SOIL-CEMENT DESIGN STUDY

INTERIM REPORT NO. 1

W. T. BURT III
PAVEMENT RESEARCH ENGINEER AND
ACTING SOILS RESEARCH ENGINEER

AND

JAMES MELANCON
SOILS RESEARCH GEOLOGIST

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ABSTRACT

Soil-cement base course materials design in Louisiana is based upon durability and compressive strength criteria, with the compressive strength requirements being the controlling factor in 95 percent of the designs. The findings to date from this study have provided reasonable verification that the previous design strength of 300 psi was being achieved in the field on-the-average. However, definite indications are that excessive variability existed in the former design system, and variability exists in the quality of the final product in the field.

A system for recommending the percent of cement for soil-cement has been developed which virtually eliminates the majority of problems associated with testing variability. This variability was inherent in the procedure and not due to careless testing techniques. In addition, compressive strength test reproducibility has been improved by strictly controlling the cement used for testing, slaking in water overnight just prior to molding specimens, closely controlling the temperature of the ingredients during the molding of specimens and increasing the number of specimens per test.

According to the mean of all the data, the construction projects reasonably met the design criteria of 300 psi at 28 days; indications suggest that some projects are poor in quality. From data to date, better quality soil-cement can be constructed since approximately half of the projects investigated developed properties in excess of, or equal to, the design criteria. Excessive variability in cement content frequently exists in the finished soil-cement. It appears that the average cement content in the field ends up approximately 1 1/2 percent less than the design percentage. In addition, the present method of field density control has several undesirable features. When using this method there is an implication of greater density than actually achieved. A different method of field density control should be considered. The specifications should disallow the use of overweight construction traffic at all times.

IMPLEMENTATION

Many of these findings have already been implemented, others are being considered for implementation.

The Soils Laboratory of the Materials Section has worked in close cooperation with the Research and Development Unit on this study; therefore, the recommended changes concerning materials design and test methods have been immediately implemented. The compressive strength test procedure has been changed according to our preliminary findings. Further improvements in test procedures and methods are currently being investigated with the close cooperation of the Materials Section's Soil Laboratory. The cement content recommendation system using the charts developed under this study are now being used.

The recommended changes in field procedure will require close scrutiny because of their effects on cost, specifications, established practice and established equipment. However, implementation of these findings should result in an improved, more consistent end product.

SCOPE

The object of this study is to establish reasonable minimum compressive strength criteria for soil-cement base courses in Louisiana utilizing available soils.

The scope of this report was to determine the percentage of laboratory design strength that may be expected of soil-cement stabilized bases. This was accomplished by comparing the compressive strength test results of cores and field molded specimens from soil cement base courses of construction projects to the respective laboratory soil-cement design values.

The system of recommending cement design percentages for soil-cement base construction was investigated, which led to an investigation of the reliability of the laboratory design test itself.

INTRODUCTION

The present method of materials design for soil-cement consists of two criteria; one is a durability determination, the other is a compressive strength determination. Because of the nature of the tests, the critical determination is the one for compressive strength since it acts as the controlling factor in about 98 percent of the decisions concerning acceptability and, when acceptable, determines the amount of cement necessary for stabilization.

A empirically derived value of 300 psi after seven days of cure is the compressive strength criteria used in Louisiana. The applicability of this value has not yet been determined in relation to field performance. However, the actual compressive strength values being achieved in the field have been determined.

It is important to realize that this report deals with soil-cement and not stabilized aggregates. The majority of soil-cement in Louisiana is constructed with soils having a A-group of A-2-4, A-4 and A-6 and plasticity indices ranging from non-plastic to 15.

METHODOLOGY

The final objective of establishing reasonable minimum compressive strength criteria for soil-cement bases in Louisiana, utilizing available soils, is to be achieved in two phases. The first consists of laboratory testing of soils sampled from soil-cement projects prior to the addition of cement, sampling and testing of the soil-cement mixture from the bases, and testing cores at various curing stages of the base. The second phase consists of sampling the major soil types by District Laboratories in their respective areas for soil-cement design testing.

The procedure to date consisted of laboratory testing of soils sampled from nine active soil-cement projects prior to the addition of cement, sampling and testing of soil-cement mixture from the bases and testing cores at various curing stages of the base (see Table 1). Also a "confidence study" of the laboratory design test was undertaken. This work was accomplished in the following manner.

Samples of the soil to be stabilized were obtained from the roadway of soil-cement projects prior to the addition of the cement. These samples were taken at minimum intervals of one mile or at each change in soil type, whichever was less. These soils were tested for laboratory compressive strength at cement contents ranging from 6 to 16 percent by weight in accordance with LDH Designation TR-422 (Appendix).

FIGURE 1

FIGURE 2

After the addition of the cement and immediately after completion of moist mixing, samples of the materials were obtained from the roadways in the same areas as those of the raw soil samples. Utilizing these materials, proctor size specimens were immediately molded in the field using equipment and procedures outlined in LDH Designation TR-422. Six specimens were left in the field for curing, and three were left in the molds, placed in airtight plastic bags and transported to the laboratory. At the laboratory, the specimens were removed from the plastic bags, extruded from the molds and placed in a moist room for curing. After curing for seven days they were tested in accordance with LDH Designation TR-422.

The specimens molded in the field and not brought immediately to the laboratory were extruded from the proctor molds, then buried in the surface of the shoulder of the roadway near the soil-cement base and left to cure for a period of 7 and/or 28 days. At the end of either curing period, the specimens were placed in airtight plastic bags and transported to the laboratory for compressive strength test in accordance with LDH Designation TR-422.

After the soil-cement base course had been cured for 7 and/or 28 days, cores were taken from the roadway at the same stations where previous raw soil and soil-cement samples had been made. These cores were brought to the laboratory for compressive strength testing. The entire core obtained was tested after a minimum of trimming. Strength values were corrected for a L over D ratio of 1:1.146 in order to be compared to proctor size specimens molded in the laboratory and/or field.

Cement content of cores and of selected soil-cement specimens molded in the laboratory and/or in the field were determined by chemical analysis (for detailed procedure see Appendix).

Two stages of the "confidence study" of the laboratory design tests have been completed as follows.

First, the researchers and one District Laboratory ran a compressive strength test in accordance with LDH Designation TR-422 using two soil types obtained by the researchers with the same type equipment and by the procedure as outlined in LDH Designation TR-422 and the design data formulated by the researchers (Table 4).

The second stage of the "confidence study" consisted of the same testing program as that of the first; however, in this case the Material's Section (the group responsible for making soil-cement designs) along with a District Laboratory and the researchers conducted the testing (Table 4).

Further work along the lines of the above "confidence study" of the laboratory design procedure is underway at the present time. The three laboratories are performing design tests on three soil types furnished by the researchers. However, this work differs from the previous work in that the several steps of the present procedure are being more closely controlled than normally required.

These controls consist of:

(1) Bringing each component in the fabrication of soil specimens to the same temperature prior to molding the specimens.

(2) Adding water to the raw soils and allowing the mixture to slake overnight before addition of cement.

(3) Holding uniform the time involved in fabrication of specimens.

The specimen density and moisture contents are closely controlled between the three laboratories by using the same density and optimum moisture for specimen design for each material tested.

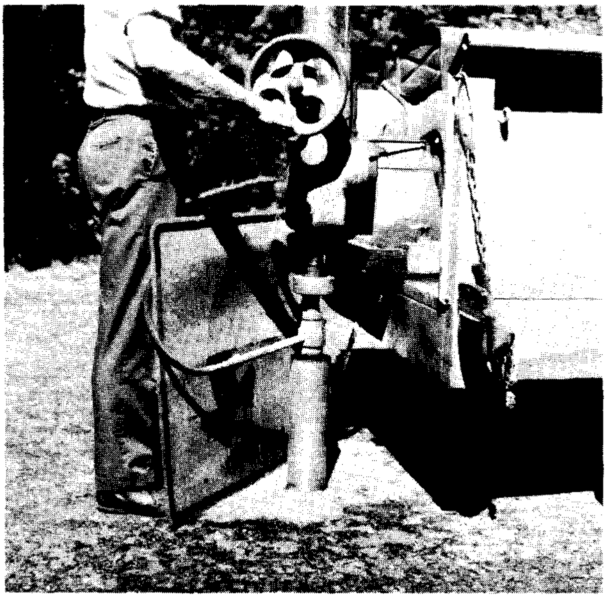


FIGURE 3

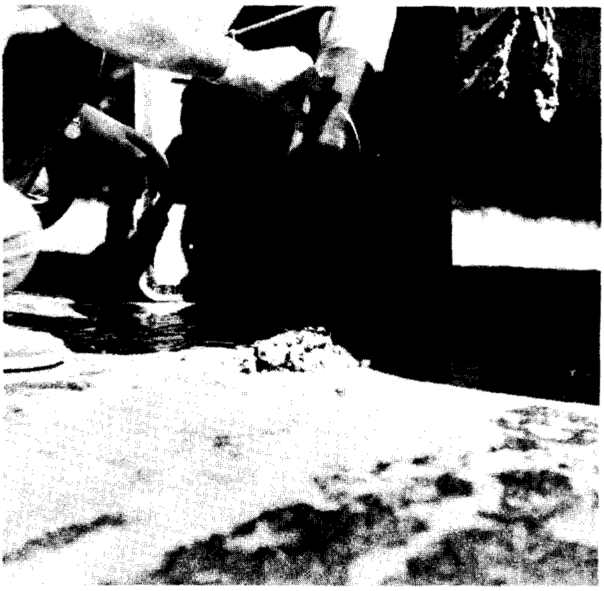


FIGURE 4

DISCUSSION OF RESULTS

Phase one is still in progress with work on nine projects completed and evaluation of the results proceeding. As frequently happens when examining results of data influenced by a multiplicity of factors and attempting causative interpretation, more questions arise than solutions found. Despite this fact, and though writers deplore solutions based upon insufficient data, trends have developed which are logically based. Data collection is continuing which should verify or rebut some of the conclusions now anticipated.

Field Evaluation

The most efficient methods of analysis employ some type of factorial design. However, there are instances, such as in this study, when the factorial design cannot efficiently be used because of the expense and time needed to construct the many number of different sections called for by the large number of influential variables.

The principle method of analysis used in the study for evaluating the field results is a close scrutiny of the averages of the various results. To scientifically "prove" a point by this method would require a tremendous quantity of data. It is felt that our data quantity is easily sufficient to indicate definite trends. Totally, the data theoretically varies equally from an absolute result, and a close approximation of the "true" absolute value can be established. In order to show our data variability, high and low values are also noted.

