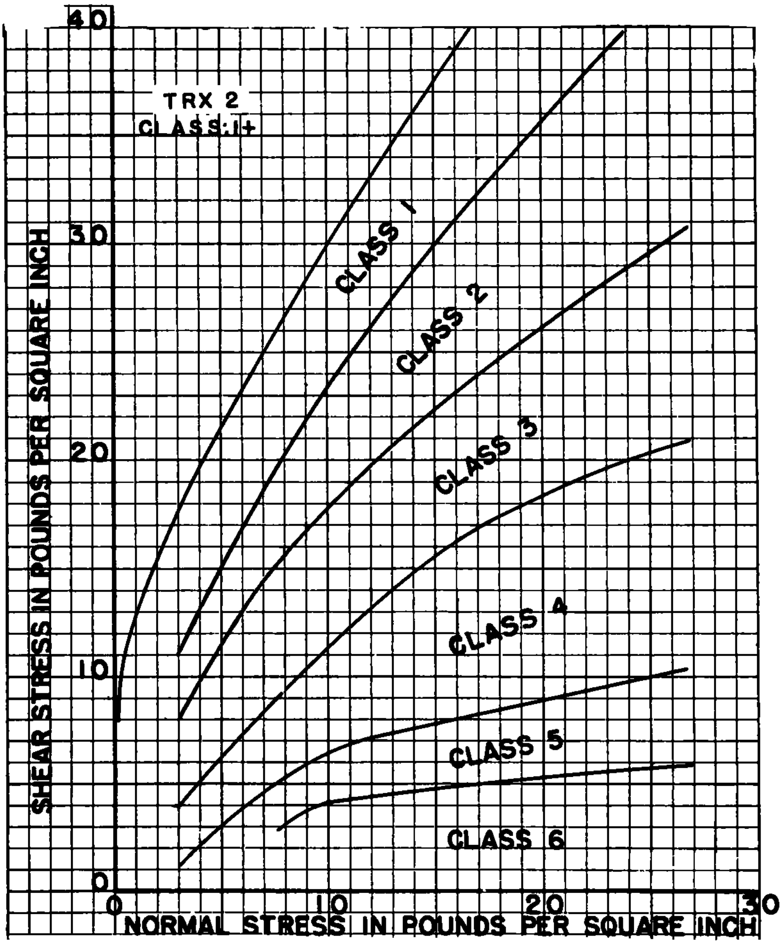

Figure 22.

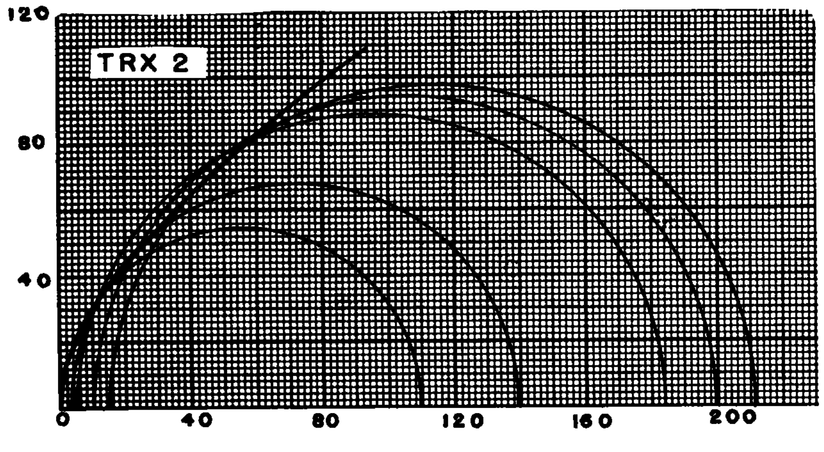

Figure 23.

STATE OF LOUISIANA
DEPARTMENT OF HIGHWAYS

TESTING & RESEARCH SECTION

Date 9/17/59

Project No. 196-01-04 Lab. No. 11531

Material Clay Loam A-4

Remarks TRX-3

Opt.Moisture 16.8 Opt. Density 109.0 Comp.Effort 13.26 Ft.Lb./cu. in.

TRI-AXIAL COMPRESSION TEST CLASS 1^+

20 YEAR ROAD REQUIRES ____ INCHES OF BETTER MATERIAL FOR ____ POUND WHEEL LOAD

10 YEAR ROAD REQUIRES ____ INCHES OF BETTER MATERIAL FOR ____ POUND WHEEL LOAD

MOLDING DATA			CURING DATA			TESTING DATA			
Cylinder No.	Moisture % Dry Wt.	Dry Den. Lbs.Per Cu.Ft.	Cap. Moist. Time Days	Moisture After Drying % Dry Wt.	Moisture After Cap. Absorption % Dry Wt.	Applied Lateral Pressure P.S.I.	Ulti. Comp. Strength	Strain at Ulti. %	Swell Volume %
41	16.22	106.3	10	14.2	17.7	0	126.2	0.992	0.02
60	16.59	107.0	10	13.9	17.1	3	170.7	1.384	0.04
37	15.98	107.2	10	14.4	17.4	5	175.8	1.121	0.01
38	16.24	107.4	10	14.6	17.2	10	190.91	1.116	0.01
19	16.63	107.5	10	14.1	17.0	15	202.6	1.741	0.05
31	16.01	107.3	10	14.8	17.5	20	220.0	2.020	0.03

Figure 24.

