LABORATORY EVALUATION OF FLYASH TREATED EMBANKMENT AND BASE MATERIALS

INTERIM REPORT NO. 1

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ABSTRACT

This study was undertaken to provide the Louisiana Department of Transportation and Development (LDOTD) with a data base from which decision-making information can be taken concerning the modification or stabilization of soils using flyash as a full or partial replacement for hydraulic cement or hydrated lime.

This report deals with application to pavement bases only. It is further restricted to two soil types that are commonly used in road bases in Louisiana. Data was obtained from soil specimens combined with cement, lime, and/or flyash from three local generating plants.

Unconfined compressive strengths and vacuum saturation strengths were compared to those presently required for stabilization using cement as the sole additive.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
Length		
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
Volume (Capacity)		
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
Mass per Volume		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

INTRODUCTION

The use of flyash, aside from a positive use of a "waste" product, could provide the LDOTD with a direct monetary savings on materials in that its use would reduce the amount of cement or lime currently being used to stabilize or modify soils. Coal burning power plants in Louisiana are now producing a self-hardening ASTM Class C flyash which may have the ability to enhance the quality of treatment of soils with lime or portland cement.

This study will provide a data base from which decision-making information can be taken to modify or stabilize pavement base soils using locally produced flyash. The proportions of flyash, cement, or lime needed to achieve acceptable strengths will be recorded. Strengths of soils modified by flyash must reach comparable strengths achieved through the addition of cement or lime alone to be acceptable. Tests used to determine strength parameters will include unconfined compression and vacuum saturation.

This interim report covers only Phase I of a two-phase study. Phase I is limited to two soils used commonly for pavement bases; Phase II will be devoted to soils used in embankment construction. Each soil will be evaluated with respect to percent additive, flyash source, strength index, and curing time.

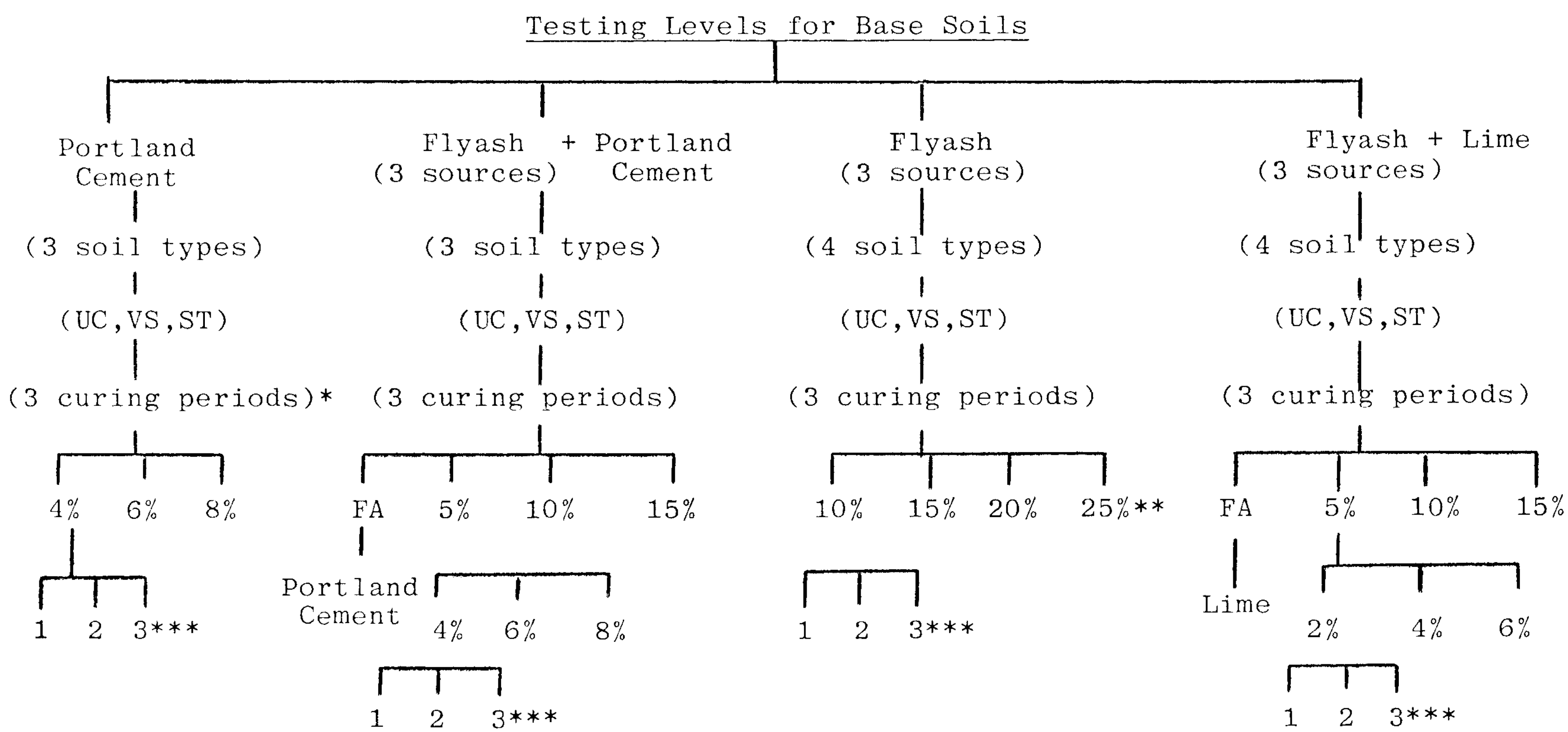
METHODOLOGY

Method of Procedure

The experimental design for Phase I of this study is illustrated in Figure 1 on Page 3. The variables discussed in this report are as follows:

soil types	sand (A-3-0) and sandy silt (A-2-4)
tests	vacuum saturation, unconfined compression, and indirect tensile
curing periods	7, 28, and 56 days
% flyash	5, 10, 15, 20, 25 and 30 (by weight)
% cement	4, 6 and 8 (by weight)
% lime	2, 4 and 6 (by weight)
flyash sources	1. Cajun Power Plant - New Roads, La. 2. Nelson Power Plant - Westlake, La. 3. Rodemacher Power Plant - Boyce, La.

EXPERIMENTAL DESIGN



*Specimens tested after 7, 28, 56 days curing.

**Percentages may vary according to specific soil types.

***Replicas.

FIGURE 1

Laboratory Molding and Testing Pocedures

Soil samples were obtained, oven-cured at 140°F, and prepared in the lab. Optimum moisture contents and dry weight densities were obtained for all combinations of flyash, cement and lime using LDOTD procedure TR418-81. Summaries of these design values are shown in Tables 5 and 6 of the Appendix (pages 53 and 54).

All materials were mechanically mixed dry for one minute and wet for two minutes. A slake time of one minute was followed by an additional two minutes of mixing. Specimens were immediately compacted in a standard Proctor mold (4 inches diameter by 4.6 inches high) with three layers at 25 blows per layer using a mechanical hammer with a drop height of 12 inches. After molding, specimens were immediately extruded and cured prior to testing for 7, 28 or 56 days at a temperature of 73.4 + 3°F and a relative humidity of 90 percent or greater.

Moisture contents during compaction were allowed to vary within plus or minus one percent of optimum, and dry weight densities were maintained to within plus or minus three pounds of the theoretical dry weight density. Any specimens not meeting moisture or density requirements were remolded.

After curing, each set of three specimens was soaked four hours and then tested in unconfined compression. Three specimens were also conditioned in a vacuum saturation chamber and tested for compressive strength according to ASTM C593 with the following exception: Vacuum specimens were cured in the Louisiana Transportation Research Center (LTRC) damp room instead of at the 100°F temperature called for in the ASTM procedure. This procedure is hereinafter called modified vacuum saturation procedure.

For each test the average of the three companion specimens was the value reported for analysis. These average values are presented in the Appendix, Tables 7 through 12 (pages 55 to 60).

Materials

Soils

The soils evaluated in this phase were a nonplastic A-3-0 sand and a slightly plastic A-2-4 sandy silt. Each of these soils is commonly used in road base construction in Louisiana. Both soils were obtained from a borrow pit located along the construction route of Interstate 49 in Evangeline Parish. (See Figure 2 on page 6 for locations.)

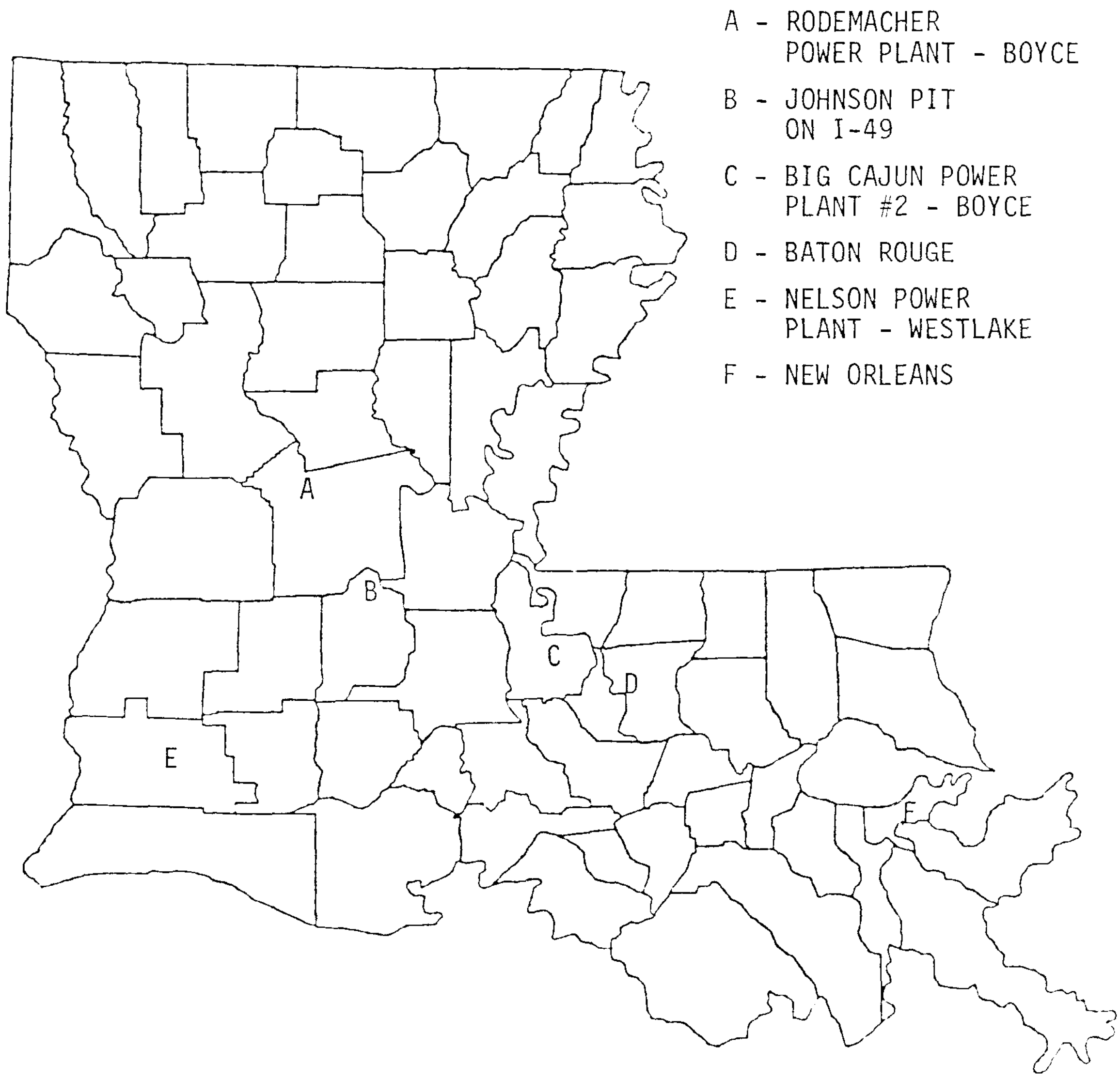
The following DOTD test procedures were used to determine the engineering properties of the raw soils:

1. TR-407-74 Mechanical Analysis of Soils
2. TR-418-81 Moisture Density Relationships
3. TR-428-67 Atterberg Limits of Soils
4. TR-430-67 pH Values of Soils

The results of these tests are summarized in Table 1 of the Appendix (page 49).

Flyash

Three flyashes were tested with each of the two soil types. The producers are currently burning subbituminous coal from the Gilette, Wyoming, area and are producing Class C flyash.



Louisiana State Map

FIGURE 2

All flyashes were tested according to ASTM-C618 for physical and chemical properties. Table 2 on page 50 gives results from these tests for the flyash specimens used in molding. A summary of flyash properties from each generating plant is shown on page 61 of the Appendix. This data was provided by the Materials Testing Laboratory from April 1982 through March 1985.

Lime

The lime used in this study was hydrated, high calcium lime conforming to LDOTD 1982 Specifications. A minimum calcium oxide plus magnesium oxide content of 90 percent by weight of total material is required by Section 1018 of the Specifications. The source of the lime was Pelican State Lime in Morgan City, Louisiana. Lime material properties are presented in Table 4 of the Appendix (page 52).

Cement

The cement used in this study was Type I portland cement which conforms to LDOTD 1982 Specifications, Section 1001. One source of cement used was produced at Lone Star Industries in New Orleans, Louisiana, and the other at Blue Circle Inc. in Birmingham, Alabama. Reported values from chemical and physical tests are shown in Table 3 of the Appendix (page 51).

ACCEPTANCE CRITERIA

Cement Base Stabilization

LDOTD Standard Specifications require that percent cement added to a soil for base stabilization be determined by LDOTD Test TR 432 (Method A or B). This test designation states that the minimum cement content producing an unconfined compressive strength of 250 psi at seven days will be considered the amount required for stabilization.

This same requirement was made of improvement sought by addition of flyash alone or flyash in conjunction with cement.

Lime Base Stabilization

The criteria for soil stabilization using lime requires that the liquid limit after treatment be less than 40 and that the plasticity index be less than 10. Both of the soil types tested in this phase met these requirements prior to testing. The strength requirements for lime specimens or lime-flyash specimens were the same as those specimens containing cement.

RESULTS

Two types of soil were evaluated against three combinations of additives in two different tests, with one of the additives (flyash) coming from three different sources. In an effort to improve readability and minimize confusion, the soils will be discussed separately. The conclusions and recommendations will be a discussion of the two soils taken together.

SAND

Sand and Cement Combinations

Sand and cement strength relationships are illustrated in Figure 3 (page 12). Cement specimens all increased in strength with time and with each additional percentage of cement for unconfined compression and modified vacuum saturation. In most cases the modified vacuum saturation strengths were equal to the compressive strengths.

Sand and Flyash Combinations

Sand and flyash strength combinations are illustrated in Figures 4 and 5 (pages 13 and 14).

Flyash was used as a single additive in quantities of 10, 15, 20 and 25 percent by weight. Above 20 percent by weight and 28 days or beyond curing time, all specimens in this group passed the 250 psi compressive strength criterion. Above 25 percent by weight flyash, all specimens passed regardless of curing time. Generally, these specimens attained a gradual strength gain with time. All specimens achieved half of the reported 56-day strength by 7 days.

The modified vacuum saturation test produced results similar to those in unconfined compression. For the lower percentages of flyash, ten and fifteen percent, the two types of test results were within 20 psi of each other. At higher flyash concentrations and longer curing times the difference grew, although not appreciably, to approximately 60 psi in favor of the unconfined compression test specimens. Figure 5 on page 14 shows the modified vacuum saturation strengths.

Sand, Cement and Flyash Combinations

With the exception of the lowest percentages of the combinations (5 percent flyash and 4 percent cement), all specimens achieved over 300 psi compressive strength at 7 and 28 days curing time. At 56 days the strengths had climbed to over 400 psi. This was true for all sources of flyash.

The modified vacuum saturation specimens followed the same pattern as the unconfined compression specimens. Strengths achieved after modified vacuum saturation were approximately the same as the unconfined strengths.

Flyash, cement and sand combination strengths are illustrated in Figures 6 through 11 on pages 15 to 20.

Sand, Lime and Flyash Combinations

Fifteen percent flyash from any source in combination with four or six percent lime produced strengths ranging from 277 psi at 7 days to over 900 psi at 56 days. Lesser combination percentages of lime and flyash achieved over 300 psi on only one specimen and at the maximum curing time of 56 days.