(1) Investigation of Field Compressive Strengths

Table 1 contains the very core of the research; compressive strength is examined from the standpoint of design and actual achievement. Influential factors, such as field mixing efficiency, field moisture and density control, and field cure were all duly measured.

The specimens molded and cured in the laboratory represented ideal conditions. The correct percentage of cement was applied; the mixing, moisture control, density and cure were ridigly controlled, as were design conditions. The resultant individual job averages ranged from 216 psi to 465 psi; the average of the total jobs being 350 psi at seven days. This appears to reasonably check the desired strength of 300 psi, with only two of the nine projects indicating inadequate design values.

The field molding of specimens added the uncontrolled, "as is" variables of moisture control (theoretically between 2 percent below optimum moisture to 2 percent above optimum moisture), cement content (varied according to uniformity of spread

TABLE I

RESULTS OF NINE PROJECTS STUDIED

Research Project Number	Predominate Soil Classification	PSI Lab. Molded 7 day Lab. Cure Project			Compressive Strength of Field Molded Specimen									Compressive Strength of Cores					
					7 day Lab. Cure Project			7 day Field Cure Project			28 day Field Cure Project			7 day Project			28 day Project		
		Ave.	High	Low	Ave.	High	Low	Ave.	High	Low	Ave.	High	Low	Ave.	High	Low	Ave.	High	Low
1	Silty Clay Loam A-4	252	325	170	284	404	162	221	326	123	284	462	130	228	346	124	375	732	126
2	Clay Loam A-6	465	345	595	221	343	101	178	235	99	254	415	121	199	292	115	264	400	176
3	Silty Clay Loam A-4, A-6	320	380	245	191	310	145	180	300	129	229	448	114	225	312	142	298	503	121
4	Clay Loam A-4 Silty Clay Loam	328	365	305	158	163	149	142	158	132	166	182	146	150	154	147	248	328	202
5	Silty Loam A-4	216	290	170	115	151	76	136	177	97	166	246	113	50	-	-	100	-	-
6	Sandy Loam A-2-4, A-4	388	415	319	296	345	245	283	340	235	300	433	225	278	285	270	474	619	218
7	Sandy Loam A-4	301	370	255	260	408	94	173	271	68	224	363	75	187	265	70	234	338	149
8	Sandy Loam A 4, Silty Clay Loam A-6	455	485	425	417	450	384	357	376	338	438	438	438	263	340	185	443	534	352
9	Sandy Loam A-2-4	424	500	395	233	340	178	222	251	197	268	391	163	138	217	90	249	402	143
TOTAL		350			242			210			259			191			298		

and/or according to depth of cut) and time delay between the incoporation of cement with the soil and the initiation of compaction. Field curing of the field molded specimens added additional variables. One important field variable, the parameter of compactive effort, was held constant at standard proctor effort.

The average of the specimens molded in the field and cured for seven days in the laboratory was 242 psi. The average of the specimens molded and cured in the field was 210 psi (seven day cure), and 259 psi (28 day cure). Thus under present methods of field control, excepting compaction which was held standard, the compressive strength of soil cement bases appears to result in a fair product, one with about 60-70 percent of the design strength at seven days and about 75 percent or more of the design strength at 28 days based upon the mean.

Naturally the results of the field cores should most truly represent actual field results since all variables and all interplay influencing relationships that could possibly exist were available to occur. However, it should be realized that the core results probably reflect slightly better than true conditions since the results do not consider those specimens damaged in collection (probably due to a localized weak area). Because more varied results are possible, more samples are necessary to reflect actual conditions. An attempt was made to obtain 618 cores; 384 core results were actually obtained. The authors feel this number of cores sufficient for consideration as a check of the results of the specimens molded in the field.

Therefore, the mean of the results as shown in Table 1 indicated that, for the projects checked, a fair product was produced. However, indications persist to hint at sections or areas with poor results as well as areas with very good results. As expected, different areas of most soil-cement bases appear to vary in quality.

The majority of soil-cement is not placed in service immediately; a practical time lapse between construction and use is approximately six months. Therefore, if minimum strength needs can be established, the soil-cement should obtain design strength within this period prior to actual service, with an estimated 75 percent of design strength obtained within one month to adequately handle construction traffic. Of course, the specifications should disallow overweight construction traffic use. Very preliminary investigations suggest that soil-cement appears to gain strength at a slower rate than does concrete; therefore, an achievement of 75 percent design strength at 28 days would appear more than adequate, assuming 300 psi minimum strength is sufficient. However, this adequacy can only be stated on-the-average for the old saw, a chain is only as strong as its weakest link applies here. Because of the magnitude and frequency of the strength values substanially below the average, the adequacy of all the parts of the product is questionable.

The non-unformity of soil-cement bases in Louisiana was verified to some extent by the Department's Research Project No. 63-4SC, AASHO Correlation Study. The Performance Index formula, as presented by the AASHO Committe, was reasonably verified by the various base courses presently used in Louisiana. Soil-cement base courses were also among these and, like the others, reasonably verified this formula on-the-average. However, individually, the soil-cement jobs varied to a much greater extent than the other materials; many jobs performed much better than expected, but an equal number performed inadequately. Recent changes in the cement content design has resulted in higher cement contents and has raised the level of quality of the base courses.

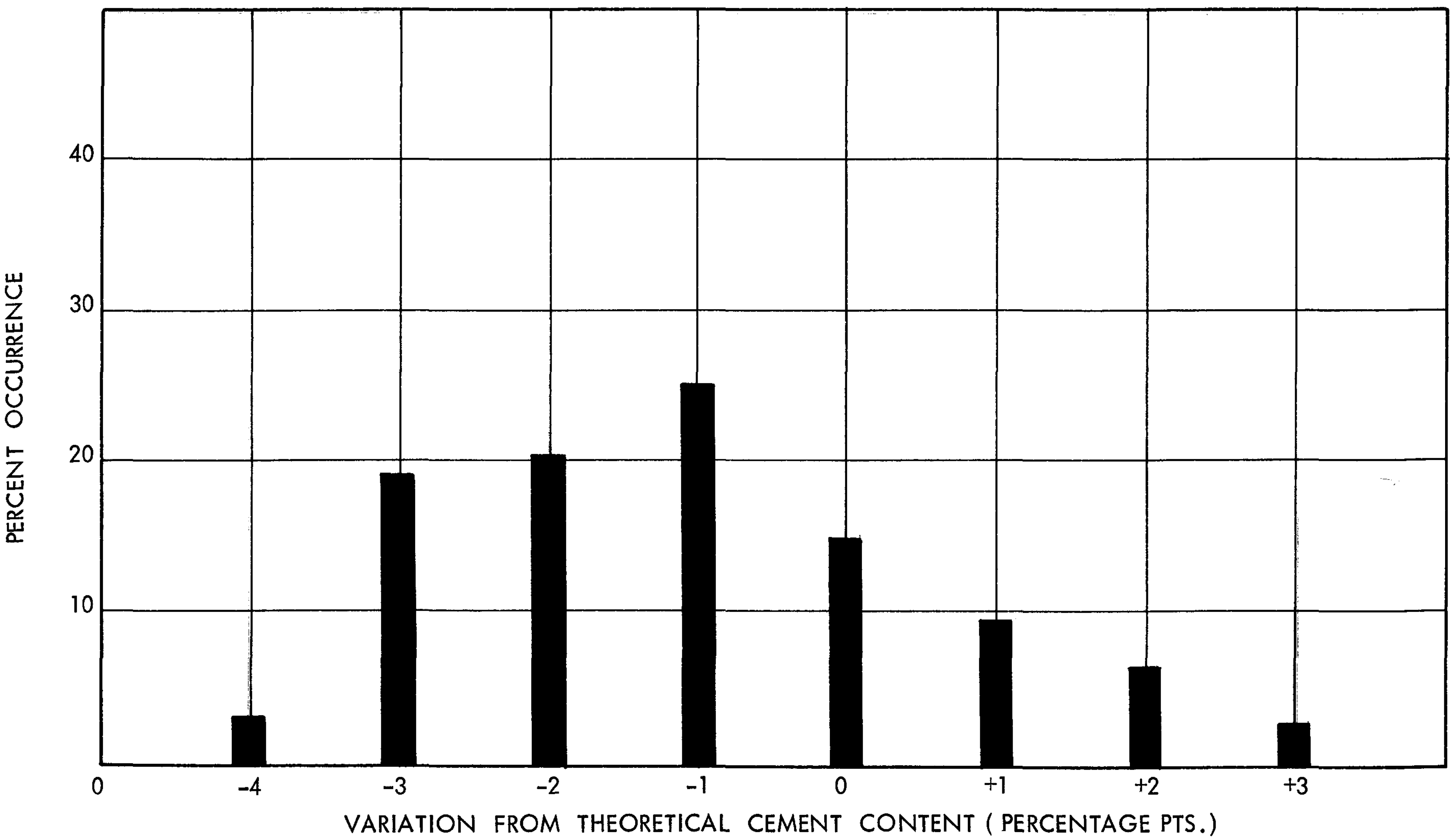
In the past soil-cement bases have given reasonably good performance. This was due to the section design being based on the weakest alternate material available rather than on a conservative design attitude. Therefore, soil-cement base course thicknesses were ultra-conservative. As such, the soil-cement base course of a given section was not required to perform to the limits of its designed capabilities. Under the present section design procedures however, soil-cement is being called upon to perform to the limits of its design expectations, and the concept that our previous soil-cement design procedure was adequate is not being justified by the performance level of our previous soil-cement sections.

From general observation, it is the authors' opinion that, in Louisiana, cured soil-cement base courses possessing compressive strength's of 200 psi or greater appears to be hard and durable. In general, at 150 psi the soil-cement begins to appear suspect. It is recognized that this opinion is extremely general in nature and that a given compressive strength means different things for different soils. These opinions will be further investigated realizing, however, that because of our investigative approach (a factorial type design investigation is not used), it will be extremely difficult to determine the "magic number" design compressive strength based upon scientific proof.

(2) Cement Rate Variability of Field Specimens

Prior to the specimen molding, the total sample taken for molding was thoroughly mixed and samples withdrawn for cement content determination by chemical analysis. Table 2 summarizes these results. Figure 5 illustrates the point that some cement is "lost". Thus the current practice of allowing a cement reduction of one percent when the pugmill method of mixing is used is well justified. Due to the uniformity of mixing, the improved moisture control and the reduction of "waste" (because the material can be shaped to the section design when using the pugmill method of mixing), consideration should be given to allowing a two percent cement reduction when the pugmill mixing method is used.