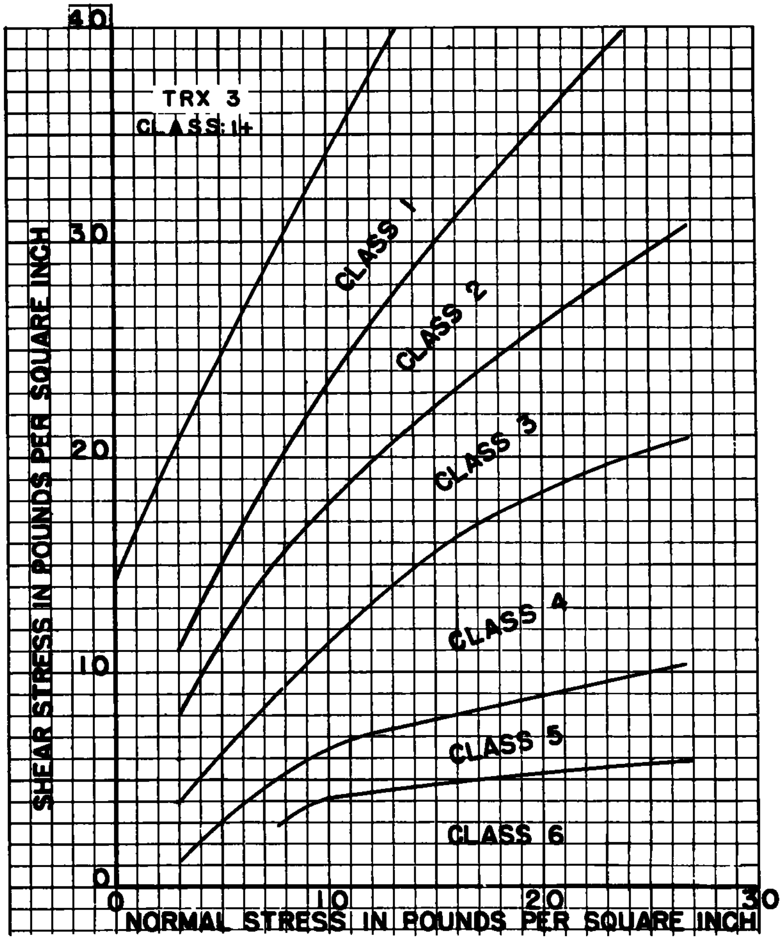

Figure 25.

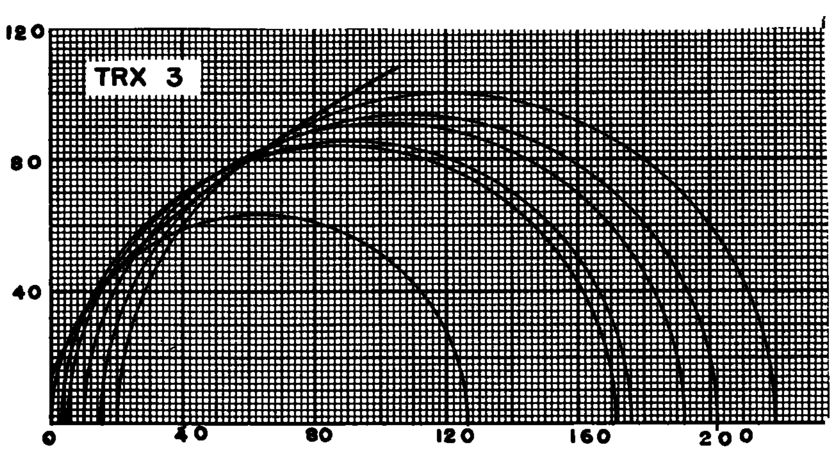

Figure 26.

STATE OF LOUISIANA
DEPARTMENT OF HIGHWAYS

TESTING & RESEARCH SECTION

Date 9/17/59

Project No. 196-01-04 Lab. No. 11532

Material Light Silty Clay A-6

Remarks TRX-4

Opt.Moisture 20.0 Opt. Density 101.6 Comp.Effort 13.26 Ft.Lb./cu. in.