The addition of lime caused a significant increase in strength over specimens containing flyash as a single additive. Increases for specimens containing lime ranged from 1.5 to 4 times the strength achieved for specimens with flyash alone.

Sand-lime-flyash specimens tested with the modified vacuum saturation procedure showed strengths similar to those achieved in unconfined compression testing.

This group's strength characteristics are illustrated in Figures 12 through 17 on pages 21 to 26.

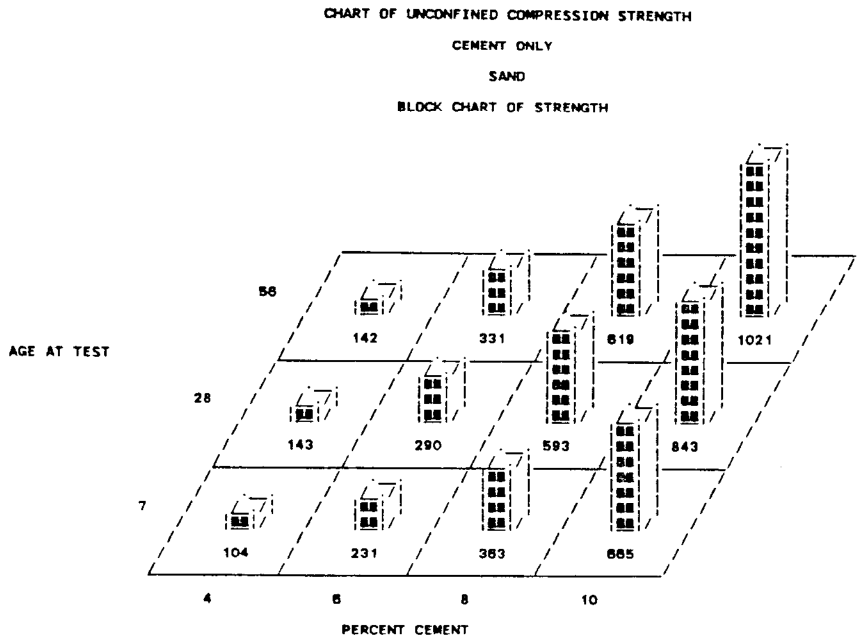


CHART OF UNCONFINED COMPRESSION STRENGTH
CEMENT ONLY
SAND
BLOCK CHART OF STRENGTH
AGE AT TEST
56
28
7
142
331
619
1021
143
290
593
843
104
231
363
665
4
6
8
10
PERCENT CEMENT

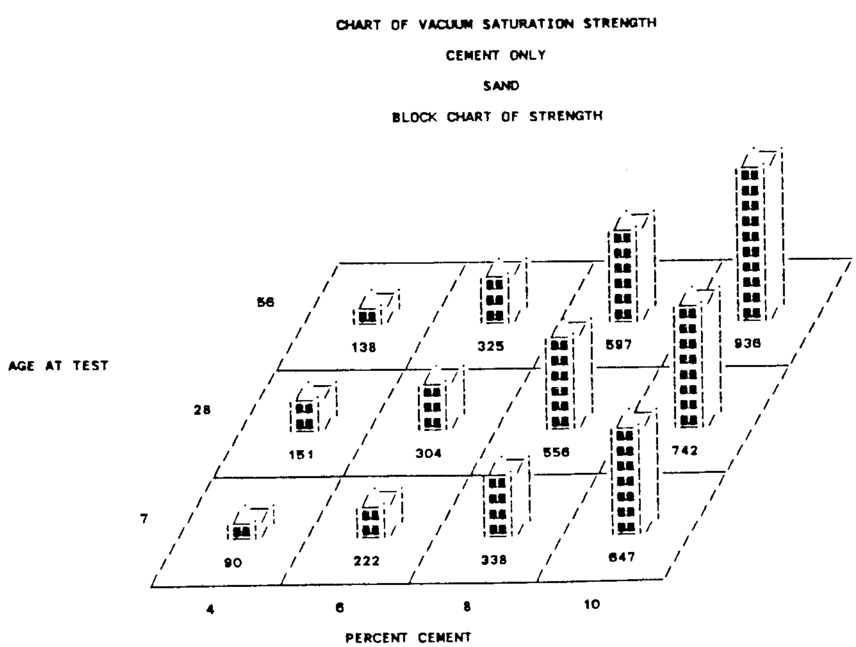


CHART OF VACUUM SATURATION STRENGTH
CEMENT ONLY
SAND
BLOCK CHART OF STRENGTH
AGE AT TEST
56
28
7
138
325
597
936
151
304
556
742
90
222
338
647
4
6
8
10
PERCENT CEMENT

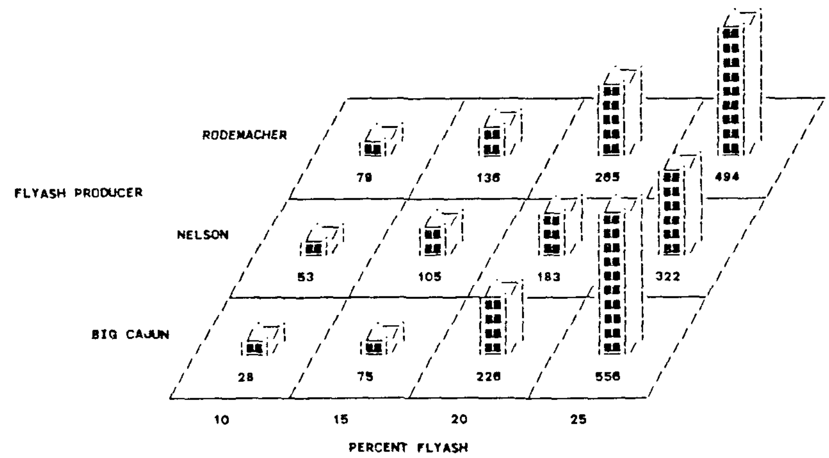
FIGURE 3

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH ONLY

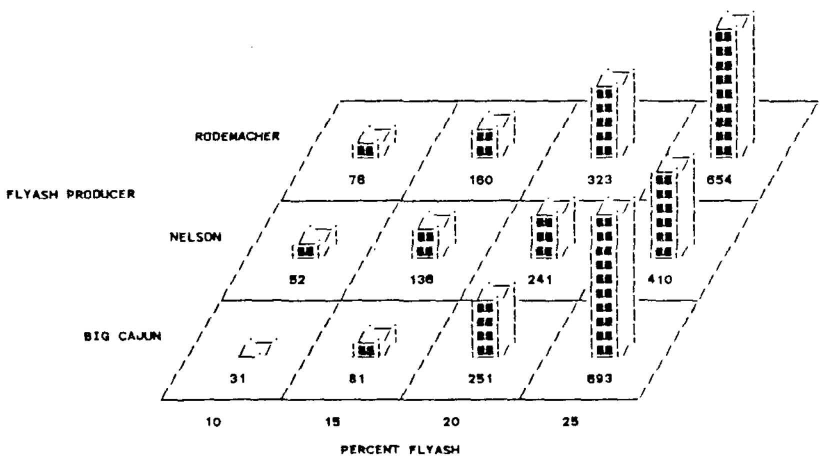
SAND
AGE AT TEST=7

BLOCK CHART OF STRENGTH



SAND
AGE AT TEST=28

BLOCK CHART OF STRENGTH



SAND
AGE AT TEST=56

BLOCK CHART OF STRENGTH

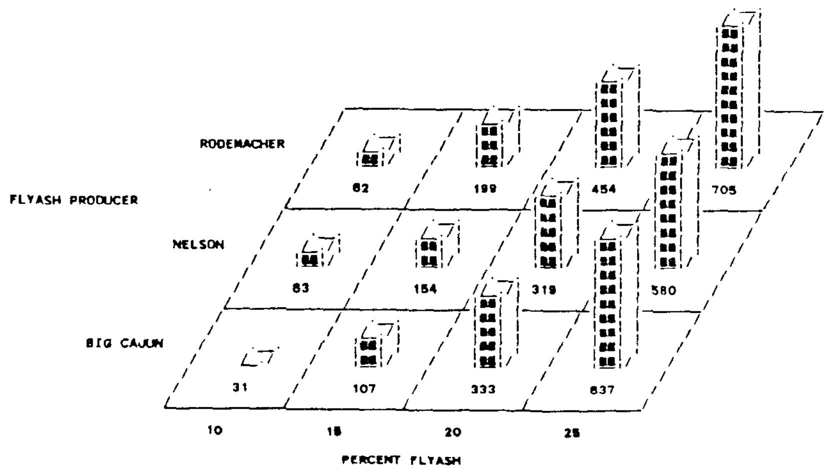


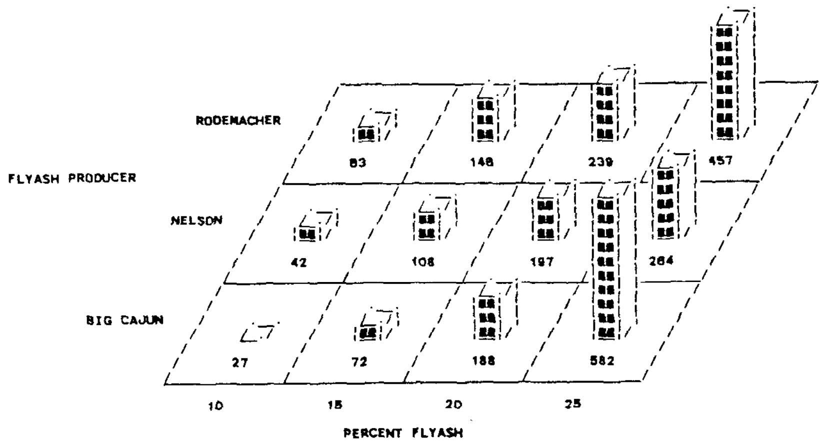
FIGURE 4

CHART OF VACUUM SATURATION STRENGTH

FLYASH ONLY

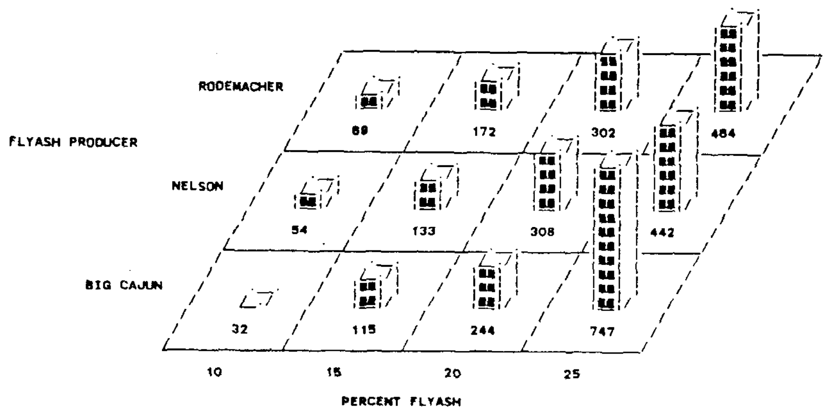
SAND
AGE AT TEST=7

BLOCK CHART OF STRENGTH



SAND
AGE AT TEST=28

BLOCK CHART OF STRENGTH



SAND
AGE AT TEST=56

BLOCK CHART OF STRENGTH

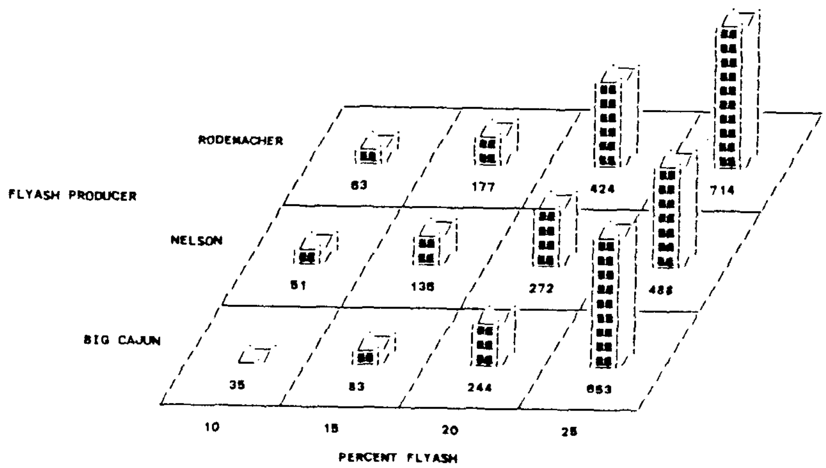


FIGURE 5

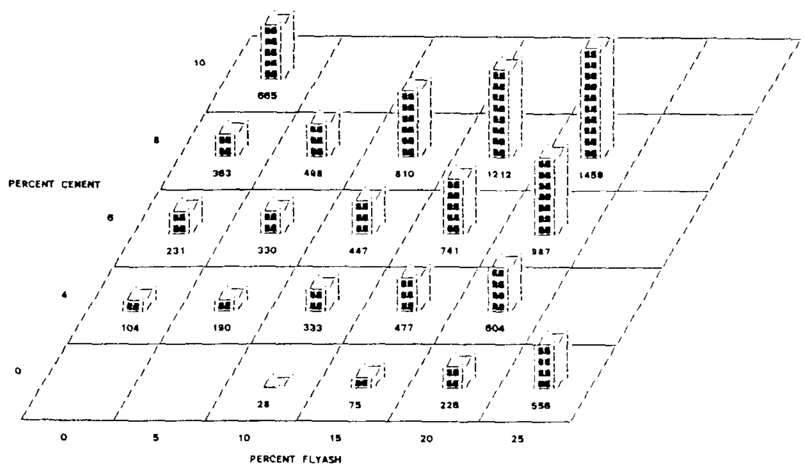
CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND CEMENT COMBINATIONS