FREQUENCY OCCURRENCE OF ACTUAL VS THEORETICAL
CEMENT CONTENTS



ROADWAY MIXED

FIGURE 5

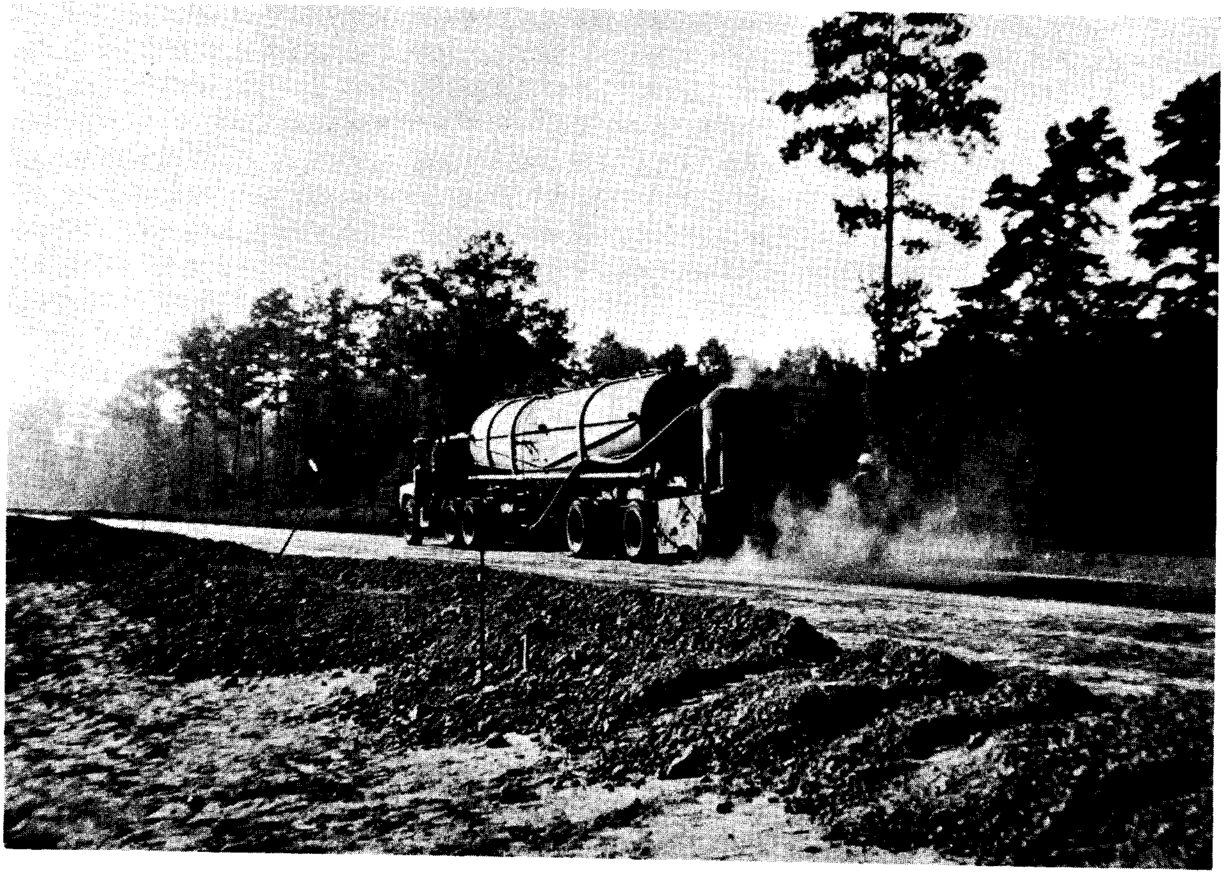


FIGURE 6

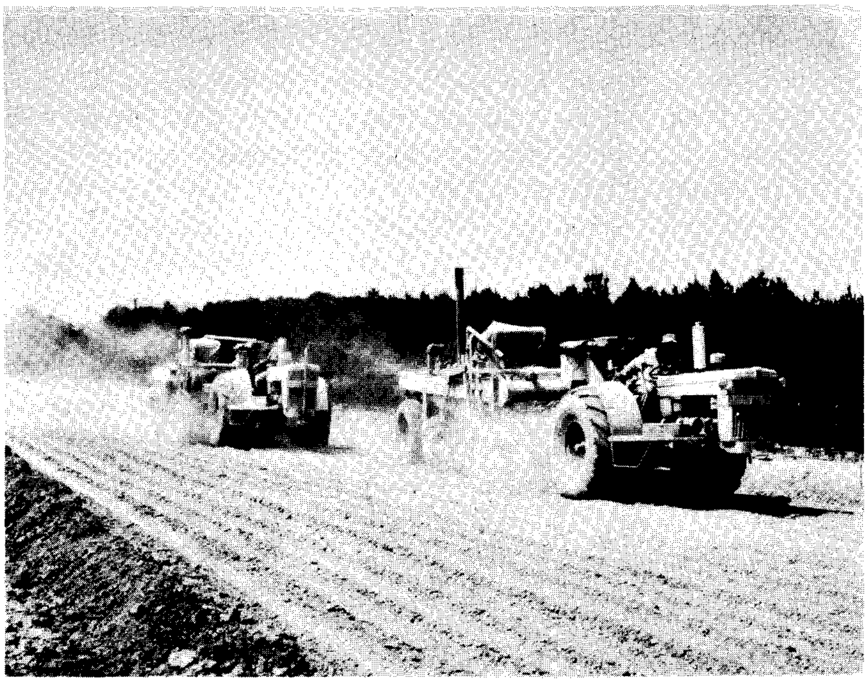


FIGURE 7

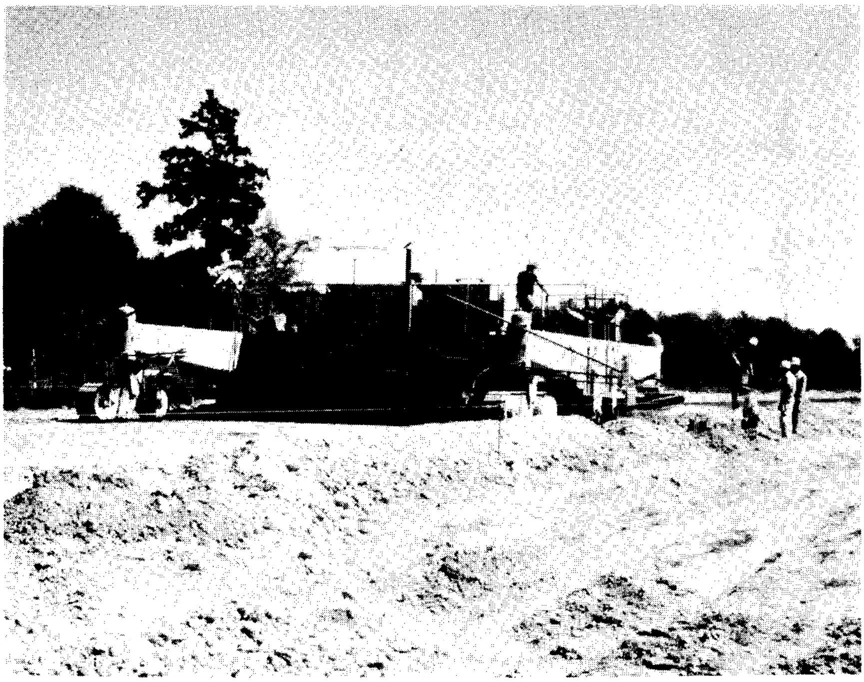


FIGURE 8

TABLE 2

CEMENT DETERMINATION BY CHEMICAL ANALYSIS OF FIELD MIXTURES

		Actual Percent Cement Content Determination by Chemical Analysis			
Project Number	Theo. % Cement Design by Weight	Lab Molded Lab Cured	Field Molded Lab Cured	Field Molded Field Cured	Cores
1	7.5	7.7	6.2	6.3	6.3
2	7.0	7.9	6.1	6.3	7.3
4	7.5	8.1	6.2	6.2	6.5
5	7.7	8.1	7.0	7.2	6.8
6	7.5	7.8	6.7	6.7	7.6
7	8.0	7.5	7.1	6.0	6.7
8	12.0	No-Test	11.3	11.1	9.7
9	8.0	7.3	5.4	5.7	6.0

Mixing efficiency appears to be somewhat less than desirable. More research effort needs to be expended in this area. One observation showed that achievement of pulverization (in one pass of the stabilizer) does not necessarily guarantee cement distribution.

(3) Field Density Evaluation

In the past, many problems occurred with project density control when using laboratory molded curves as the basic unit because of soil type inconsistency, difficulty of matching soils with curves and differences between construction time and laboratory time in molding curves. Therefore, the Department adopted a method whereby a location is selected for testing, two one-point proctors are run and the results averaged. This average value is used as the maximum laboratory density. A density test is run in this exact location, compared to this maximum density value obtained from the two one-point proctors and reported as percent compaction. During rolling, moisture content is theoretically kept within two percent of optimum. Therefore, when the moisture content is at optimum, the maximum density is the same value as the maximum density of a laboratory curve; when the moisture content varies from optimum, the maximum density is less than the same maximum density as obtained by a laboratory curve.

The importance of the density of a soil upon its strength is well documented. By the present specifications, the probability exists that the density will be less than the 95 percent of maximum density of a design moisture-density curve. Preliminary investigations indicate that the family of curves may be reliable for use as a field control to determine maximum density quickly and reliably in the field. This possibility is being explored.

TABLE 3

FIELD DENSITY EVALUATION

Project	Actual Roadway Density A	Actual Density of Field Proctor Test B	Lab Design Maximum Density C	Ratio of Present Require. vs Lab Design Density $\frac{B}{C}x(95\%)(100)$	Actual % Compaction Based upon Lab Design Density $\frac{A}{C}x\ 100$	Percent of Research Tests Below 95% Design Density
1	108.3	108.0	112.2	91	97	42
2	110.6	113.3	118.6	91	93	67
3	100.2	100.3	107.8	88	93	92
4	108.1	107.6	111.6	92	97	0
5	101.2	102.5	110.1	88	92	86
6	108.4	109.1	116.1	89	93	75
7	107.3	109.1	115.0	90	93	75
8	103.0	106.3	116.0	87	89	100*
9	110.5	113.2	120.3	89	92	80
Total Average				89	93	69

*Based on small number of tests.

Data substantiating this viewpoint is presented in Table 3. The "Ratio of Present Requirements versus Laboratory Design Density" shows the percent compaction requirements as based upon the maximum density of the laboratory design curve. "Actual percent compaction based upon Laboratory Design Density" presents the percent compaction of the actual field densities using the laboratory design curve's maximum density for the maximum density. As shown, the present method of controlling density has actually lowered the density requirements and density achievement, based upon the laboratory design curve. Sixty-eight percent of the tests of the research data, which met present specification requirements, do not meet 95 percent compaction requirements based upon the laboratory design curve.