TRI-AXIAL COMPRESSION TEST CLASS 1^{+}

20 YEAR ROAD REQUIRES ______ INCHES OF BETTER MATERIAL FOR ______ POUND WHEEL LOAD

10 YEAR ROAD REQUIRES ______ INCHES OF BETTER MATERIAL FOR ______ POUND WHEEL LOAD

MOLDING DATA			CURING DATA			TESTING DATA			
Cylinder No.	Moisture % Dry Wt.	Dry Den. Lbs.Per Cu.Ft.	Cap. Moist. Time Days	Moisture After Drying % Dry Wt.	Moisture After Cap. Absorption % Dry Wt.	Applied Lateral Pressure P.S.I.	Ulti. Comp. Strength	Strain at Ulti. %	Swell Volume %
28	16.5	105.8	10	16.1	16.7	0	115.92	1.332	0.06
33	16.9	105.5	10	16.4	17.1	3	168.79	0.997	0.09
49	16.1	106.0	10	16.6	17.3	5	146.47	1.247	0.03
26	16.7	106.1	10	16.7	17.4	10	169.59	1.475	0.07
10	17.1	105.1	10	16.2	17.0	15	182.31	1.512	0.07
45	16.8	105.8	10	16.2	17.4	20	199.03	1.965	0.09

Figure 27.

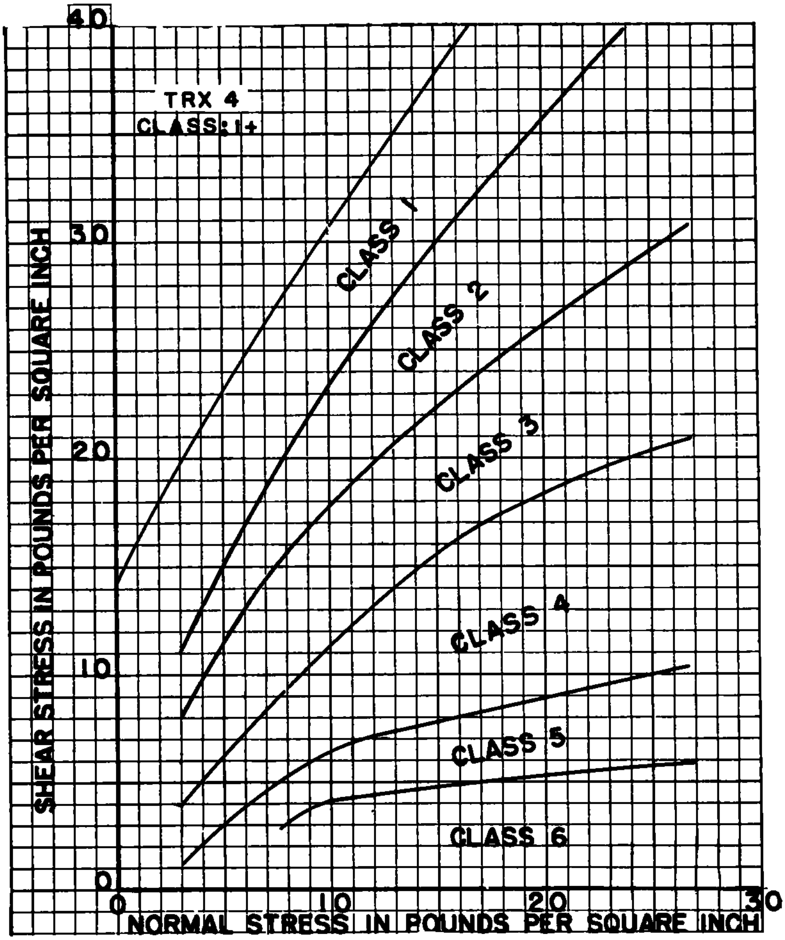

Figure 28.

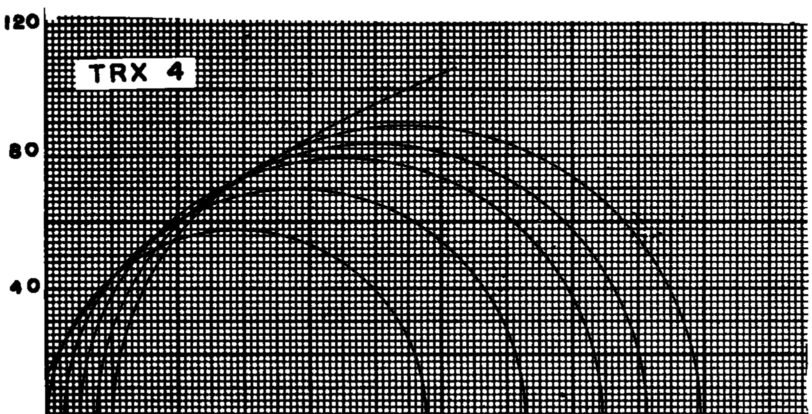

Figure 29.