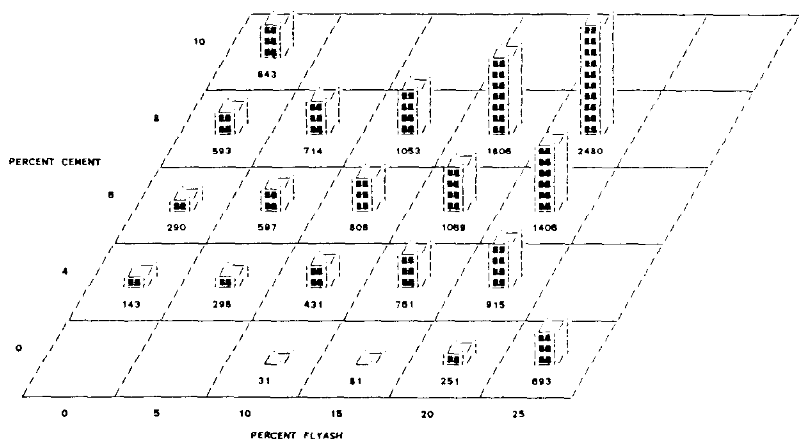
SAND

AGE AT TEST=7   FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH



AGE AT TEST=28



AGE AT TEST=56

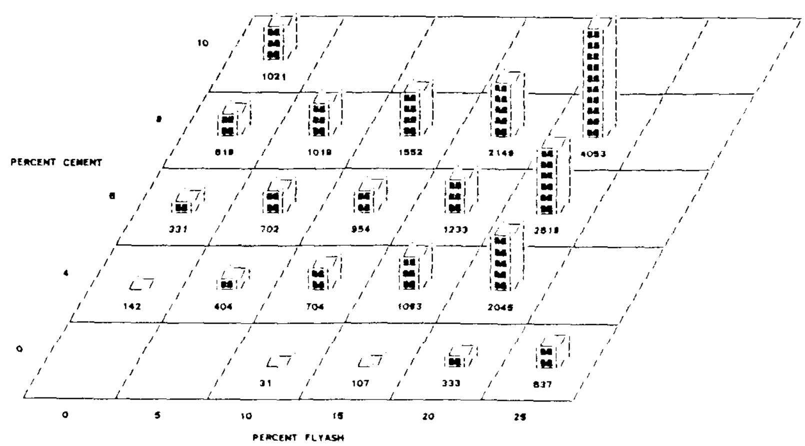


FIGURE 6

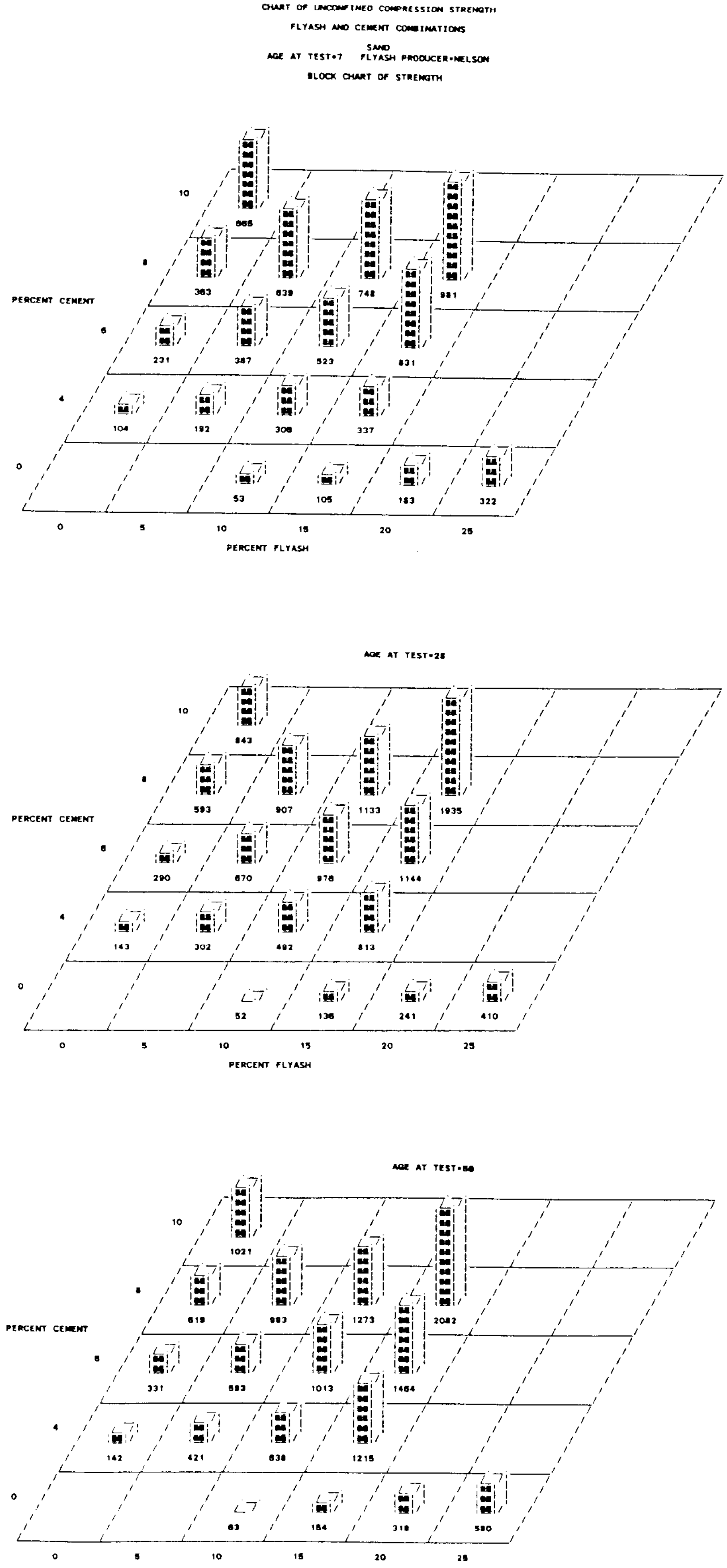
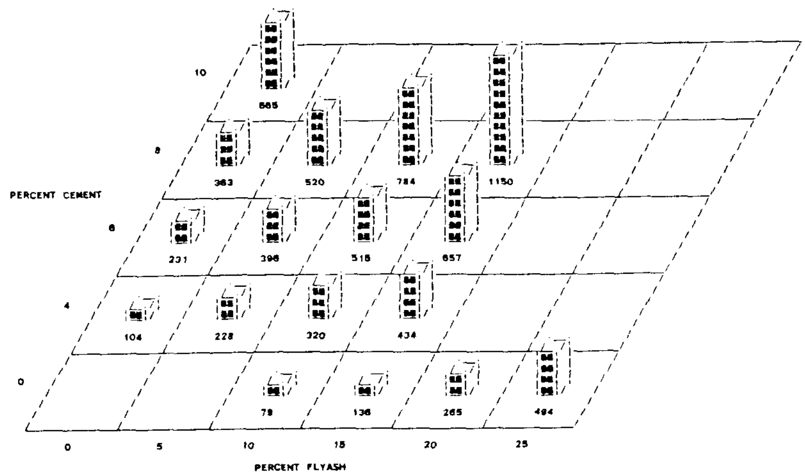


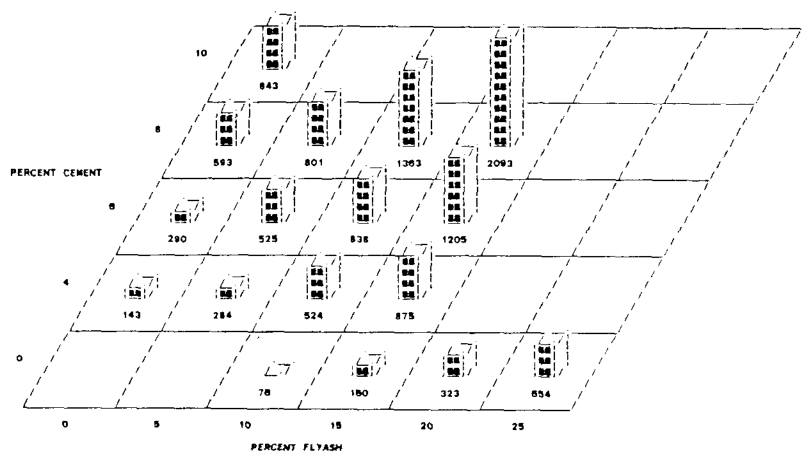
CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT CEMENT
10
8
6
4
0
665
363
839
748
981
231
387
523
831
104
192
306
337
53
105
183
322
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=28
PERCENT CEMENT
10
8
6
4
0
843
593
907
1133
1935
290
670
978
1144
143
302
492
813
52
136
241
410
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=56
PERCENT CEMENT
10
8
6
4
0
1021
619
983
1273
2082
331
583
1013
1464
142
421
638
1215
63
164
318
580
0
5
10
15
20
25
PERCENT FLYASH

FIGURE 7

CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER
BLOCK CHART OF STRENGTH



AGE AT TEST=28



AGE AT TEST=56

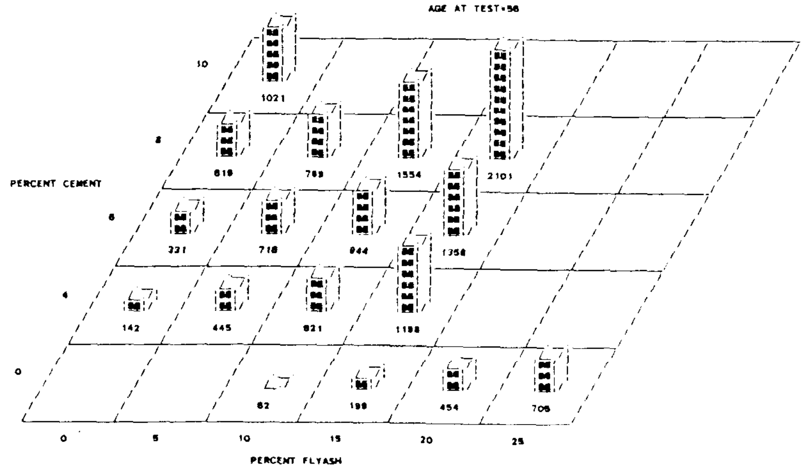


FIGURE 8

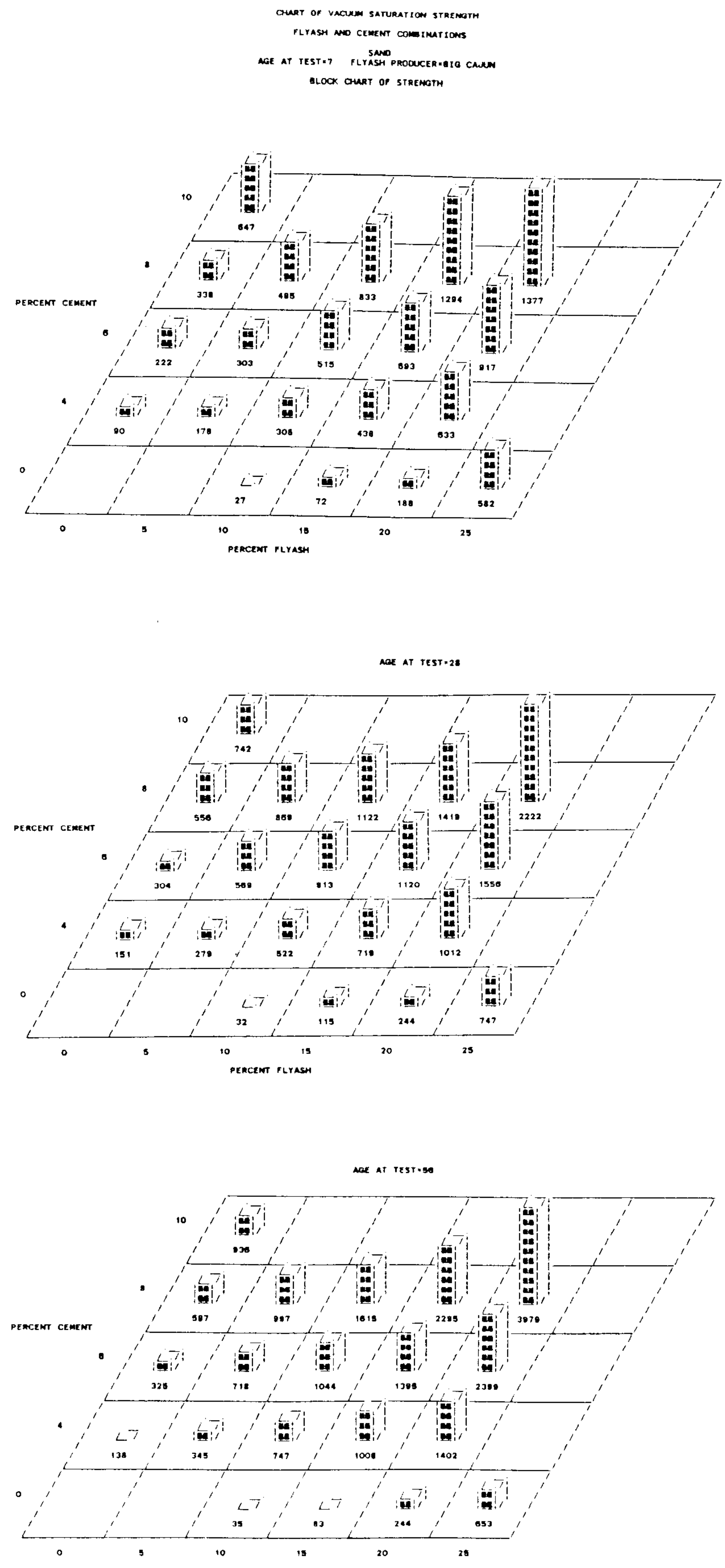


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH
PERCENT CEMENT
10
8
6
4
0
647
338
485
833
1294
1377
222
303
515
693
917
90
178
306
438
633
27
72
188
582
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=28
PERCENT CEMENT
10
8
6
4
0
742
556
869
1122
1419
2222
304
569
913
1120
1556
151
279
522
719
1012
32
115
244
747
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=56
PERCENT CEMENT
10
8
6
4
0
936
597
997
1615
2295
3979
326
718
1044
1396
2399
138
345
747
1006
1402
35
83
244
653
0
5
10
15
20
25
PERCENT FLYASH

FIGURE 9

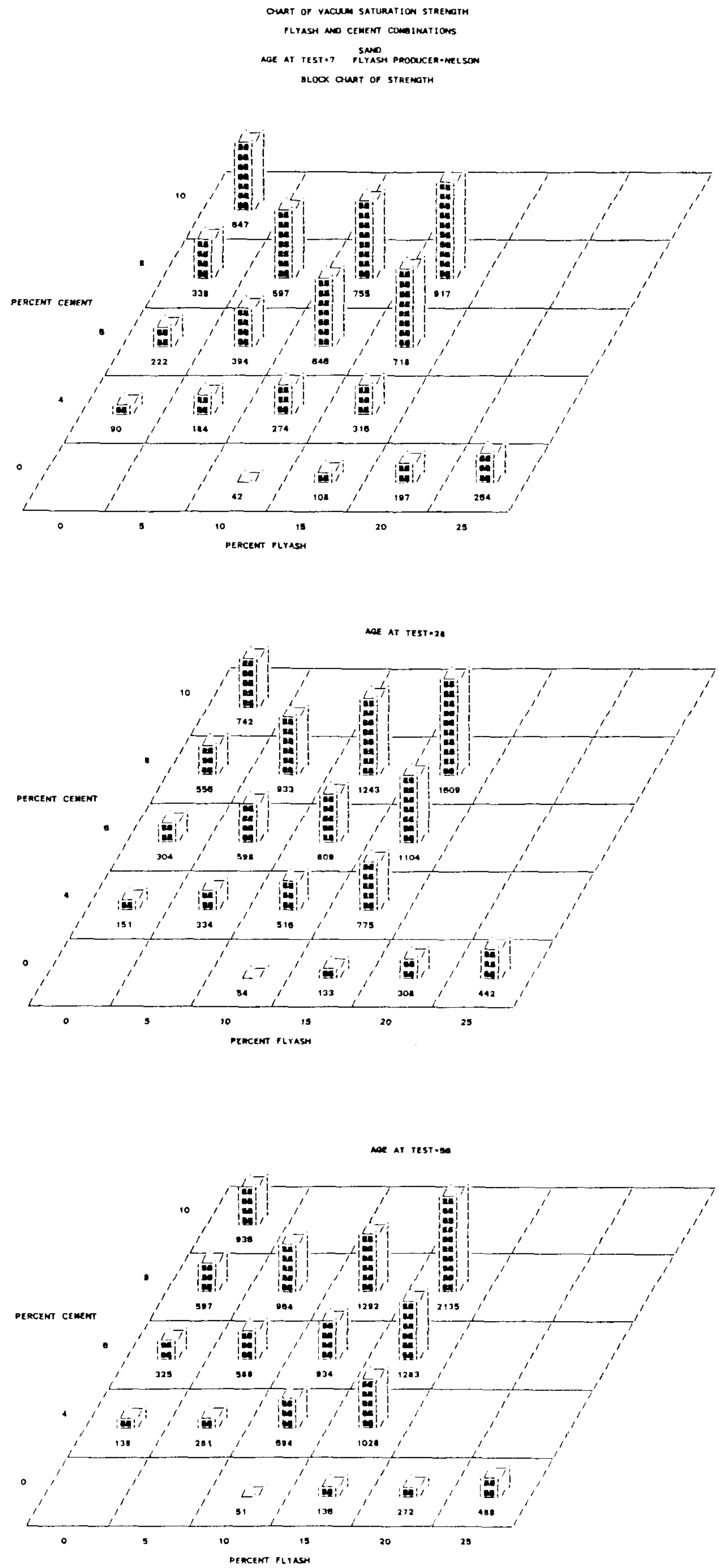


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT CEMENT
10
8
6
4
0
647
338
597
755
917
222
394
848
718
90
184
274
316
42
108
197
264
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=28
PERCENT CEMENT
10
8
6
4
0
742
556
933
1243
1609
304
598
809
1104
151
334
516
775
54
133
308
442
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=56
PERCENT CEMENT
10
8
6
4
0
936
597
964
1292
2135
325
568
934
1283
138
281
684
1028
51
136
272
488
0
5
10
15
20
25
PERCENT FLYASH