Figure 9 shows a typical relationship between density and compressive strength. It is quite apparent that there is a significant strength increase between 90 percent and 105 percent compaction, which is the range of values occurring most frequently in the field. It appears that a compaction difference between 90 percent and 100 percent affects strength similarly to a cement content of two percent. In addition, according to Marshall, Reference 7, "A relationship existed between density and cracking, the higher density resulting in less shrinkage."

On some projects, the density closely approached 100 percent laboratory compaction with little difficulty, yet on other projects difficulty was encountered meeting the 95 percent compaction of the present two-proctor method. Naturally,

REPRESENTATIVE STRENGTH-COMPACTION CURVES

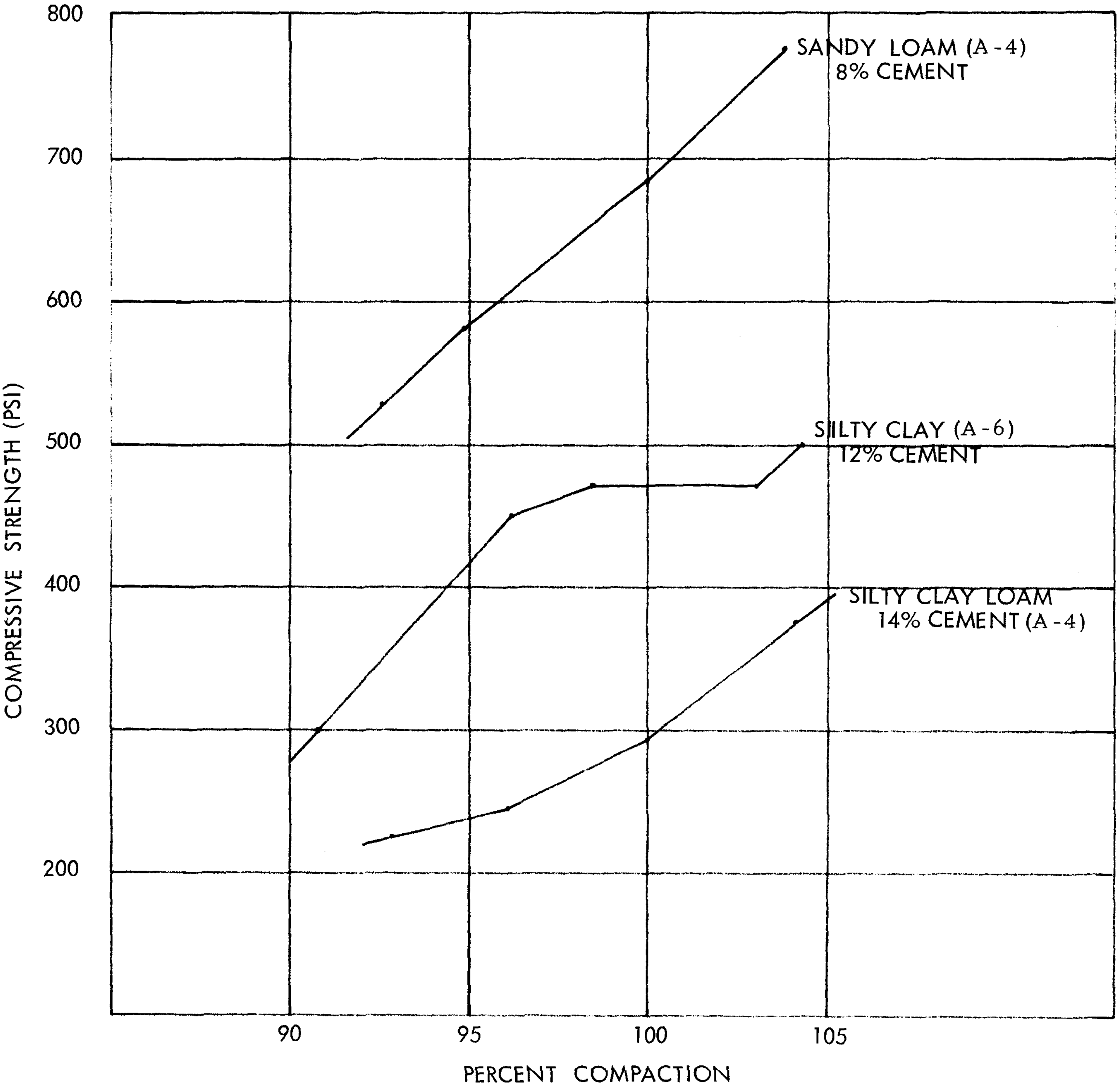


FIGURE 9

the characteristics of a soil had a great effect upon the ease of densification; however, this does not appear to be the cause of the compaction difficulties. Those contractors having the least difficulty were most observant of the basic factors, good moisture control and the correct kind and size of equipment.

One problem common to soil-cement construction is that of a yielding sublayer. The deflection characteristics can be quite high for a raw soil compacted to 95 percent of standard proctor. Effort should be given to consider the compaction needs of the subgrade as well as the soil-cement base course.

Again the pugmill method of soil-cement construction offers advantages. A soil's moisture content greatly affects its deflection characteristics regardless of density. When the pugmill method is used, the layer beneath the soil-cement can be more closely observed and controlled prior to soil-cement placement; therefore, this layer is usually drier and thus offers a more rigid layer to roll against.

In any case, densification approaching 100 percent compaction is very difficult but, as Figure 9 illustrates, when successful very definite strength advantages are effected. Thus, optimization of densification is an important goal.

Present methods of density control under different methods of field construction, particularily moisture control, appear to increase the probability of density variation. In addition, a possible lessening of the maximum density obtainable appears to occur. Table 3 shows that with the present control method of using an average of two one-point proctors, 89 percent compaction can be accepted as 95 percent compaction. This directly results in a loss of strength, a fact well documented. According to Maclean and Lewis (6) "with increasing knowledge of factors affecting soil-cement strength it became apparent that small differences in moisture content and state of compaction from the specified requirements could have as great an effect on the properties of the soil-cement as a significant error in cement content. Also, a change in dry density of only one percent will produce a change in the strength of the stabilized materials of 10 percent." Another method of field compaction control, perhaps the family of curves, appears desirable.

The possible effects of a change in the method of density control on the product, contractor and Highway Department is unknown. Therefore, before adoption of some new method of control, it is suggested that several trial simulations on actual projects be completed and evaluated.

(4) An Opinion on Field Controls

Critically speaking, the present specifications stress the practicality of economical construction equipment and methods rather than the importance of the effects of the various limits imposed. For example, though 95 percent compaction can be economically obtained, 100 percent compaction may be necessary to achieve design strength. Therefore, either 100 percent compaction should be specified or additional cement added to compensate. All too often, the goal of the contractor is to be within variously imposed limits rather than obtain a good finished product. The Department's present specifications foster this attitude. It is assumed that, if all the various limits are met, a good product will result. From a position of adequacy this is true primarily because of the additional cement usually required or the fact that soil-cement in Louisiana is so seldom used to its ultimate section design. However, a cursory glance at the "low" specimens or "low" cores of Table 1 indicates that great improvements in soil-cement could and should be attempted. Unfortunately, the effects of the multiplicty of combined factors are now known. Whereas efficient mixing and quickly achieved compaction may compensate for excess depth, insufficient moisture and a slightly "lean cement spread; inadequate cement distribution negates the achievement of all other specification limits.

The system of compensation for field inadequacies by the continual addition of cement is not the cure-all generally supposed. There appears to be an efficiency limit in the quantities of cement that can be incorporated by traveling stabilizers. This limit appears to be around 10 percent to 12 percent by volume. Above this amount, uniformity of spreading becomes a problem as well as potentially undesirable phenomena such as (1) the cement tends to flow like a liquid in front of the stabilizer, (2) the chemical set is accelerated thus the compactive effort can be damaging, and (3) a larger amount of cement is lost because of wind, additional fluff, etc.

The actual importance of mixing efficiency, pulverization, construction time, moisture control and density control needs to be determined and translated into limits. What limits are necessary can only be theorized, unsupported at present by actual data. Pulverization controls appear adequate if persistently checked based upon field observations. Construction time and moisture control appear reasonable; however, the limits need to be re-evaluated.

While overweight haul traffic can sometimes be beneficial to some construction phases of raw soil embankments, these overloads can detrimentally affect stabilized base courses as well as other courses. Loads and overloads should be studied for base protection.

Laboratory Design

In the process of obtaining the field data, an unanticipated discovery was made; the soil-cement laboratory design procedure based upon compressive strength limits exhibited a greater amount of variability than previously acknowledged. At first, procedural errors were blamed, but repeated tests under strictly controlled circumstances confirmed the degree of variability. Under the Louisiana laboratory procedure for determining compressive strength (which closely approximates the procedure used by Portland Cement Association), a cement content recommendation may vary as much as ±2 percent based upon a minimum 300 psi value with a possible error of about 40 percent. Table 4 and 5 show an example of variability under control conditions. Table 6 contains the statistical analysis of this data.

Degree of variability, reliability, or accuracy are all relative terms. If one was surveying property, a much greater degree of accuracy would be required in the location of property lines for urban property worth $100,000.00 an acre than swampland worth $20.00 an acre. This same fact applies to materials design. In determining the percent cement content necessary to stabilize a soil in a small parking lot, a conservative guesstimate based upon a few tests would be adequate since the cost of an additional two percent cement would be slight, probably less than the costs of an extensive investigation. In materials stabilization design for highways which involves large quantities of soils and cement, an additional percent or two of required cement boosts costs greatly. It is the author's opinion that a materials stabilization design within a laboratory should be accurate and repeatable within a tolerance of ±1/2 percent cement (an error of approximately 10 percent). In addition, specifications should control design recommendations in such a way that unexpected cement requirements are not forced upon the contractor. Contractor's doubt is always translated into higher bids or potential trouble.

Investigations into possible sources of variability within the present laboratory procedure have isolated the following possibilities.

(1) Cement Variability

In the past, cement used for design testing came from differing sources, provided the cement met specifications. Seven days compressive strength (AASHO T-106) varied from 2100 psi to 4500 psi. Different chemical make-ups and different degrees of fineness both contributed to differing strength rate gains as well as differing strengths from the cement itself.

To alleviate this problem, arrangements were made to obtain the cement from one source, and control limits within the specifications were established to more rigidly regulate the cement. For design purposes, the seven day compressive strength for the Ottawa sand and cement tests are: target, 4150 psi, allowable range, 3900 psi to 4400 psi.