FIGURE 10

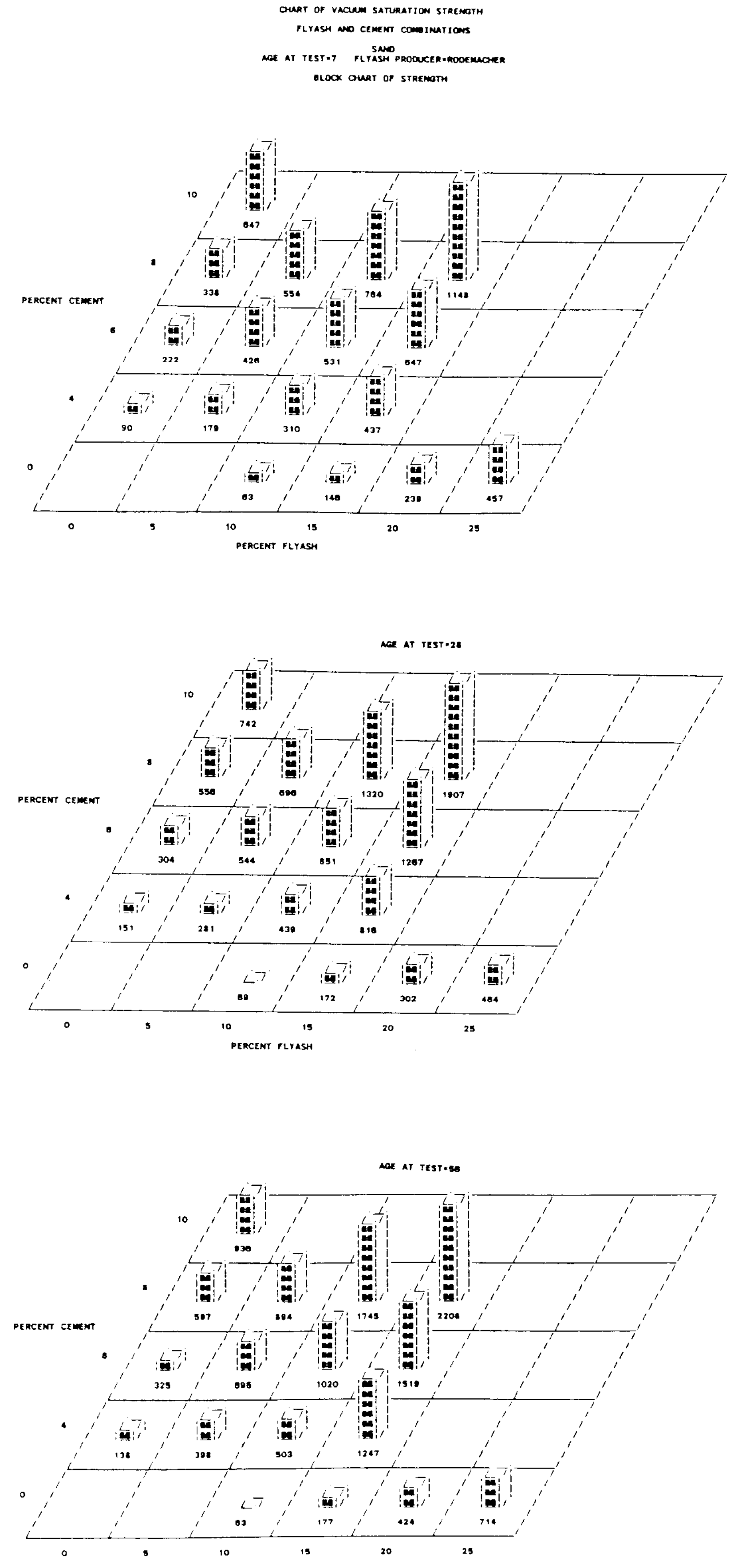


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER
BLOCK CHART OF STRENGTH
PERCENT CEMENT
10
8
6
4
0
647
338
554
784
1148
222
426
531
647
90
179
310
437
63
148
238
457
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=28
PERCENT CEMENT
10
8
6
4
0
742
556
696
1320
1907
304
544
851
1267
151
281
439
816
89
172
302
484
0
5
10
15
20
25
PERCENT FLYASH
AGE AT TEST=56
PERCENT CEMENT
10
8
6
4
0
836
587
894
1745
2206
325
696
1020
1519
138
398
503
1247
63
177
424
714
0
5
10
15
20
25
PERCENT FLYASH

FIGURE 11

CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

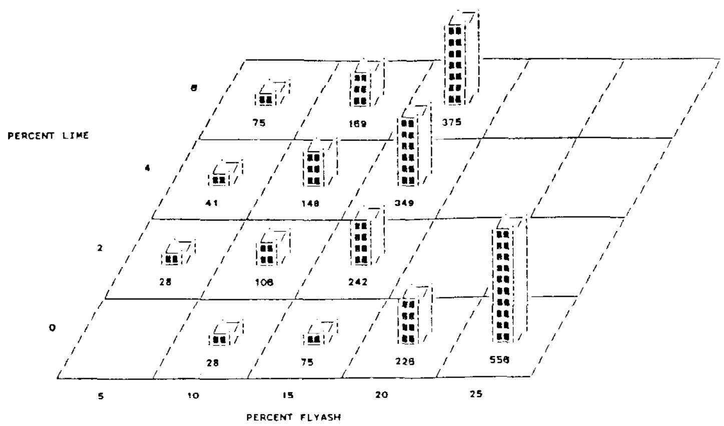


CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=28 FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

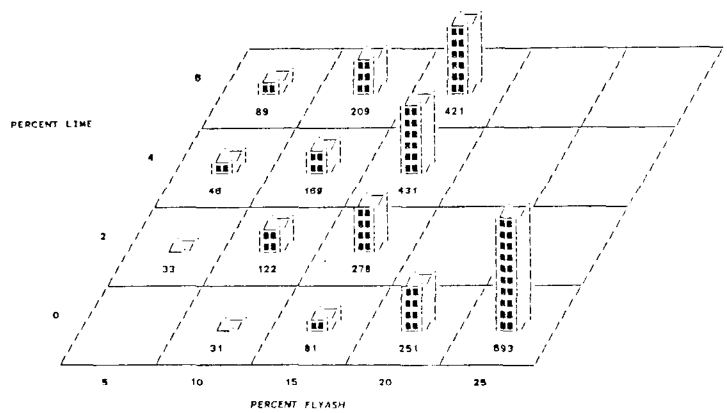


CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=56 FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

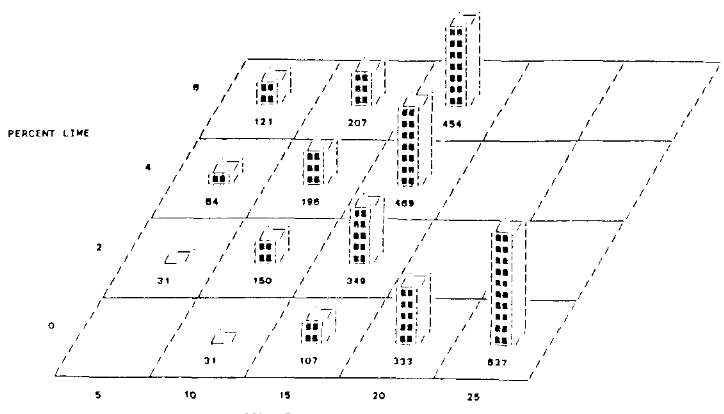


FIGURE 12

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=7   FLYASH PRODUCER=NELSON

BLOCK CHART OF STRENGTH

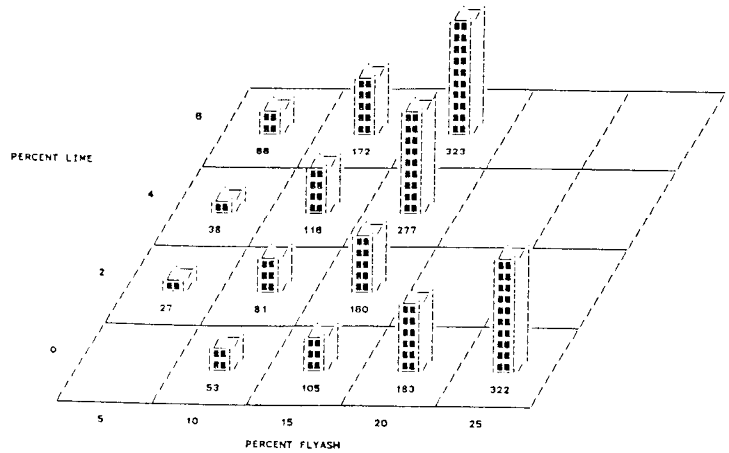


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=28   FLYASH PRODUCER=NELSON

BLOCK CHART OF STRENGTH

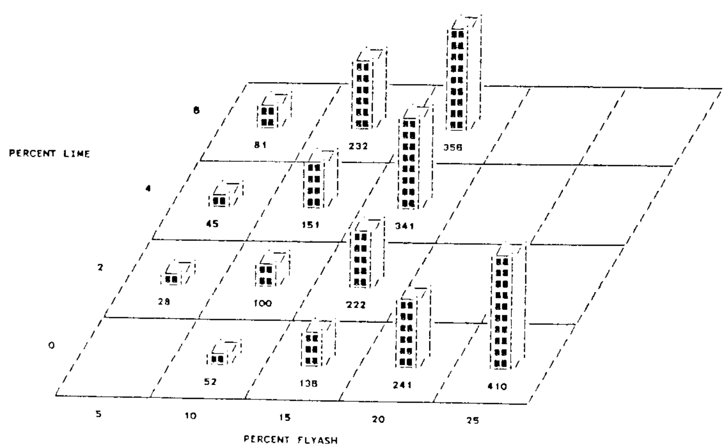


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=56   FLYASH PRODUCER=NELSON

BLOCK CHART OF STRENGTH

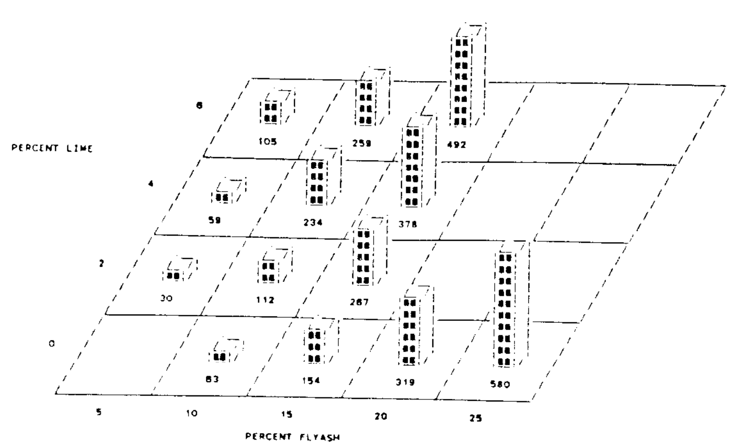


FIGURE 13

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND
AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

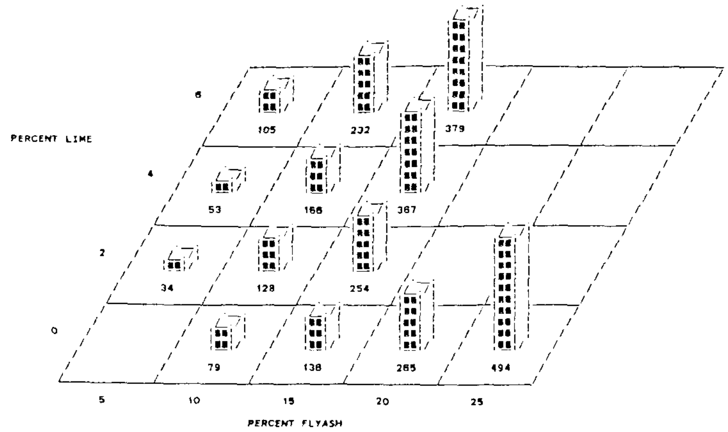


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND
AGE AT TEST=28 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

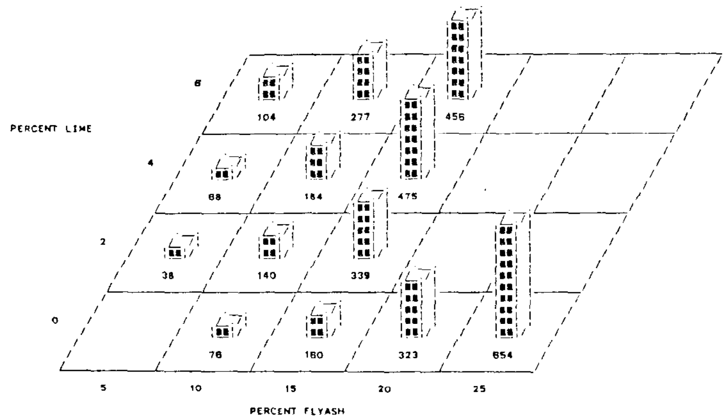


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND
AGE AT TEST=56 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

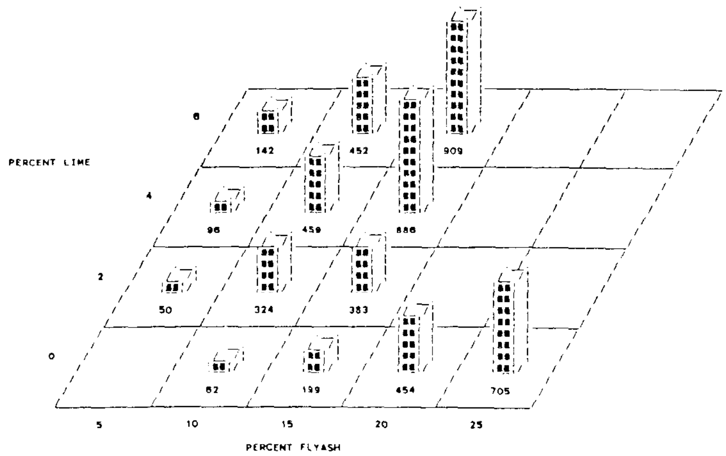


FIGURE 14

CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=7   FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

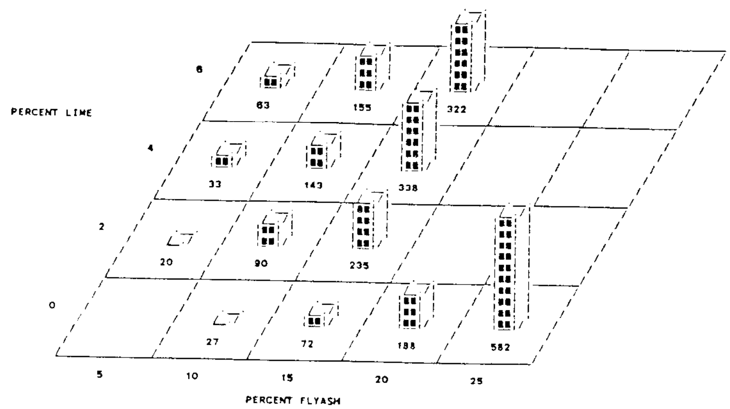


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=28   FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

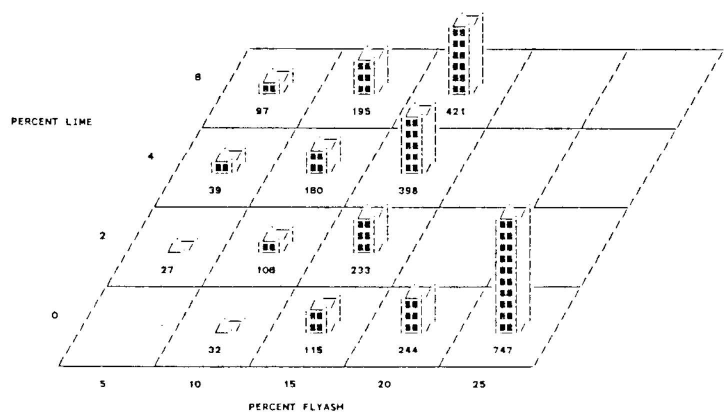


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=56   FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH

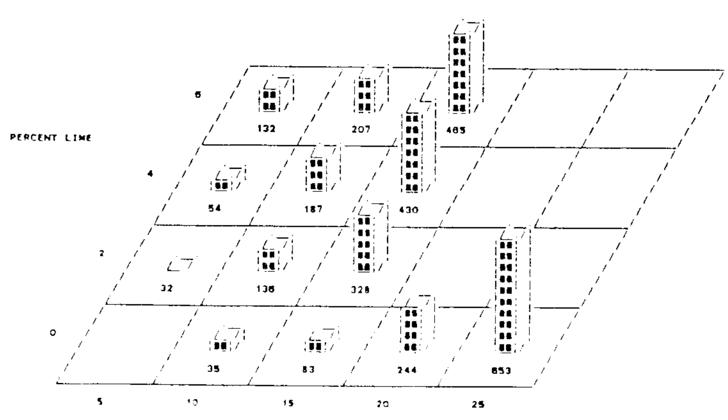


FIGURE 15

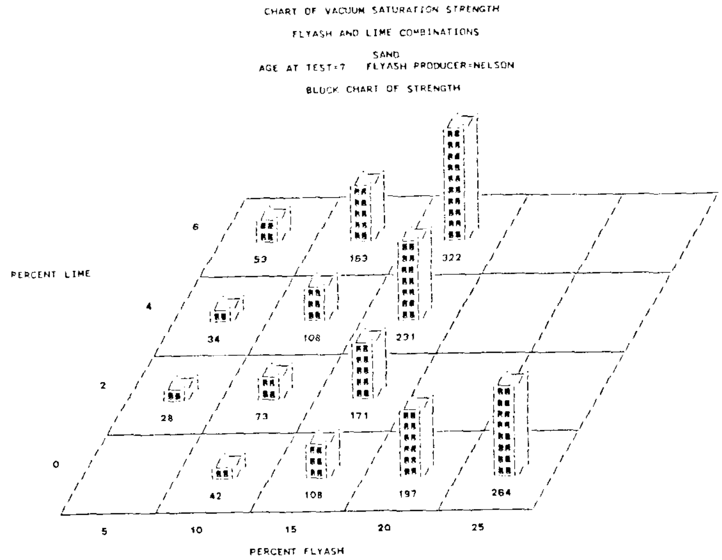


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=7 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT LIME
6
4
2
0
53
163
322
34
108
231
28
73
171
42
108
197
264
5
10
15
20
25
PERCENT FLYASH

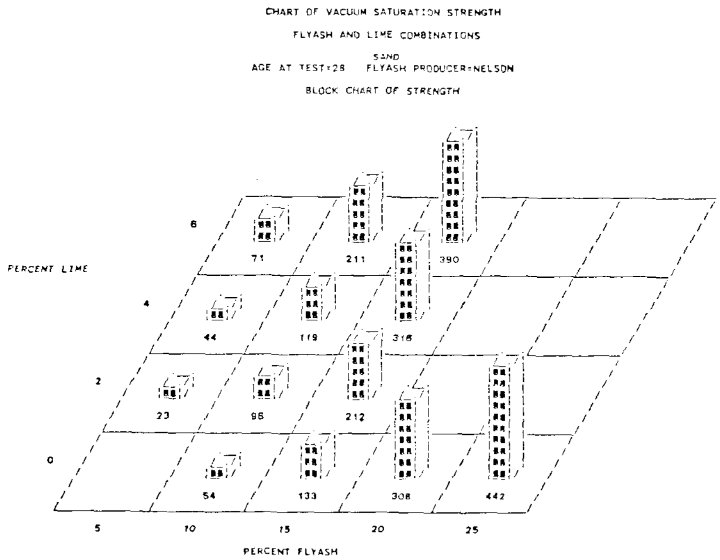


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=28 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT LIME
6
4
2
0
71
211
390
44
119
316
23
98
212
54
133
308
442
5
10
15
20
25
PERCENT FLYASH

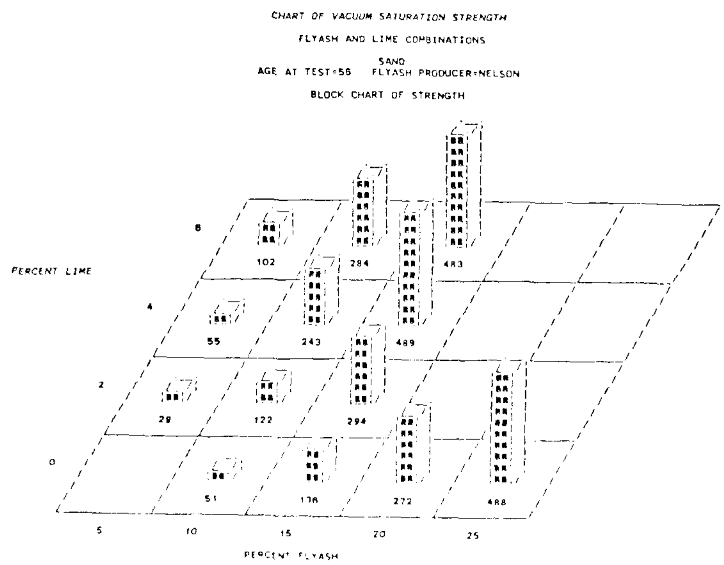


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND LIME COMBINATIONS
SAND
AGE AT TEST=56 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT LIME
6
4
2
0
102
284
483
55
243
489
29
122
294
51
136
272
488
5
10
15
20
25
PERCENT FLYASH

FIGURE 16

CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=7   FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

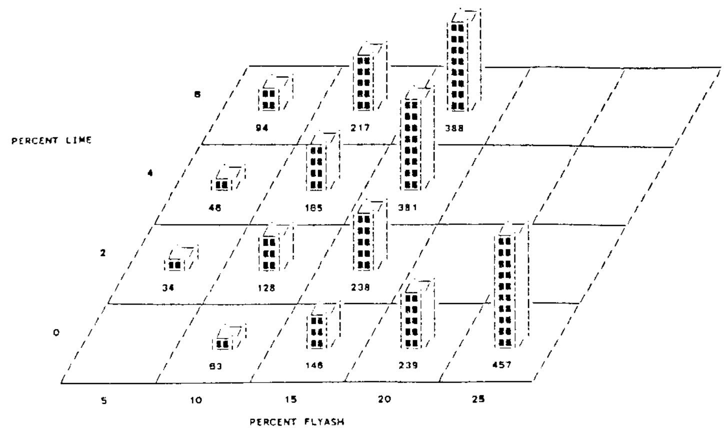


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=28   FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

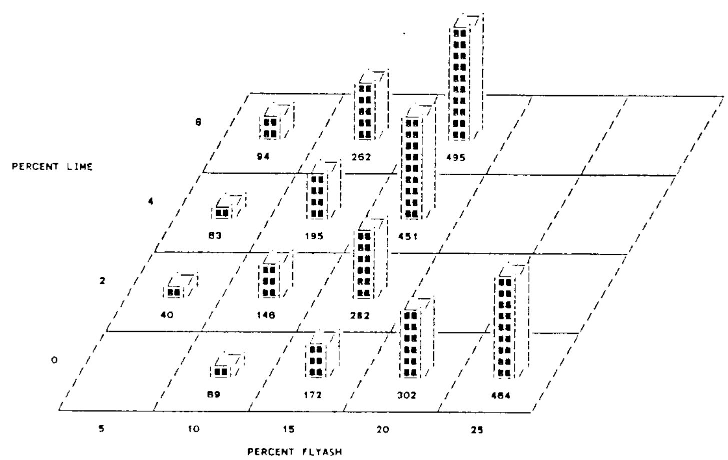


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SAND

AGE AT TEST=58   FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

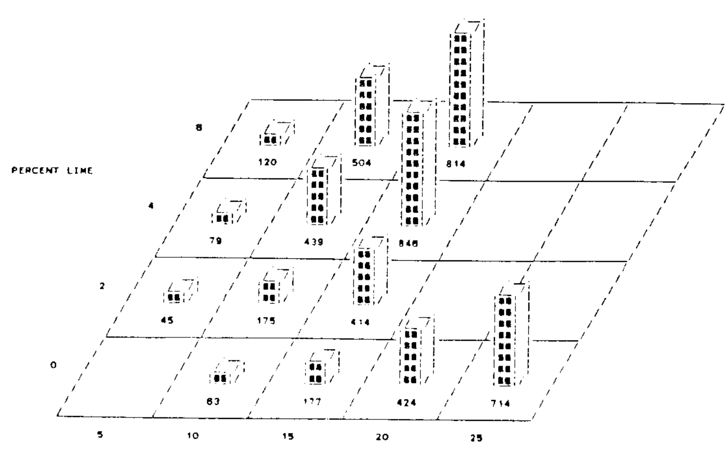


FIGURE 17

SANDY SILT

Sandy Silt Cement Combination

Cement was added to the sandy silt in quantities ranging from 4 to 10 percent by weight. Strength relationships are illustrated in Figure 18 (page 29) for the unconfined compression and the modified vacuum saturation tests.

Specimens increased in strength with additional curing time and with each additional percentage of cement. Minimum and maximum strengths were 321 psi at 7 days and 1032 psi with 10 percent at 56 days, respectively.

Modified vacuum saturation specimens were generally lower in strength than the unconfned compressive samples. As curing time and percentage of cement was increased, the strength differential between the two tests also increased. Modified vacuum saturation strengths varied from 283 psi to 735 psi.

Sandy Silt and Flyash Combination

Strength relationships for the sandy silt flyash combinations are shown in Figures 19 and 20 (pages 30 and 31).

With one exception, at 25 percent by weight flyash at 56 days curing time from Nelson Power Plant, no specimens achieved the minimum requirement of 250 psi until the flyash proportion was at 30 percent at 56 days curing time.

Samples tested using the modified vacuum saturation method were very close in strength to those tested under unconfined compression. Most of the combinations tested were within 30 psi of their counterparts.

Sandy Silt, Cement and Fyash Combinations

Figures 21 through 26 on pages 32 to 37 show the strength relationships of this group.

All of the specimens in this group exceeded the minimum strength criterion of 250 psi in 7 days. Those with no cement, included as a control, behaved as previous sandy silt samples with flyash only as an additive--none reaching the minimum strength until 30 percent by weight flyash was reached at 56 days curing time.

The modified vacuum saturation test produced the same strength increase pattern as the unconfined compression test. In most cases, the vacuum saturation specimens developed less strength than their counterparts.

Sandy Silt, Lime and Flyash Combinations

This group of strength relationships is shown in Figures 27 through 30 (pages 38 to 41). Only two sources of flyash were tested in this combination.

No combination of lime-flyash met the minimum strength criterion of 250 psi in 7 days curing time.

Modified vacuum saturation testing results were generally lower than the unconfined compressive testing results.

CHART OF UNCONFINED COMPRESSION STRENGTH

CEMENT ONLY

SANDY LOAM

BLOCK CHART OF STRENGTH

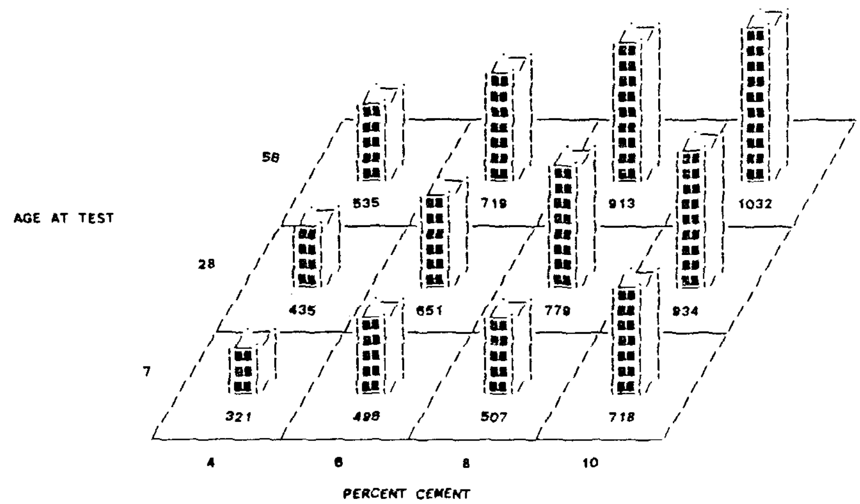


CHART OF VACUUM SATURATION STRENGTH

CEMENT ONLY

SANDY LOAM

BLOCK CHART OF STRENGTH

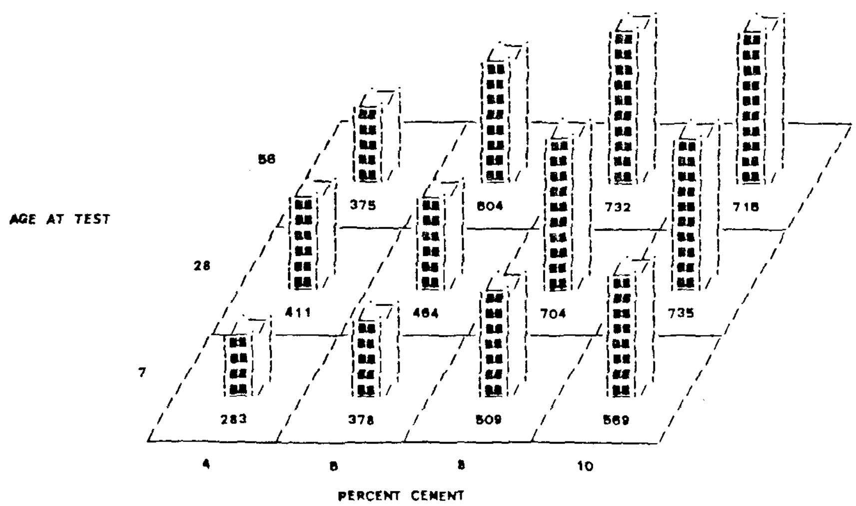


FIGURE 18

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=7

BLOCK CHART OF STRENGTH

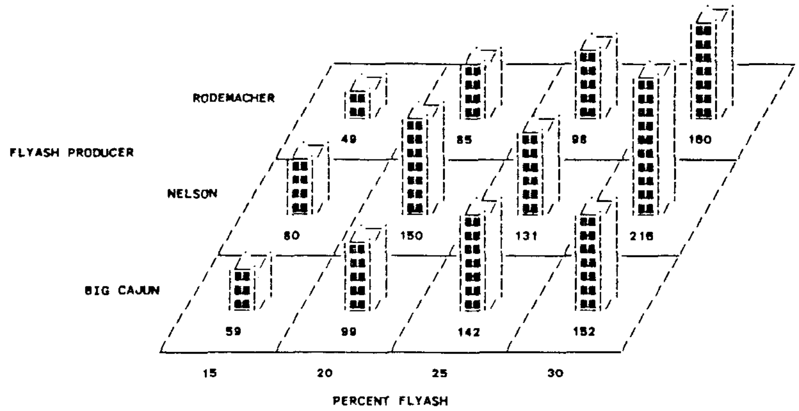


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=28

BLOCK CHART OF STRENGTH

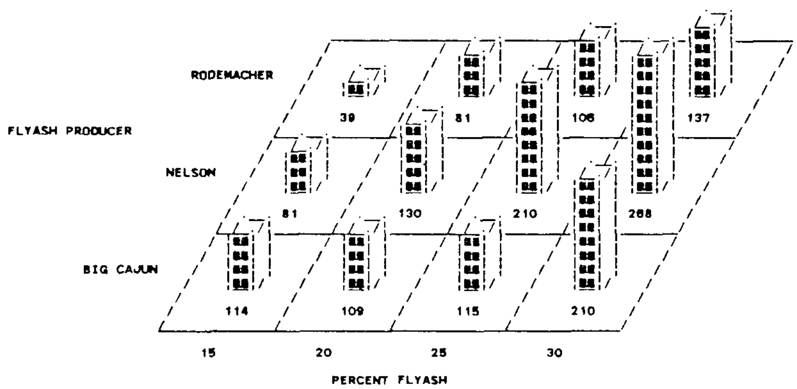


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=56

BLOCK CHART OF STRENGTH

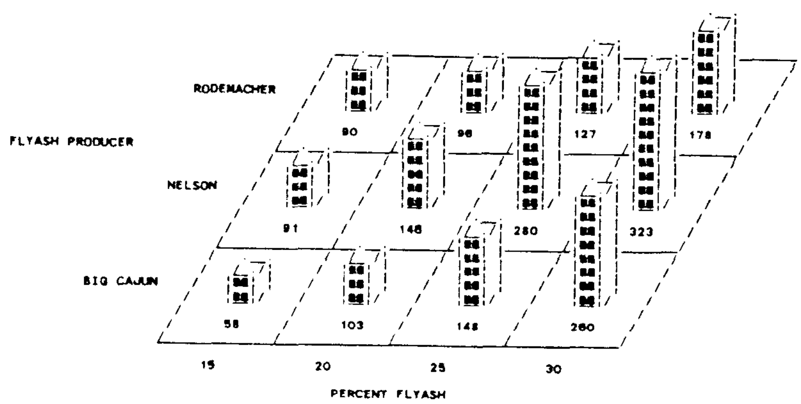


FIGURE 19

CHART OF VACUUM SATURATION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=7