Limits for other properties such as Blaine fineness and amounts of C_3S and C_3A were also established. It is believed that this range will allow strength deviations up to 10 percent. The possibility of obtaining even more rigidly controlled cement specifically for testing is being investigated.

(2) Statistical Number of Specimens

Under present procedure LDH Designation TR-422 three specimens are molded for each of the three different cement contents, with a two percent step between each of the three cement contents. Due to specimen damage or poor strength determination, a minimum of two specimens of each of the cement contents was acceptable. After seven days cure, the specimens were broken; the results plotted with cement content and compressive strength as coordinates; a curve was drawn, and the cement content necessary to stabilize the soil to 300 psi at seven days was found. Thus six specimens could be used to establish this value.

As shown in Tables 4 and 5, a difference of 100 psi between identical specimens frequently occurs. Because of the innumerable factors possibly influencing specimen strength which are not easily controlled by procedural techniques, more specimens are necessary to confidently establish the value sought. At this time, because procedural control techniques are currently under investigation, the number of points necessary to reliably establish an accurate curve is now known. Based upon very preliminary information, some procedural changes have been implemented, and the minimum total specimen requirement changed from six to twelve.

It is hoped that the procedural technique investigation will offer alterations which will reduce variability; thus, the number of specimens can be reduced.

One interesting phenomenon is exemplified by Figures 10A, 10B and 10C. The data points of each separate curve group themselves about its particular curve, presenting the illusion of accuracy. Each separate curve is similar in appearance and slope to the other curves with the exception that a projection of each curve would cross the ordinate differently. It would seem that the curves would continually intersect (like the two dashed line curves do in Figure 10A), rather than "stack" as they do, similar to a family of curves. This suggests a constant source of differences either between laboratories, between times of molding, or in procedural technique.

This phenomenon results in a false sense of confidence . A repeat test run six months later by the same laboratory could easily result in a different cement content recommendation.

(3) Procedural Technique

The past laboratory procedure allowed the full incorporation of water and cement immediately prior to mixing. The soil particles did not adequately absorb the water immediately, causing density variations. Later, during the curing process, these soils particles competed with the cement for the availabe water. In addition, the rapid change from a completely dry state to a moist state did not correlate to actual field conditions. Therefore, the water is now slaked in overnight, allowing water absorption by the soil prior to the incorporation of cement.

Temperature affects the strength gain rate and the ultimate strength of cement stabilized products. The molding water can vary from 40°F to 95°F, while the soils temperature can vary greatly due to its storage temperature or where the soil is used soon after drying. Therefore, the temperature of all the ingredients should be kept uniform and within an acceptable range.

Though procedural alternations controlling the aforementioned factors have increased test consistency, variability still exists that the writers feel is too great. Preliminary tests suggest that the present standard proctor molding method as well as an inadequate length-diameter specimen ratio may be influential causes. Shackel(9) in "A Nuclear Method of Detecting Small Variations in Density with Soil Specimens" states, "where samples are to be used for strength tests such as the triaxial test, non-uniformity within the specimens give a large scatter in the test results."

It is also possible that a more consistent, stable relationship exists for 28 day cured specimens as opposed to seven day cured specimens. These additional possibilities are currently being explored.

Cement Recommendation System

As stated in the Laboratory Design Section, variability in a soil's cement content recommendation could occur based upon innumerable factors. Yet every day the Department is forced into making recommendations based upon a few tests. One fact was clear; regardless of accuracy, each cement content recommendation must be similar and repeatable for each separate project. Therefore, all of the Department's previous soil-cement compressive strength data was thoroughly explored in the hopes of finding a key.

As shown in Figure 10A, variability exists between the three curves. However, should ten more curves be run on the same soil and all thirteen of these curves averaged into one, the probable error is greatly reduced. Available for study were the results of 20,000 specimens accompanied by test results of gradation, group index, plasticity index, A-group, soil type, pH, compressive strength, geographical location and in some cases, wet-dry and freeze-thaw data.

In close cooperation with the Materials Section's Soils Unit, a system based upon compressive strength, A-group, soils type, and geographical location was developed. As shown in Table 7 immediately after soils classification, the soil's cement content necessary for stabilization is known. Once this system was placed in the contracts, the contractor knew, prior to bidding, the cement recommendations for all possible soils allowable. Thus, with any preliminary soils investigation and search on his part, he could select the best and least expensive soils available.

Not only will this system prevent disputes concerning cement recommendations, but it should also reduce costs.

Soil-cement compressive strength testing continues, both to verify and improve this system. In addition, to the previous information, the soil's precise geographical location, depth, soils horizon and classification according to the General Soils Map of Louisiana by LSU Extension Service are included in Figure 11. After approximately one year, the original charts (Table 7) will be improved, and the more conflicting data closely examined and investigated.

CONCLUSIONS

I. Laboratory Design

Excessive inconsistency had existed when using the Department's laboratory design method for soil-cement which was based largely upon compressive strength.

This inconsistency has been reduced by: a) utilizing cement whose physical and chemical properties are rigidly controlled within strict limits, b) controlling the temperature of the ingredients, c) slaking the water into the soil overnight prior to molding. However, indications exist that the technique of proctor molding and the 1:1 length/diameter specimen ratio are adversely affecting consistency; work is continuing in these areas.

II. Field Observations

a) The application and/or mixing process of incorporating the cement into the soil is fairly uniform within a project; however, an actual cement content of the finished roadway appears to be 1 1/2 percent less than the design percentage. Using a different investigative approach, cement content and distribution will be examined.

b) The present method for controlling densities in the field contains several undesirable features. When using this method, there is an implication of greater density than actually achieved.

c) On the average, soil-cement bases in Louisiana obtain approximately 75 percent of the design compressive strength of 300 psi within 28 days. However, based upon compressive strengths, the quality of the soil-cement bases varies greatly, both within a project and between different projects.

RECOMMENDATIONS

1. The basic laboratory inconsistency problem as related to construction contract relationships can be circumvented by the adoption of stablization design recommendations. This system has recently been implemented.

2. A different method, preferably based upon the family of curve system, should be investigated for field compaction control.

3. Since soil-cement bases vary greatly in quality, an investigation should be made of the adequacy of the present specifications' various limits of quality control. This will be partially attempted during the next study phase.

4. A thorough investigation should be conducted with the purpose of reducing the test variability of the soil-cement design procedure. This is currently under investigation.

5. Consideration has been given toward reducing the seven day design compressive strength from 300 psi to 250 psi provided that field variability can be reduced, field quality controls can be improved, and cement compensation made for various specification limits. Thus, the actual 300 psi "working strength" at a field age of six months would be achieved.

The above recommendation has already been implemented based largely upon the improved laboratory design "chart" procedure, expected field control improvements, and previous experiences of job quality as related to the individual cement recommendations of the recommendation chart system.

6. Consideration should be given toward allowing a two percent cement content reduction should the pugmill method of construction be used.

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APPENDIX

TABLE 4

RESULTS OBTAINED BY TWO LABORATORIES

Soil Types	Soils Research Laboratory		District Laboratory	
Sandy Clay Loam A-4(3)				
8% Cement	394	376	245	206
10% Cement	470	443	270	288
12% Cement	520	519	373	348
14% Cement	563	566	423	430
Loam A-4(4)				
8% Cement	445	425	202	288
10% Cement	541	610	440	373
12% Cement	573	648	536	444
14% Cement	641	645	539	543

TABLE 5

RESULTS OBTAINED BY THREE LABORATORIES

Soil Type	Soils Research Laboratory								District Laboratory								Central Laboratory							
Sandy Loam A-2-4(0)																								
6% Cement	282	305	302	266	287	294			247	262	211	247	266	270	283	247	240	219	218	219	208	215	224	217
8% Cement	420	437	423	441	381	382			337	349	276	357	325	365	305	345	313	340	314	329	309	373	398	378
10% Cement	571	563	548	524	561	525			480	535	480	452	507	483	511	495	461	407	445	422	433	432	459	454
12% Cement	672	696	767	702	645	589			594	527	674	634	741	674	638	694	723	704	698	760	654	720	670	657
14% Cement	812	732	684	756	796	844	844	848	575	1050	888	900	884	927	931	820	761	785	794	772	856	926	884	865
Clay Loam A-6(11)																								
6% Cement	271	266	272	285	303	268	282	275	186	246	246	222	206	269	226	250	182	196	211	197	210	204	235	213
8% Cement	366	353	321	374	325	364	310	342	222	266	297	281	321	313	281	289	277	272	264	270	300	286	299	265
10% Cement	384	412	410	411	382	403	373	411	424	412	321	289	396	329	297	329	303	318	334	297	306	292	313	311
12% Cement	408	429	475	477	436	457	449	429	551	487	491	357	507	488	495	460	385	392	320	363	345	356	343	348
14% Cement	500	497	501	497	508	599	610	573	507	468	416	460	487	487	511	420	404	311	404	407	405	404	424	438
Silty Loam A-4(8)																								
8% Cement	273	267	282	275	298	302	263	267	262	202	198	194	162	198	230	218	228	207	185	210	215	210	218	190
10% Cement	302	320	326	319	323	322	308	307	262	281	266	321	333	289	277	285	212	220	210	223	218	224	224	226
12% Cement	364	375	363	395	403	394	401	403	305	345	309	293	289	289	269	333	309	326	284	294	318	300	320	278
14% Cement	438	419	479	415	454	438	393	407	305	400	361	337	349	384	357	365	330	367	333	277	330	365	329	356
16% Cement	470	457	485	463	462	464	475	449	396	432	468	373	384	396	483	487	432	426	425	390	394	423	399	406

TABLE 6
STATISTICAL EVALUATION OF TRI-LAB DATA

	Cement	$\overline{X}$, Mean			σ, Standard Deviation			ν, Coefficient of Variation					
Soil	Content	Research	Central	07	Research	Central	07	Research	Central	07	R^2	b	a
A	6	289.33	220.00	254.13	14.36	9.26	21.72	0.05	0.04	0.08			
	8	414.00	344.25	344.88	26.41	34.31	22.63	0.06	0.10	0.07			
	10	548.67	439.13	492.88	20.13	19.06	25.09	0.04	0.04	0.05			
	12	678.33	698.25	647.00	59.80	36.62	65.42	0.09	0.05	0.10			
	14	789.25	830.78	871.88	60.29	60.33	136.43	0.08	0.07	0.16			
	16												
	Research										0.9988	63.85	-95.30
	Central										0.9739	78.70	-280.80
	07										0.9769	76.90	-246.80
B	6	211.63	-	-	10.41	-	-	0.05	-	-			
	8	278.38	207.88	208.00	14.60	14.20	29.39	0.05	0.07	0.14			
	10	315.88	219.63	289.25	8.87	5.90	25.19	0.03	0.03	0.09			
	12	387.25	303.63	304.00	17.19	17.53	24.91	0.04	0.06	0.08			
	14	442.88	335.88	357.25	30.76	28.82	28.85	0.07	0.09	0.08			
	16	465.63	411.88	427.38	11.06	16.47	46.49	0.02	0.04	0.11			
	Research										0.9867	25.20	71.60
	Central										0.9587	26.20	-18.40
	07										0.9649	25.30	13.40
C	6	277.75	206.00	231.38	12.12	15.55	26.75	0.04	0.08	0.12			
	8	344.38	279.13	283.75	23.65	14.37	30.65	0.07	0.05	0.11			
	10	398.25	309.25	349.63	15.94	13.11	53.03	0.04	0.04	0.15			
	12	445.00	356.50	479.55	24.04	23.40	55.75	0.05	0.07	0.12			
	14	535.63	399.65	469.50	49.51	37.40	36.15	0.09	0.09	0.08			
	Research										0.9876	30.85	91.70
	Central										0.9831	23.30	77.20
	07										0.9276	33.70	26.00

October 1970
300 PSI

TABLE 7
SOIL-CEMENT REQUIREMENT CHART

PARISHES: Allen, Avoyelles, Beauregard, Grant, Natchitoches, Rapides, Sabine, Vernon, Winn

Soil Types	A-Group	% Cement by Volume Recommended
Sand	A-3	13%
Sand	A-2-4	10%
Sandy Loam	A-2-4, A-4, A-2-6, A-6	9%
Sandy Clay Loam	A-2-4, A-4, A-2-6, A-6	9%
Sandy Clay	A-2-4, A 4, A-2-6, A-6	11%
Lt. Sandy Clay	A-4, A-6	11%
Loam	A-4, A-6	10%
Clay Loam	A-4, A-6	10%
Silty Loam-50%-69% Silt	A-4, A-6	11%
Silty Loam-70%-74% Silt	A-4, A-6	12%
Silty Loam-75%-79% Silt	A-4, A-6	14%
Silty Clay Loam-50%-69% Silt	A-4, A-6	11%
Silty Clay Loam-70%-74% Silt	A-4, A-6	12%
Silty Clay Loam-75%-79% Silt	A-4, A-6	14%
Silty Clay	A-4, A-6	11%
Lt. Silty Clay	A-4, A-6	11%
Silt	A-4, A-6	*

* NOTE: Must be tested prior to use. Testing time 5 weeks. (LDH TR-432)

Corrections: The following adjustments shall be made according to the occurrence of gravel or clam shell found in the above soils. In no case shall the final cement recommended be less than 6%.

% by weight retained on No. 4 Sieve	Cement Reduction (% by Volume)
0-14	0
15-24	1%
25-39	2%
40-60	3%

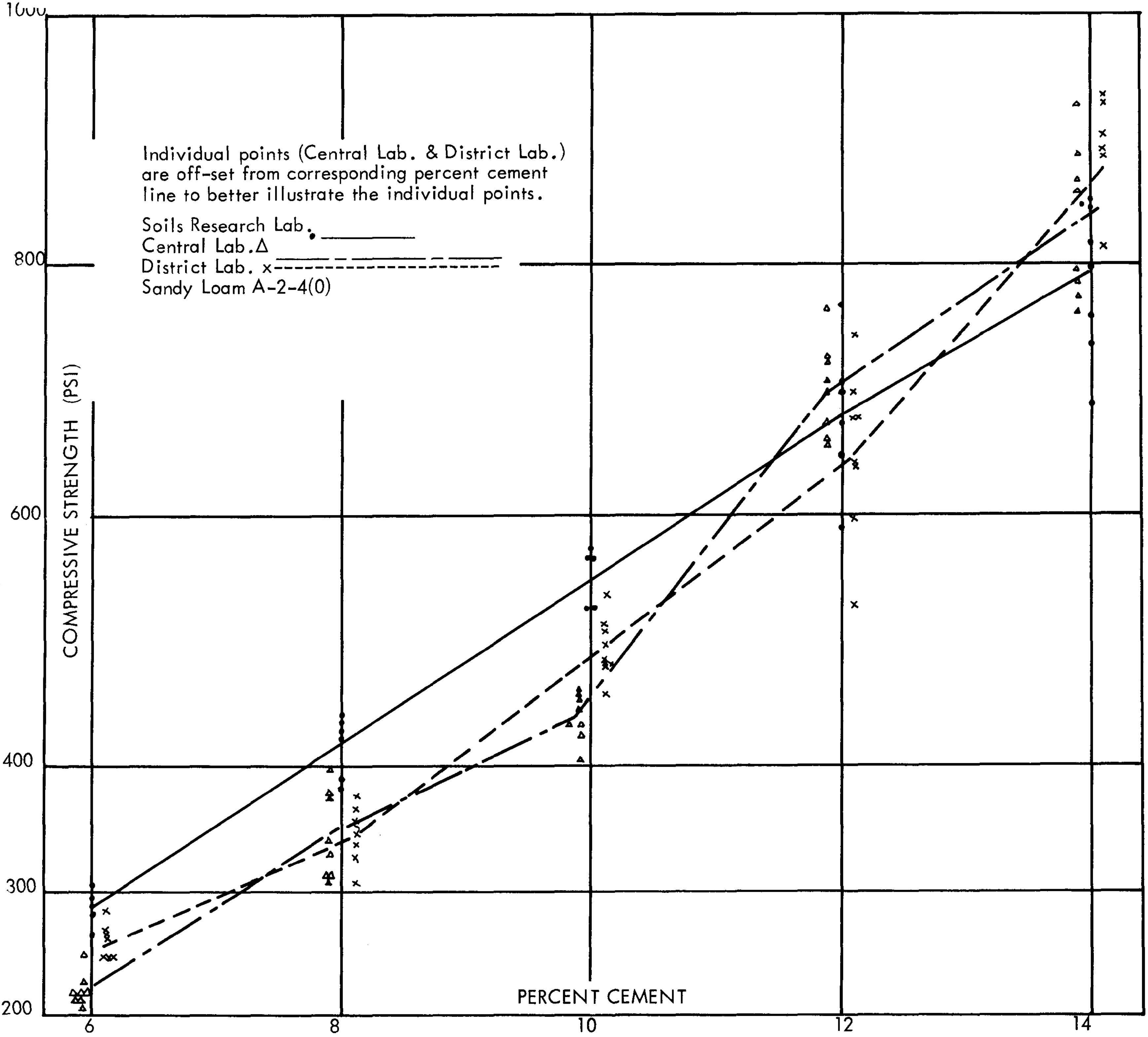

1000
800
600
400
300
200
COMPRESSIVE STRENGTH (PSI)
PERCENT CEMENT
6
8
10
12
14
Individual points (Central Lab. & District Lab.) are off-set from corresponding percent cement line to better illustrate the individual points.
Soils Research Lab. ● ————
Central Lab. Δ — — — —
District Lab. x - - - - - - -
Sandy Loam A-2-4(0)