BLOCK CHART OF STRENGTH

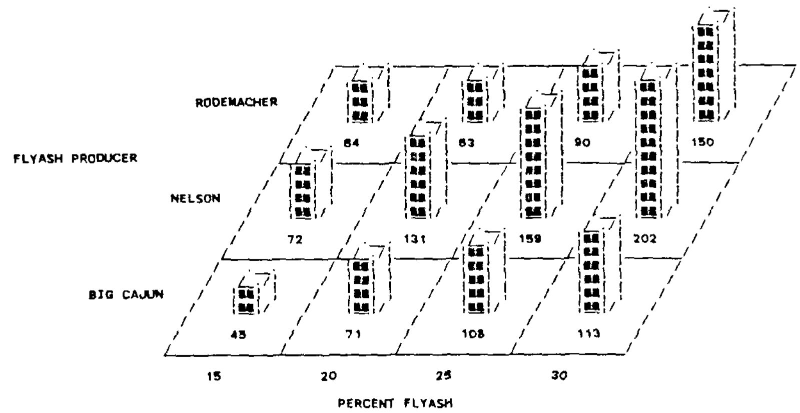


CHART OF VACUUM SATURATION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=28

BLOCK CHART OF STRENGTH

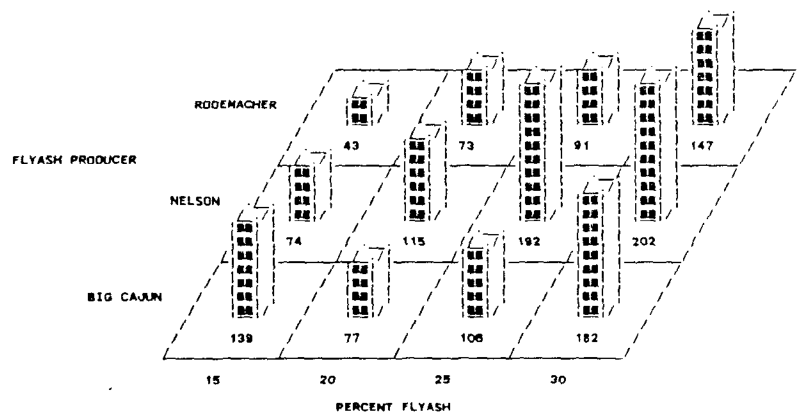


CHART OF VACUUM SATURATION STRENGTH

FLYASH ONLY

SANDY LOAM
AGE AT TEST=56

BLOCK CHART OF STRENGTH

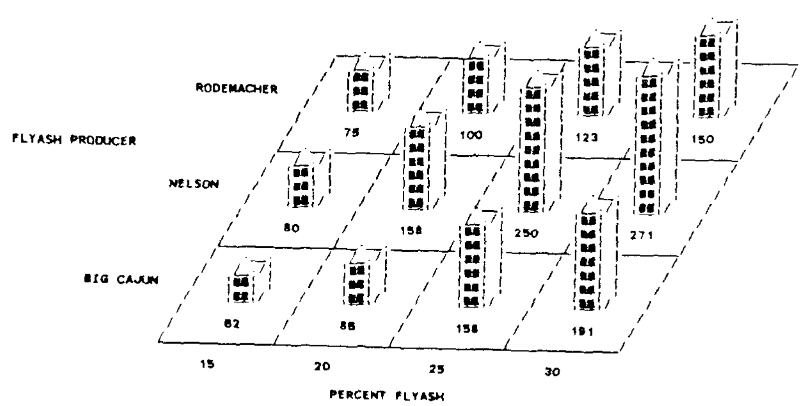


FIGURE 20

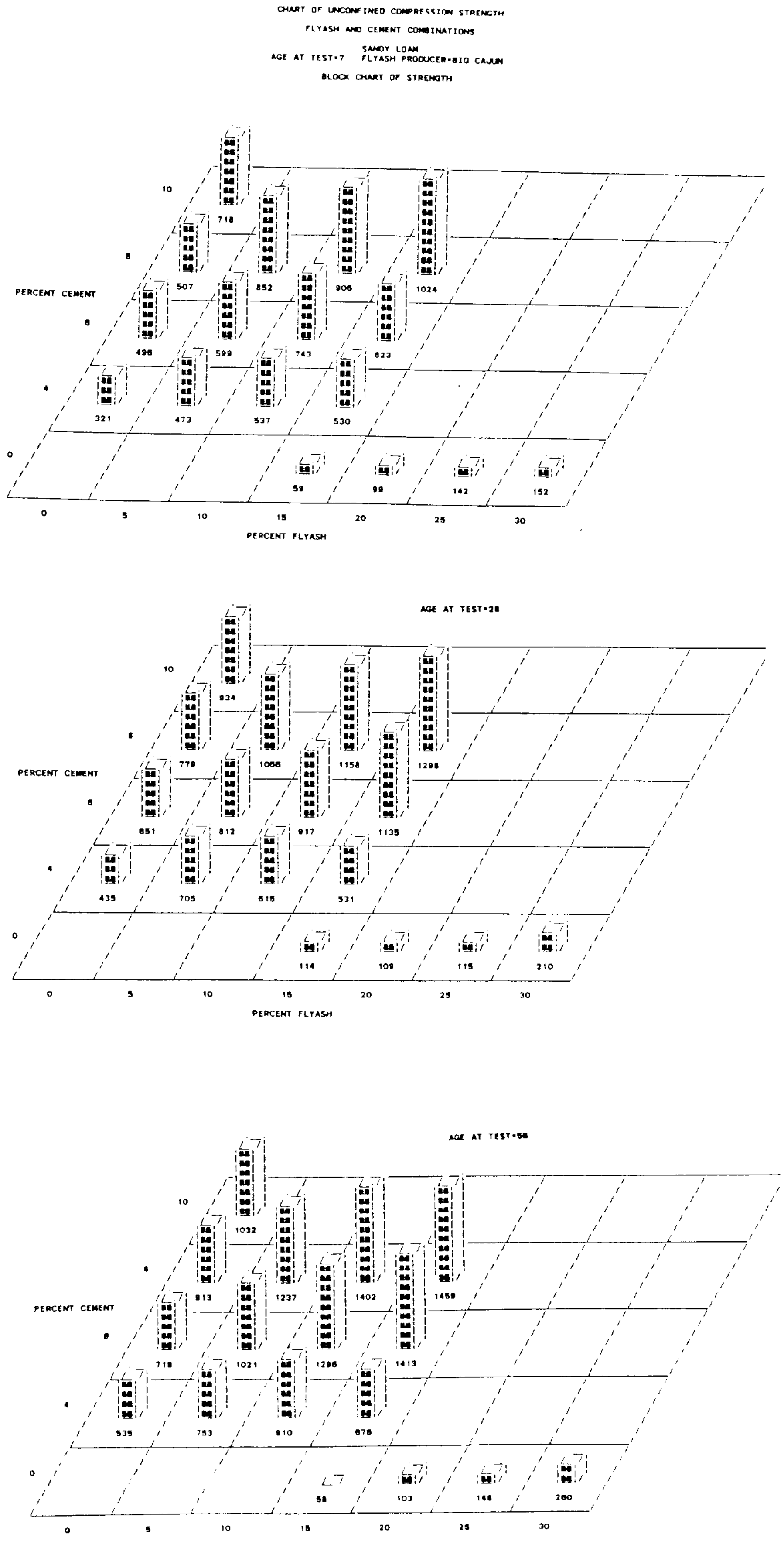


CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN
BLOCK CHART OF STRENGTH
PERCENT CEMENT
10
8
6
4
0
718
507
852
906
1024
496
599
743
823
321
473
537
530
59
99
142
152
0
5
10
15
20
25
30
PERCENT FLYASH
AGE AT TEST=28
934
779
1066
1158
1298
651
812
917
1135
435
705
815
531
114
109
115
210
AGE AT TEST=56
1032
913
1237
1402
1459
719
1021
1296
1413
535
753
910
876
58
103
148
260

FIGURE 21

CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH

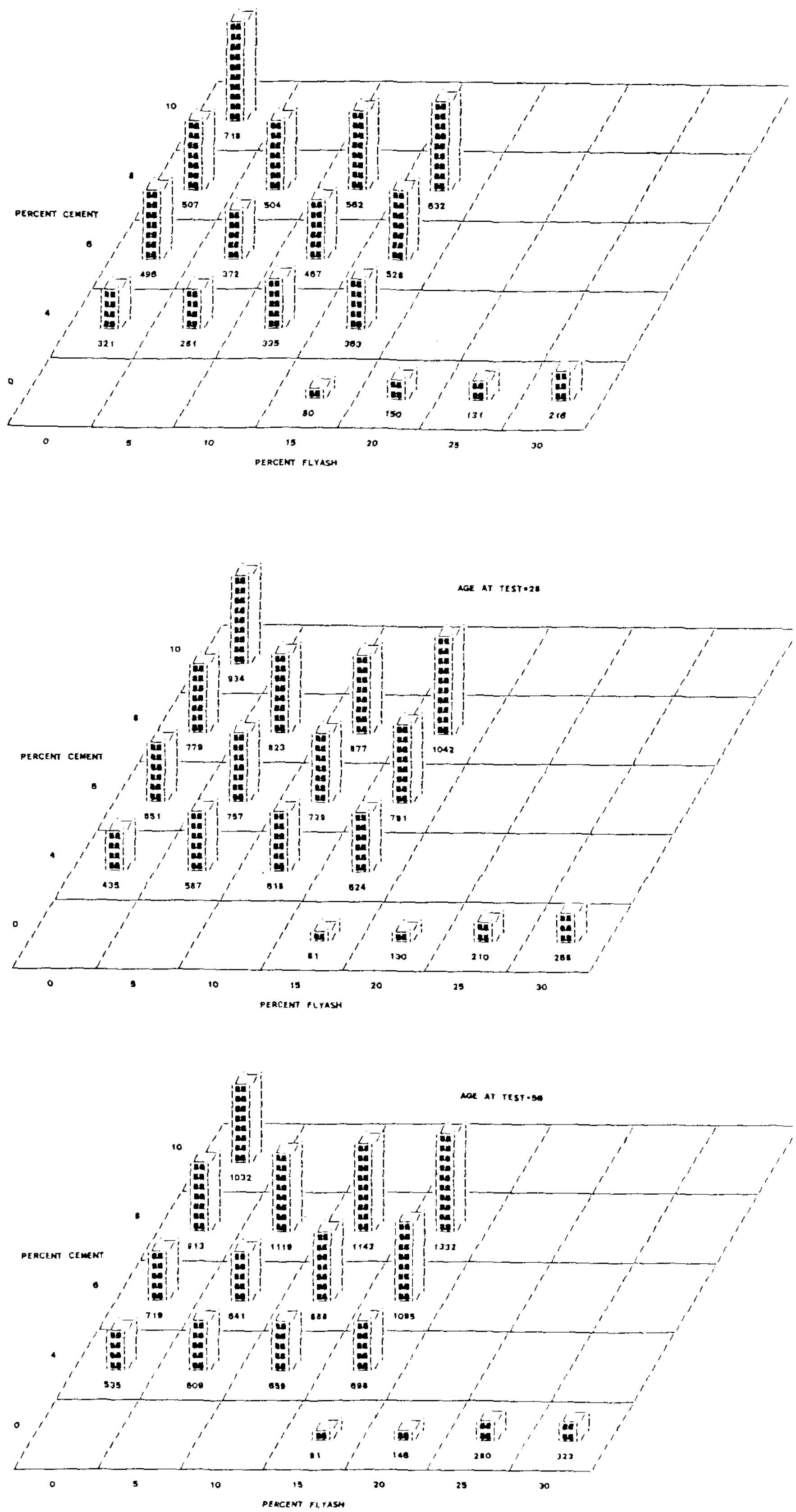


FIGURE 22

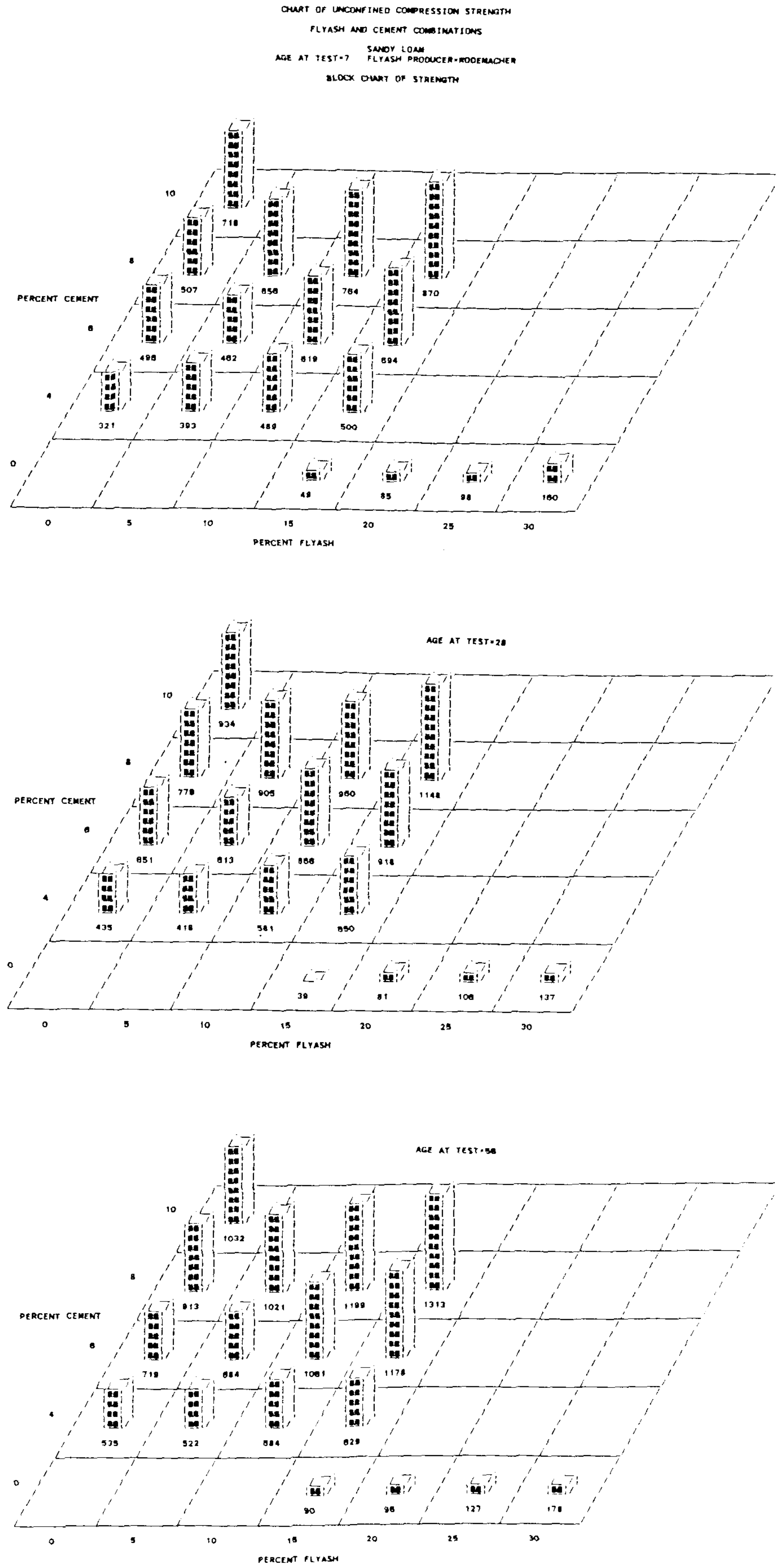


CHART OF UNCONFINED COMPRESSION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER
BLOCK CHART OF STRENGTH
PERCENT CEMENT
PERCENT FLYASH
AGE AT TEST=28
AGE AT TEST=56