Figure 10-A

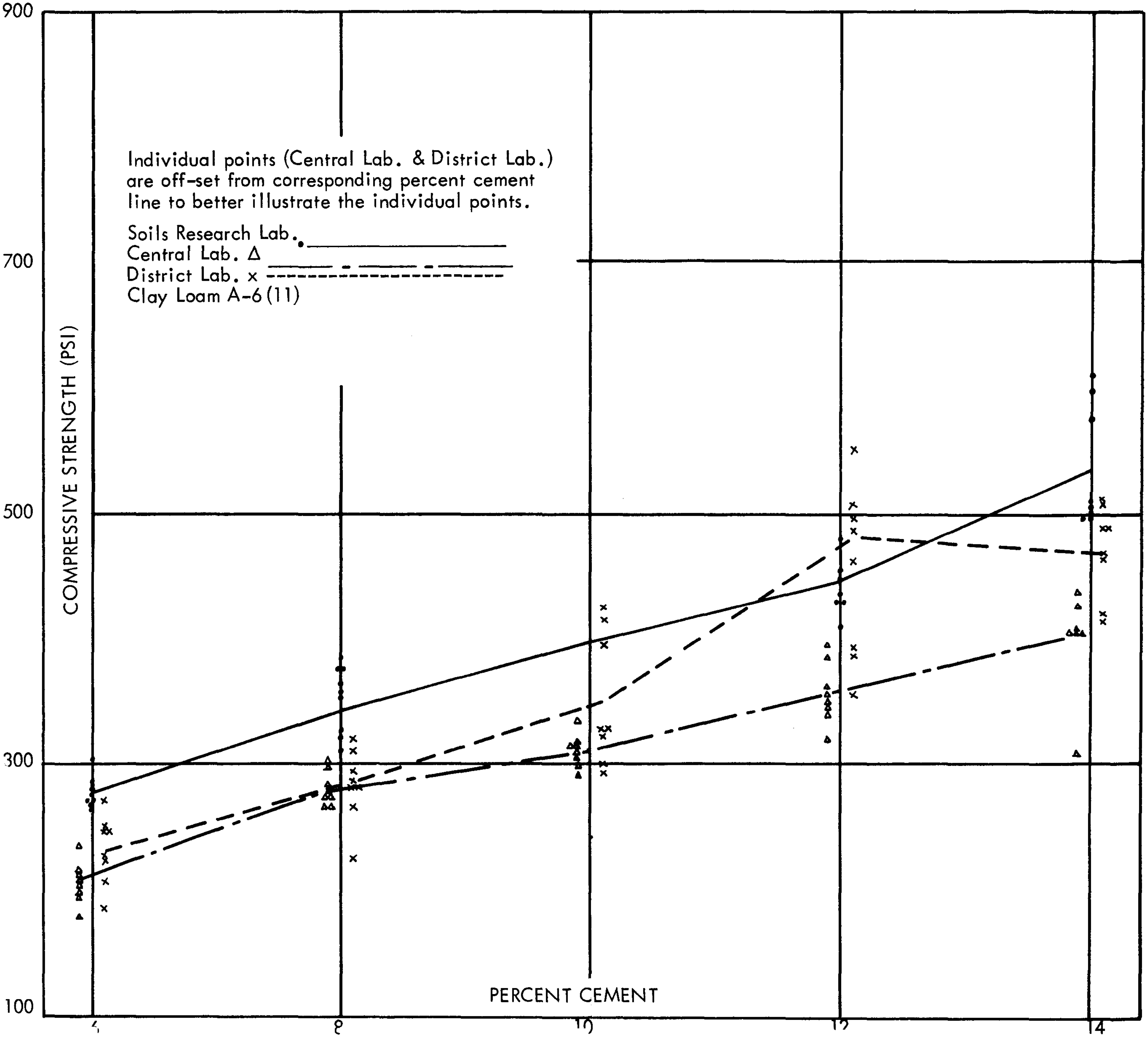
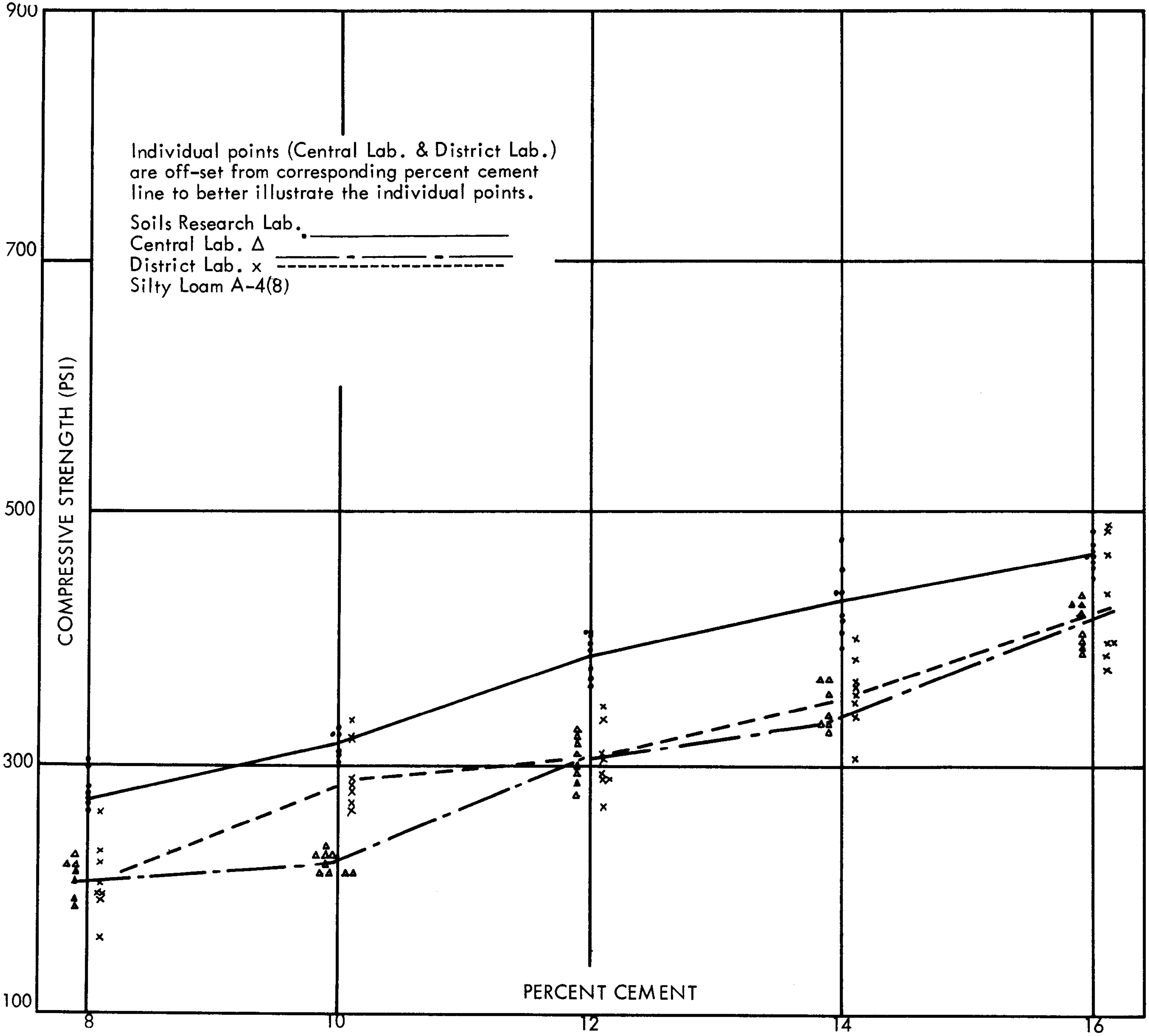
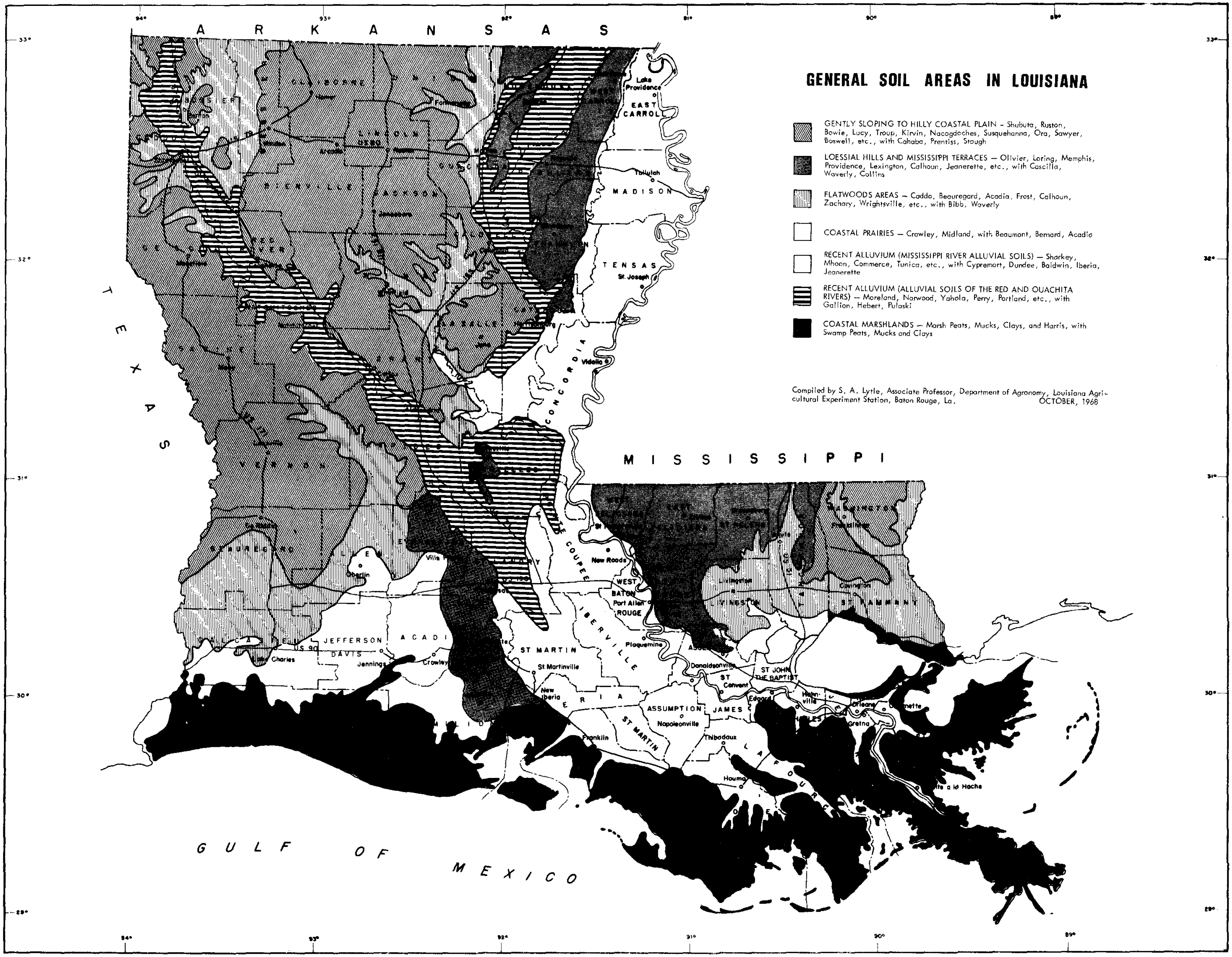

Individual points (Central Lab. & District Lab.) are off-set from corresponding percent cement line to better illustrate the individual points.
Soils Research Lab. •
Central Lab. Δ
District Lab. x
Clay Loam A-6 (11)
COMPRESSIVE STRENGTH (PSI)
900
700
500
300
100
PERCENT CEMENT
6
8
10
12
14

Figure 10-B

Figure 10-C


Individual points (Central Lab. & District Lab.) are off-set from corresponding percent cement line to better illustrate the individual points.
Soils Research Lab. •
Central Lab. Δ
District Lab. x
Silty Loam A-4(8)
COMPRESSIVE STRENGTH (PSI)
900
700
500
300
100
PERCENT CEMENT
8
10
12
14
16

GENERAL SOIL AREAS IN LOUISIANA



▧ GENTLY SLOPING TO HILLY COASTAL PLAIN – Shubuta, Ruston, Bowie, Lucy, Troup, Kirvin, Nacogdoches, Susquehanna, Ora, Sawyer, Boswell, etc., with Cahaba, Prentiss, Stough

▩ LOESSIAL HILLS AND MISSISSIPPI TERRACES — Olivier, Loring, Memphis, Providence, Lexington, Calhoun, Jeanerette, etc., with Cascilla, Waverly, Collins

▥ FLATWOODS AREAS — Caddo, Beauregard, Acadia, Frost, Calhoun, Zachary, Wrightsville, etc., with Bibb, Waverly

☐ COASTAL PRAIRIES — Crowley, Midland, with Beaumont, Bernard, Acadia

☐ RECENT ALLUVIUM (MISSISSIPPI RIVER ALLUVIAL SOILS) — Sharkey, Mhoon, Commerce, Tunica, etc., with Cypremort, Dundee, Baldwin, Iberia, Jeanerette

▤ RECENT ALLUVIUM (ALLUVIAL SOILS OF THE RED AND OUACHITA RIVERS) — Moreland, Norwood, Yahola, Perry, Portland, etc., with Gallion, Hebert, Pulaski

■ COASTAL MARSHLANDS — Marsh Peats, Mucks, Clays, and Harris, with Swamp Peats, Mucks and Clays

Compiled by S. A. Lytle, Associate Professor, Department of Agronomy, Louisiana Agricultural Experiment Station, Baton Rouge, La. OCTOBER, 1968

CEMENT CONTENT OF SOIL-CEMENT MIXTURES

SCOPE

The laboratory determination of cement content in soil-cement mixtures.

APPARATUS

1. Analytical balance capable of weighing to .0001 of a gram.
2. No. 40 Whatman filter paper.
3. Furnace capable of 1200°F.
4. No. 40 sieve.
5. Glass funnels and beakers.
6. Jaw crucible.
7. Hot plate.
8. Dessicator.

REAGENTS

1. Ammonium hydroxide (1:1) ratio.
2. Hydrochloric acid (1:1) ratio.
3. Ammonium oxalate solution (50 gram/lites).
4. Methyl orange indicator (1 gram/lites).