FIGURE 23

CHART OF VACUUM SATURATION STRENGTH

FLYASH AND CEMENT COMBINATIONS

SANDY LOAM

AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

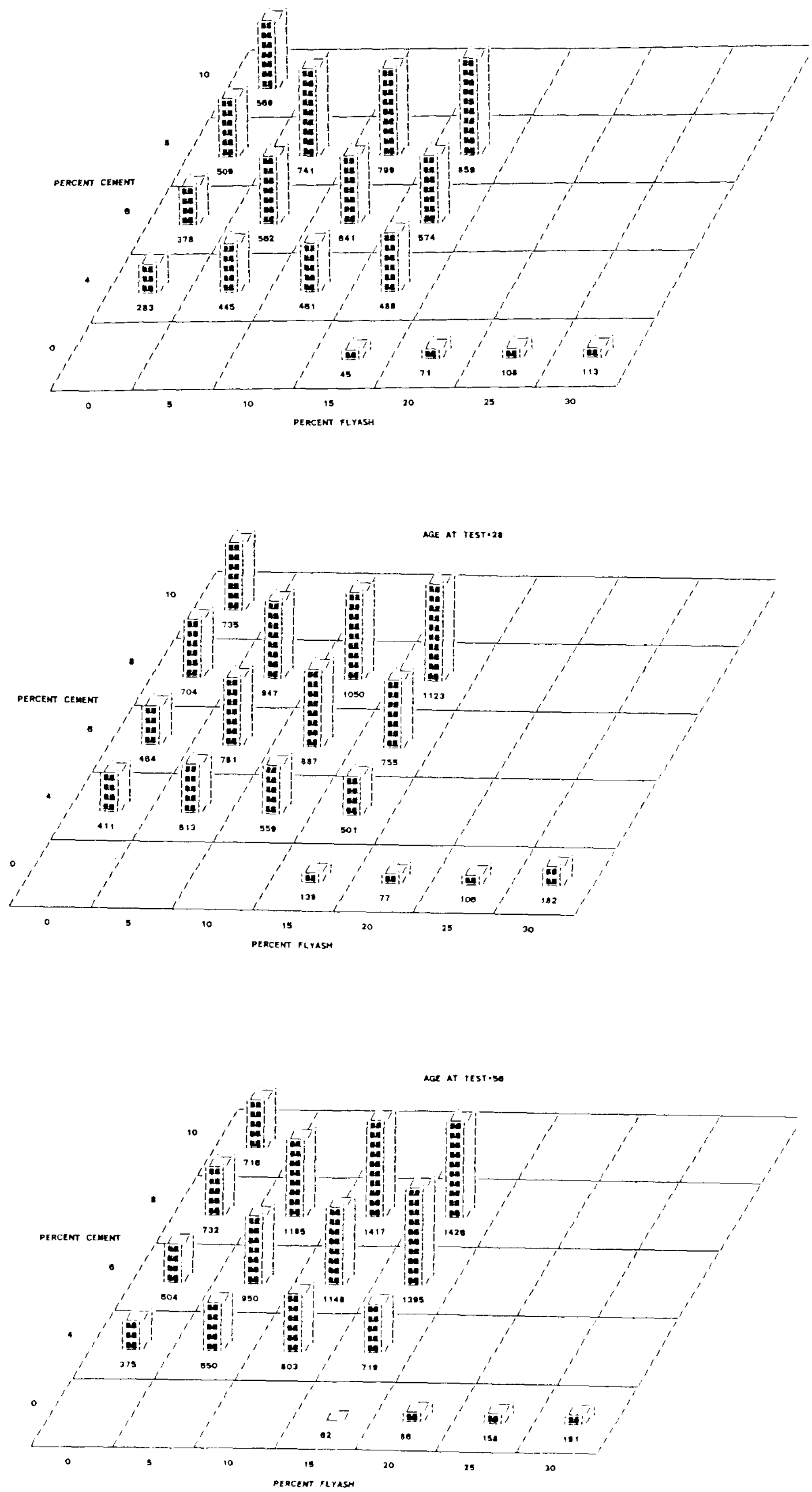


FIGURE 24

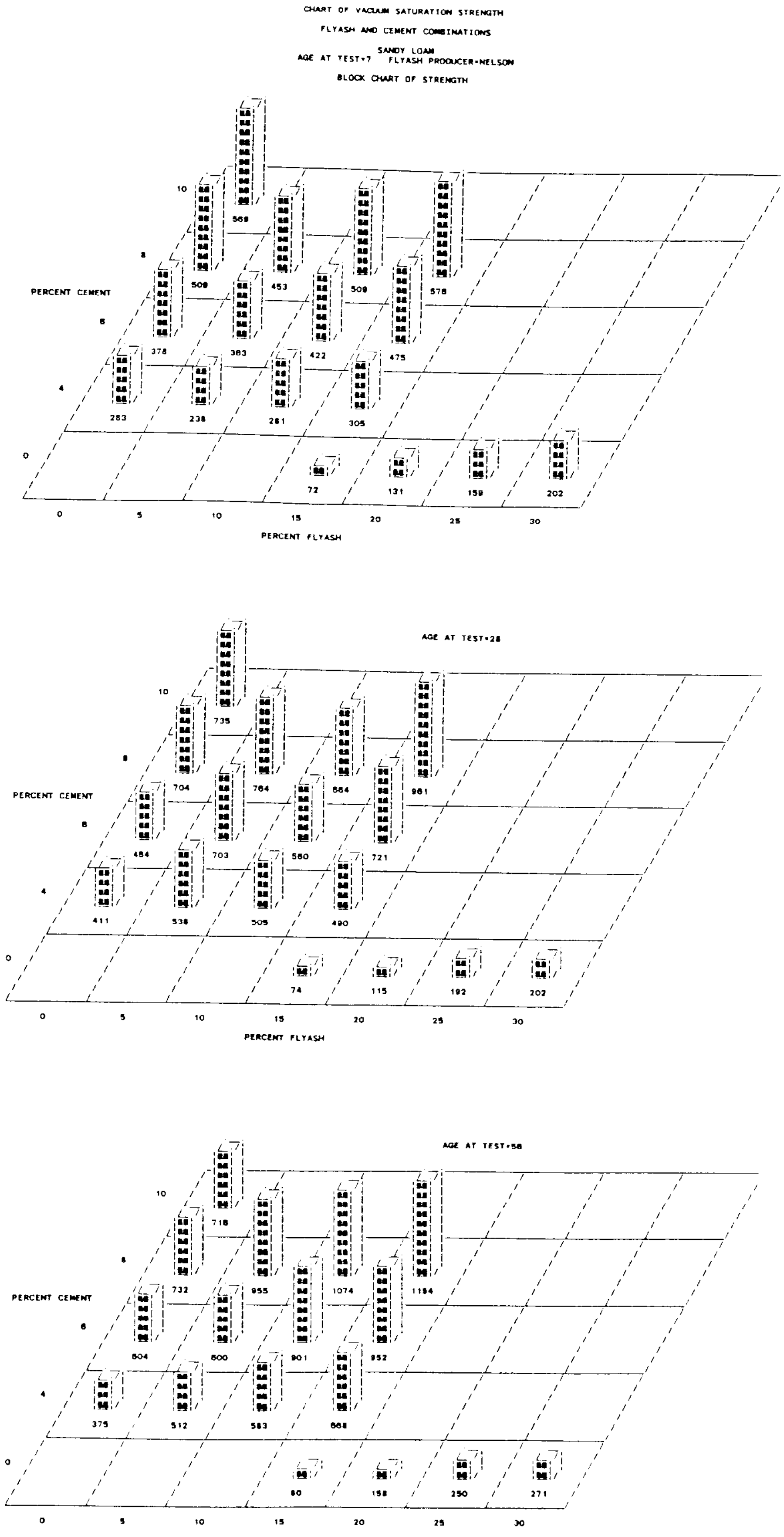


CHART OF VACUUM SATURATION STRENGTH
FLYASH AND CEMENT COMBINATIONS
SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=NELSON
BLOCK CHART OF STRENGTH
PERCENT CEMENT
PERCENT FLYASH
0
4
6
8
10
0
5
10
15
20
25
30
AGE AT TEST=28
AGE AT TEST=56

FIGURE 25

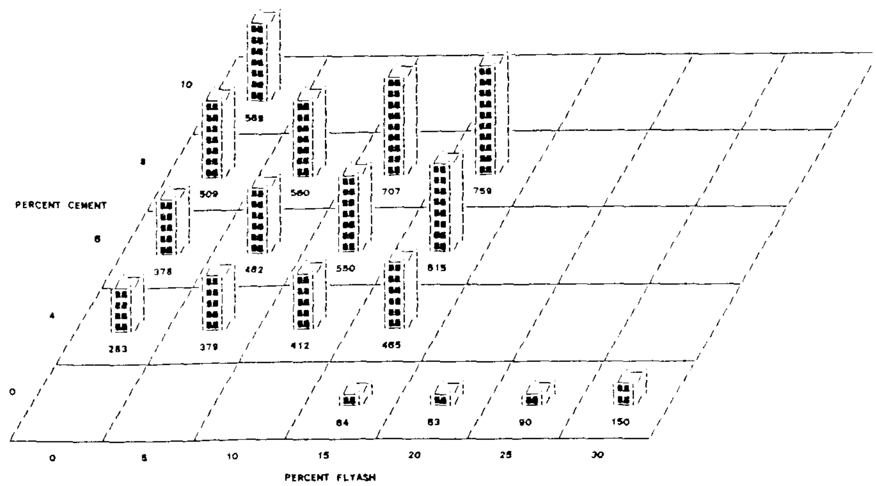
CHART OF VACUUM SATURATION STRENGTH

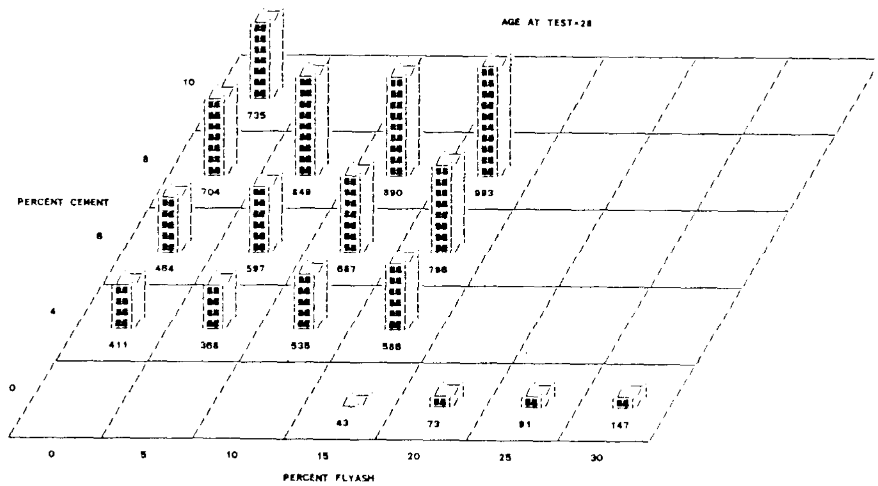
FLYASH AND CEMENT COMBINATIONS

SANDY LOAM

AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH





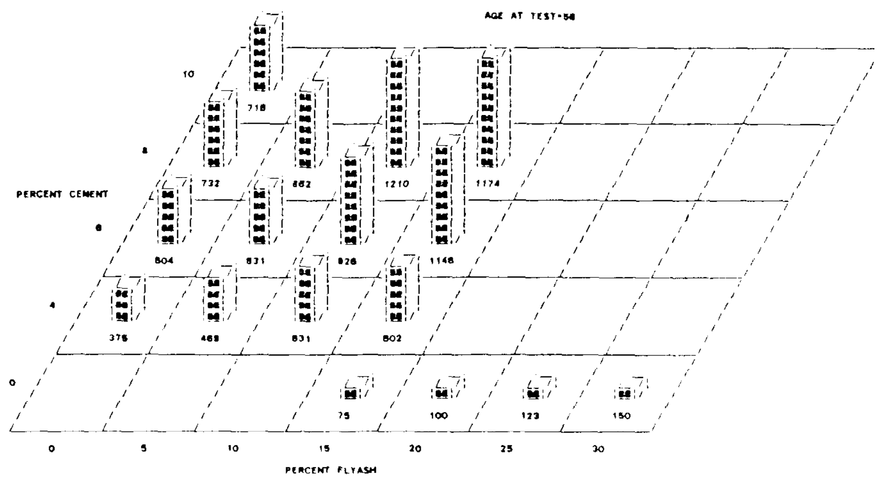


FIGURE 26

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM

AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

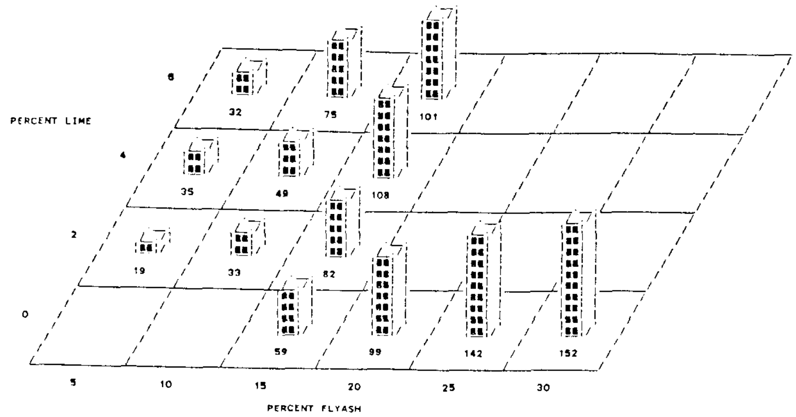


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM

AGE AT TEST=28 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

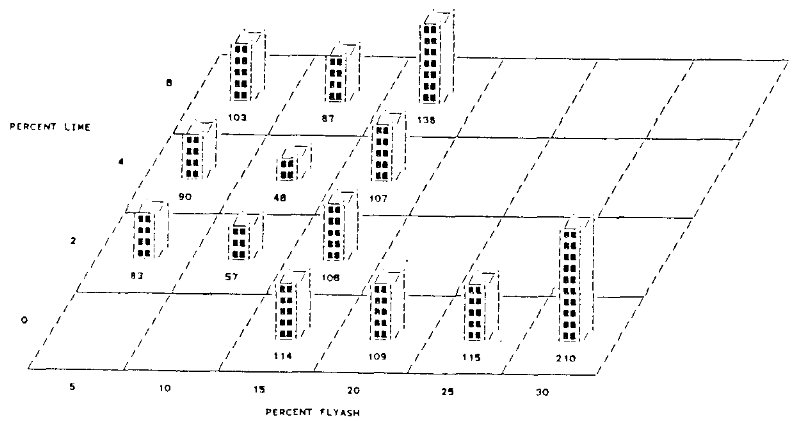


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM

AGE AT TEST=56 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

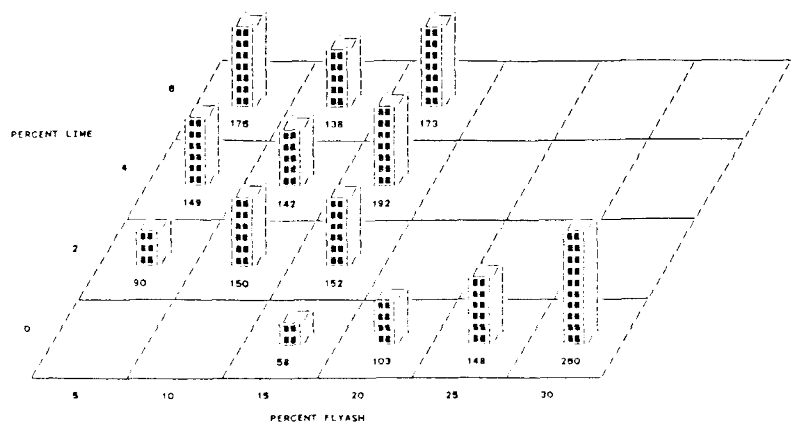


FIGURE 27

CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

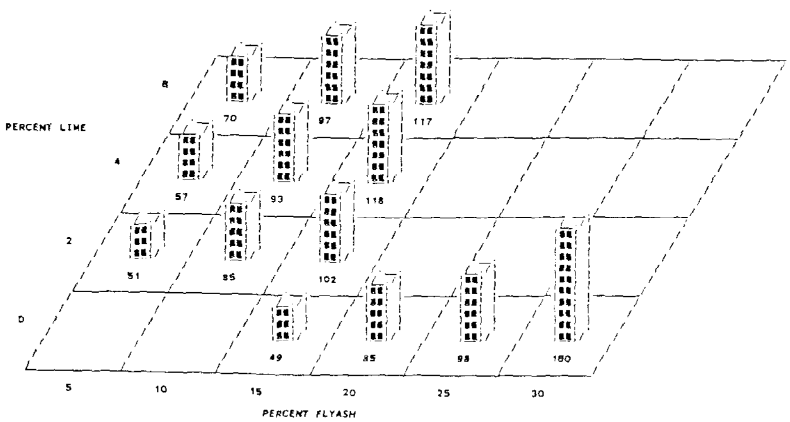


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=28 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