SAMPLE

1. Raw soil.
2. Sample of Portland Cement used.
3. Soil-cement mixture to be tested.
4. Sample size-200 grams and passing No. 40 sieve.

PROCEDURE

1. Dry one gram of material (.50 gram for Portland Cement) in an oven overnight at 230°F.
2. Record dry weight of sample.
3. Place sample in beaker, add 1:1 HCl, pulverize with glass rod and allow one minute for digestion.
4. Add distilled water and evaporate until dry.
5. Add 25 ml of 1: 1 HCl and heat for 10 minutes at 80°C.

6. Filter the sample and wash with hot HCl and then 3 times with hot H_20.
7. Discard the precipitate.
8. Heat filtrate on hot plate to 80°C for five minutes.
9. Add three drops of methyl orange to filtrate.
10. Add ammonium hydroxide slowly until yellow color appears, then boil for one minute. Do not allow sample to sit for more than five minutes before filtered. Filter the sample through two filter papers.
11. Wash filter paper with hot distilled water three times. Discard precipitate.
12. Place filtrate on hot plate until temperature reaches 80°C, then add HCl until solution turns red.
13. Add 30cc of ammonium oxalate and allow precipitate to form for five minutes. Add HCl, a drop at a time, until all precipitate is dissolved.
14. Let solution digest for five minutes.
15. Add NH_3OH until precipitate forms, bring to boil, then remove from hot plate. Allow the sample to sit for 30 minutes undisturbed.
16. Filter the sample through 2 No. 40 filter papers, wash three times, then discard filtrate.
17. Place the filter paper and the precipatate in a crucible on a hot plate at 500°F for 30 minutes.
18. Place the crucible in a furnace at 1200°F for four hours.
19. Remove crucible from furnace and place in dessicator to cool.
20. Weigh residue (Ca0) to .0001 of a gram.

CALCULATIONS

1. % Ca0 in Portland Cement $= \dfrac{\text{wt. Ca0}}{\text{wt. of dry sample}} \times 100$

2. Weight of Ca0 in Raw Soil $= \dfrac{\text{wt. of Ca0}}{\text{wt. of dry sample -wt. Ca0}}$

3. Weight of Ca0 in Soil-Cement Mixtures $= \dfrac{\text{wt. of Ca0}}{\text{wt. of dry sample-wt. Ca0}}$

4. % Portland Cement in Soil-Cement Mixtures =

$$\frac{\text{wt. of Ca0 (S/C)-wt. of Ca0 (RS)}}{\text{Ca0 of Portland Cement}} \times 100$$

Method of Rapid Design For
THE CEMENT CONTENT OF SOIL-CEMENT MIXTURES
by
THE LOUISIANA SLOPE VALUE METHOD
LDH DESIGNATION: TR 422-66

Scope

1. This method is intended for determining the minimum cement requirement for design use in the construction of soil-cement base and subbase courses.

Test Methods

2. (a) Soil samples shall be prepared in accordance with AASHO Designation: T 87-49 (LDH Designation: 411-58) Standard Method of Dry Preparation of Disturbed Soil Samples for Test.

(b) Soils shall be classified in accordance with AASHO Designation: M 145-49 - The Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes.

(c) The moisture-density relations of the soil-cement mixture shall be determined by adhering to AASHO Designation: T 134-57 - Standard Methods of Test for Moisture-Density Relations of Soil-Cement Mixtures.

(d) Specimens for unconfined compressive strength determinations shall be molded in accordance with Paragraph 4, ASTM Designation: D 559-57 - Wetting and Drying Tests of Compacted Soil-Cement Mixtures.

(e) The compressive strength specimen shall be tested in accordance with ASTM Designation: D 1633-59T with the following exceptions:

(1) Test specimens shall have a diameter of 4.0 inches and a height of 4.6 inches.

(2) Specimens shall be moist room cured at approximately 100% relative humidity for a period of seven days.

(3) Immediately upon removal from the moist room, the specimens shall be measured for height and diameter, capped with a commercial capping compound (Trade Name: Vitrobond or gypsum plaster), and immersed in clean water for a period of four hours prior to testing.

Procedure

After the soil is classified, a range of cement contents is selected according to the following: A-2-4, A-3 and A-4 should be molded at cement contents ranging from 5% to 9% by weight, and the range for A-6 soils should be from 6% to 10% by weight.

A minimum of two (preferably three) cylinders are molded at each of the three cement contents selected, tagged and cured in the moist room for the required 7 days, after which the samples are measured, capped and immersed in water for 4 hours prior to testing for unconfined compressive strength. Upon completion of the compressive strength, the appropriate "slope values" are determined by the following formula:

$$\text{Slope Value} = \frac{B-A}{Y-X} \times \frac{1}{100} \text{ or } \frac{C-B}{Z-Y} \times \frac{1}{100}$$

Where:

A = Unconfined compressive strength at the lowest cement content.

B = Unconfined compressive strength at the median cement content.

C = Unconfined compressive strength at the highest cement content.

X = Lowest cement content by weight.

Y = Median cement content by weight.

Z = Highest cement content by weight.

"Maximum Slope Value" represents the highest value obtained from the above expression and is used for A-2-4, A-3, and all A-4 soils with plasticity indices of ten or less. "Minimum Slope Value" would be the lowest value derived from the above formula and is used for the A-6 and A-7-6 groups of soils. For example:

Point	Cement Content % by Weight	Failure Stress PSI
A	5.08	342
B	6.89	455
C	8.77	603

$$\text{Maximum Slope Value} = \frac{603 - 455}{8.77 - 6.89} \times \frac{1}{100} = 0.79$$

$$\text{Minimum Slope Value} = \frac{455 - 342}{6.89 - 5.08} \times \frac{1}{100} = 0.62$$

The appropriate slope value is then located on the proper chart or on the following table for the minimum cement content requirement.

MINIMUM CEMENT REQUIREMENT

USING THE LOUISIANA SLOPE VALUE METHOD

Soil Classification	Slope Value Type	Slope Value	Min. Cement Requirement by Weight, %
A-2-4, A-3	Maximum	0.46 - 0.60	6
		0.61 - 0.85	7
Non-plastic A-4 (P.I. 0.0 - 3.0)	Maximum	0.24 - 0.36	5
		0.37 - 0.56	6
		0.57 - 0.75	7
		0.76 - 0.90	8
		0.91 - 0.94	9
Plastic A-4 (P.I. 3.0 - 10.0)	Maximum	0.18 - 0.20	5
		0.21 - 0.30	6
		0.31 - 0.67	7
		0.68 - 1.25	8
A-6 and A-7-6	Minimum	0.17 - 0.27	8
		0.28 - 0.34	7
		0.35 - 0.36	6

Note: Slope values which vary greatly from the limiting values should be verified by the complete Wetting-Drying Test (AASHO Designation: T 135-57).

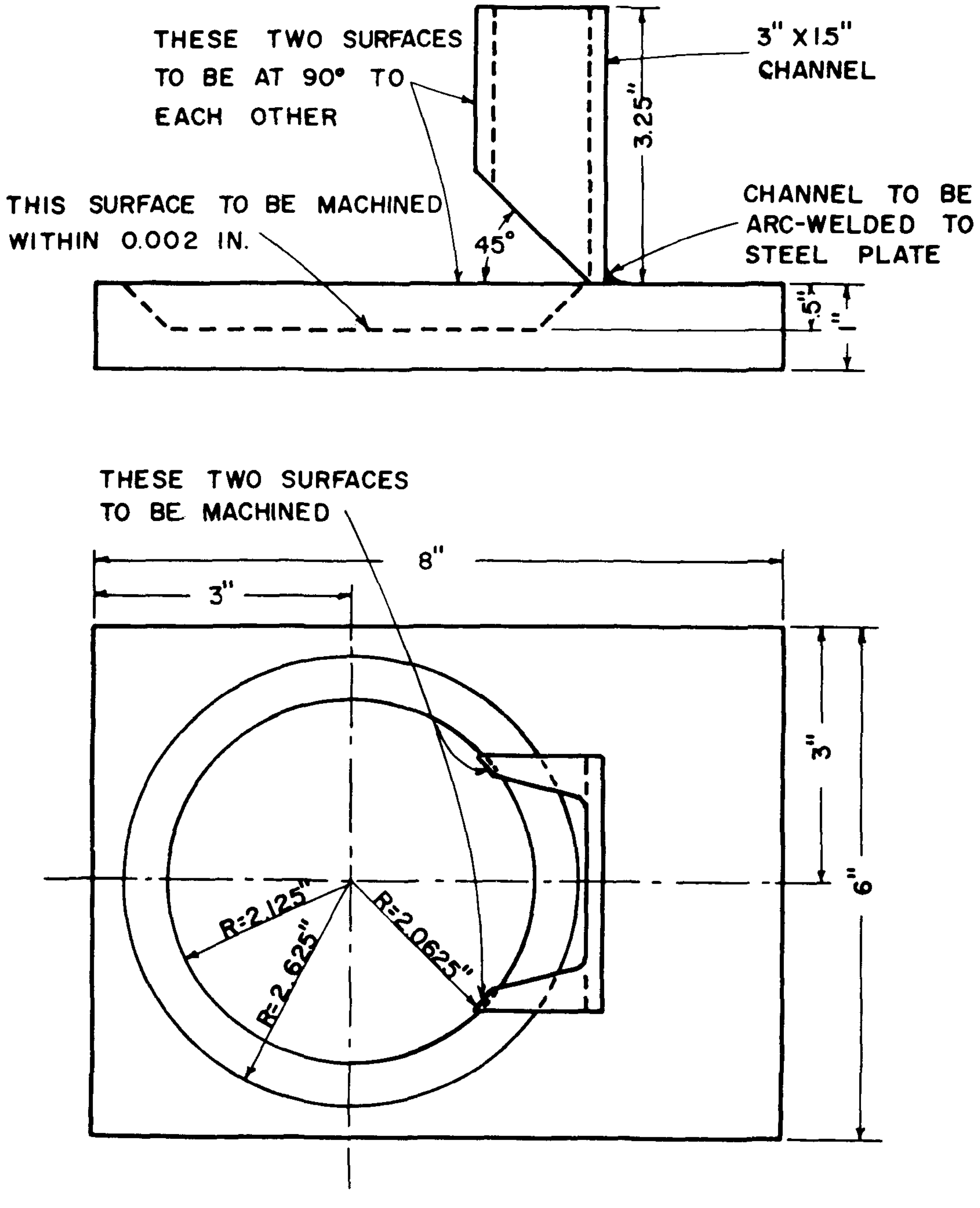


FIGURE 1

Cylinder Capping Mold