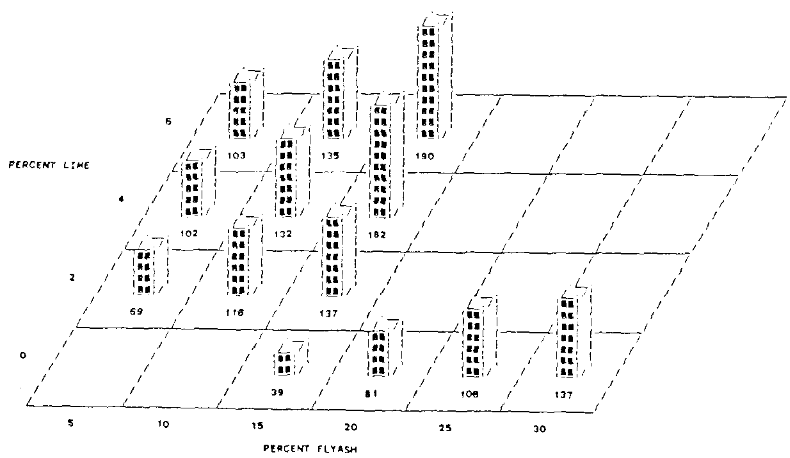


CHART OF UNCONFINED COMPRESSION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=56 FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

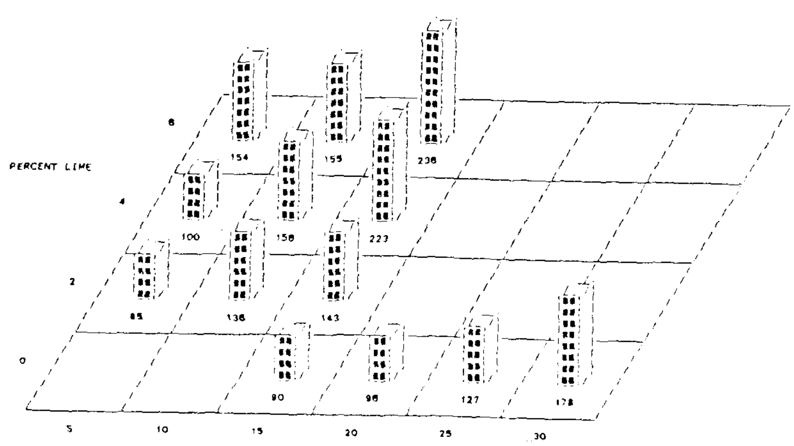


FIGURE 28

CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=7 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

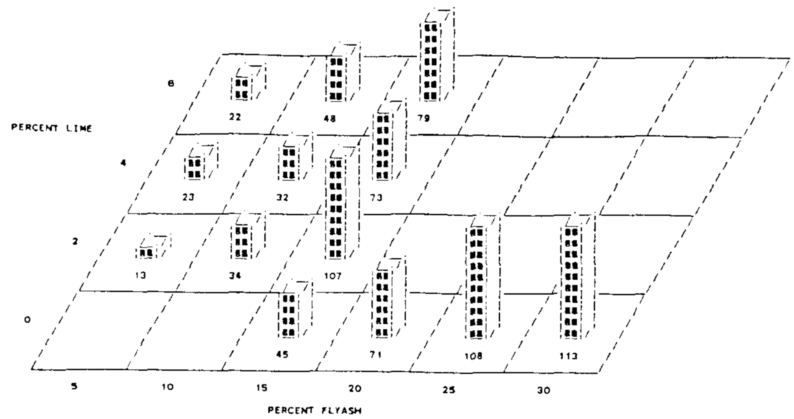


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=28 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

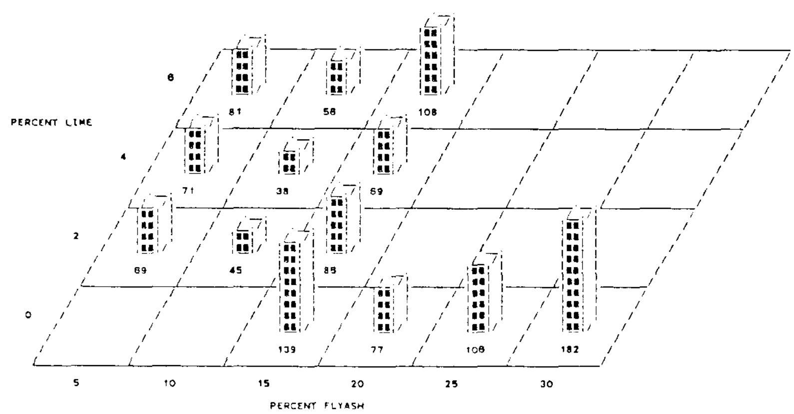


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

SANDY LOAM
AGE AT TEST=56 FLYASH PRODUCER=BIG CAJUN

BLOCK CHART OF STRENGTH

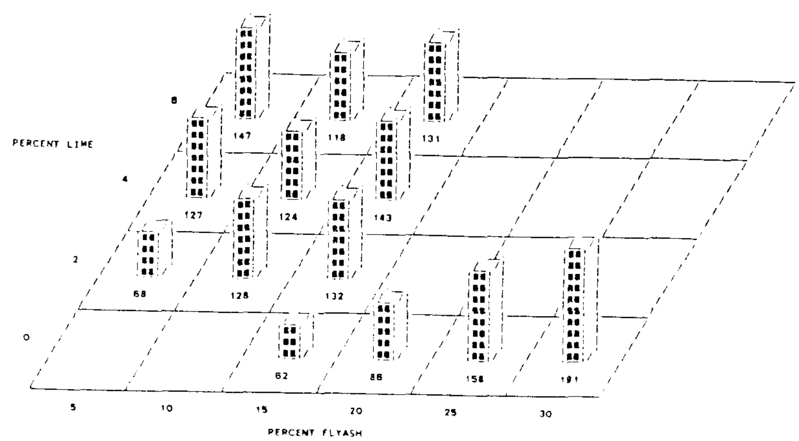


FIGURE 23

CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

AGE AT TEST=7 SANDY LOAM FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

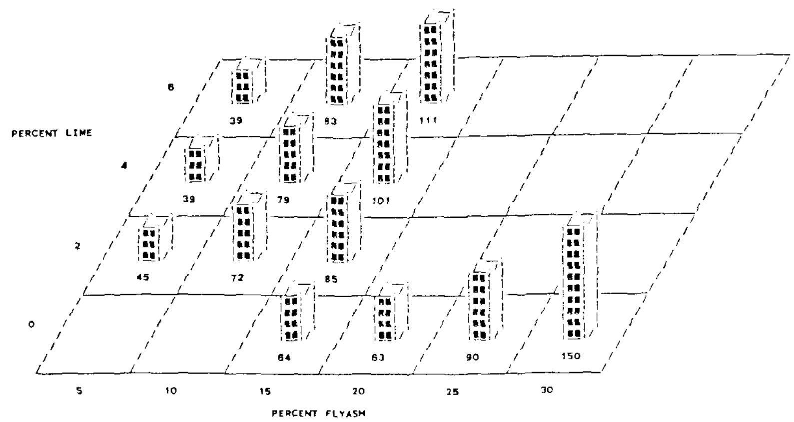


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

AGE AT TEST=28 SANDY LOAM FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

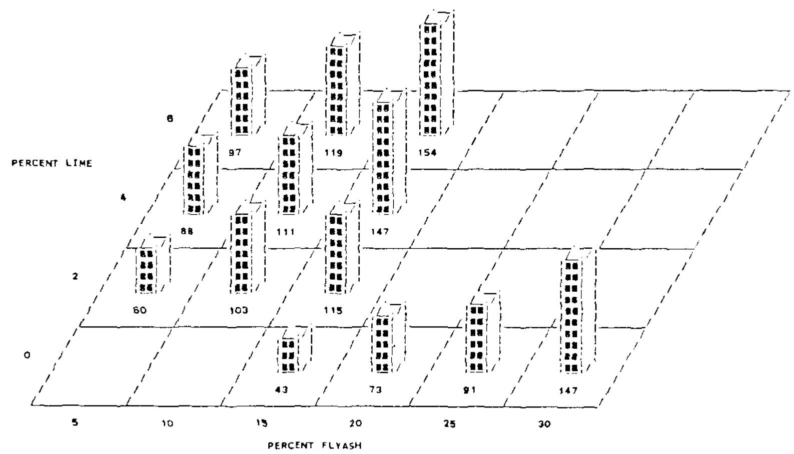


CHART OF VACUUM SATURATION STRENGTH

FLYASH AND LIME COMBINATIONS

AGE AT TEST=58 SANDY LOAM FLYASH PRODUCER=RODEMACHER

BLOCK CHART OF STRENGTH

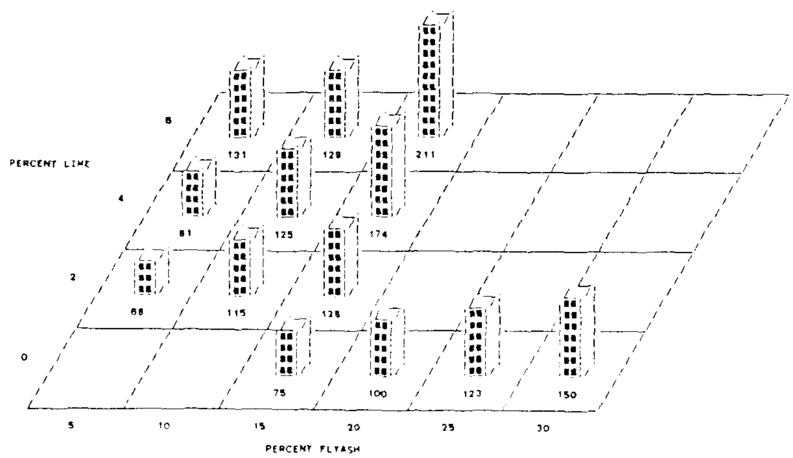


FIGURE 30

CONCLUSIONS

Neither the sand nor the sandy silt soil was effectively improved by the addition of flyash alone as an additive. The sand did not achieve the minimum required strength until the flyash proportion had reached between 20 and 25 percent. The sandy silt did not meet the minimum performance criterion with one exception, and that required 56 days curing time to achieve it.

Adding lime to either of the soils in conjunction with flyash acting as a pozzolan was not notably effective. The sand did not reach acceptable strengths until the level of flyash had reached 15 percent with 4 to 6 percent lime. The sandy silt did not reach acceptable strengths at all.

Cement alone worked well as a stabilizer with both types of soils. The sand exceeded minimum strength requirements with 8 percent by weight cement added, while the sandy silt exceeded the strength criterion at only 4 percent cement content.

The combination of cement and flyash was an effective stabilizer with either of the tested soils. Some very low percentages (5 percent flyash and 4 percent cement) did not reach the minimum strength criterion with the sand. All of the rest of the specimens tested met the criterion successfully and most far exceeded it.

The modified vacuum saturation procedure did not cause any startling differences from the results of the ordinary unconfined compression test. As was expected, the strengths were consistently slightly less than the unconfined compression tests.

The predictability of strength increase due to source of flyash is very low. The only consistency noted when comparing strengths between sources under "identical" testing conditions was inconsistency of results. There is a considerable variance in activity of this by-product not only from source to source but also from truckload to truckload from a particular source.

RECOMMENDATIONS

There is so much about the performance of flyash that is unpredictable that it is essential that each instance of using it either alone or with another additive must be very carefully evaluated on a case-by-case basis. Cost of the product must be considered along with engineering properties.

Field evaluations of actual base courses should be undertaken to determine performance and construction criteria to be used.

Procedures for incorporating two additives into an actual base course project should be studied to determine the difficulty that will be encountered in achieving the desired quality of the final mix.

BIBLIOGRAPHY

1. Ledbetter, W. B., et al. "Construction of Flyash Test Sites and Guidelines for Construction," SDHPT Report 240-2, Texas State Department of Highways and Public Transportation, October 1981.

2. "Lime-Flyash-Stabilized Bases and Subbases," NCHRP Report 37, Transportation Research Board, 1976.

3. Mateos, M. "Stabilization of Soils With Flyash Alone," Highway Research Record No. 52, Highway Research Board, 1964.

4. Meyers, J. F., et al. "Flyash as a Construction Material for Highways," FHWA-1P-76-16, Federal Highway Administration, June 1976.

5. Rosner, J. C., and M. K. Harmm. "Utilization of Waste Boiler Ash in Highway Construction in Arizona," Report: ADOT-RS-14(158), Arizona Department of Transportation, March 1977.

6. Thornton, S., et al. "Self Hardening Flyash," AHTD Report HPR-52, Arkansas Highway and Transportation Department, July 1980.

7. Thornton, S., and D. G. Parker. "Flyash as Field and Base Material in Arkansas Highways," AHTD Report HRP-43, Arkansas Highway and Transportation Department, October 1975.

A P P E N D I X

Table 1

Soil Properties

Variable	Sand	Sandy Silt
% Coarse Sand (Ret # 40)	40	3
% Fine Sand (Ret # 200)	52	62
% Silt	5	18
% Clay & Colloids	2	17
Liquid Limit	NP	21
Plasticity Index	NP	7
Max. Dry Wt. Den. (pcf)	109.1	119.1
Optimum Moisture (%)	13.0	12.1
Specific Gravity	2.62	2.63
Ph	6.6	5.4
Soil Classification	Sand	Sandy Loam
AASHTO Classification	A-3 (0)	A-2-4 (0)

Table 2

Chemical and Physical Analysis of Fly Ashes *

Flyash Source	Cajun		Rodemacher		Nelson	
% Retained #325	9.2	7.6	12.0	11.0	13.9	18.3
Loss On Ignition	1.30	0.50	0.50	1.90	0.70	1.00
Total Oxides **	65.80	66.50	62.30	64.70	51.50	62.90
Calcium Oxide	21.50	24.50	27.20	24.00	25.20	25.80
Magnesium Oxide	4.40	4.70	4.90	4.50	4.90	2.90
Sulfer Trioxide	2.80	2.80	2.70	2.90	3.10	3.30
Alkalais	1.34	0.66	1.40	1.06	1.45	1.74

* - Material tested accordingto ASTM Designation : C 311.

** - $SiO2 + Al2O3 + Fe2O3$

Table 3

Portland Cement
Chemical and Physical Properties

Variable	SPECIFICATION	LONE STAR	BLUE CIRCLE
Loss on Ignition	3.0 max. %	1.3	1.5
Sulfur Trioxide	3.0 max. %	2.0	2.7
Iron & Alum. Oxide	12.0 max. %	8.0	5.9
Magnesium Oxide	5.0 max. %	0.4	1.0
Insoluble Residue	0.75 max. %	0.49	0.23
Tricalcium Aluminate	15.0 max. %	4.3	6.0
Ferric Oxide		3.9	2.2
Aluminum Oxide		4.1	3.7
Alkalais	0.6 max. %	0.44	0.25
Set Time Vicat Init.	0.75 hr. min.%	1.15	1.50
Set Time Vicat Final	8.0 hr. max.%	3.55	3.50
Autoclave Expansion	0.8 max.	0.03	0.04
Air Permeability	2600min 4200max	3310.00	3960.00
Air Content	12.0 max.%	10.40	7.50
Comp. Stength 72hrs	1800 min. PSI	3330.00	4310.00
Comp. Strength 7days	2800 min. PSI	5100.00	5220.00

Table 4

Chemical Properties of Lime

Lab Number	22-422122	22-394023
Total Calcium plus Magnesium Oxides	95.9	95.6

Table 5

Theoretical Dry Weight Densities and Optimum Moisture Contents

Soil Type -- Sandy Silt A-2-4(0)

Flyash Source	% Flyash	Percent Cement 4	Percent Cement 6	Percent Cement 8
Cajun	5	122.5 @ 11.5	121.5 @ 11.9	121.8 @ 11.9
	10	122.5 @ 11.8	122.6 @ 11.8	122.3 @ 11.8
	15	121.7 @ 11.9	122.3 @ 11.1	122.6 @ 11.4
Rodemacher	5	117.5 @ 14.0	118.3 @ 13.8	117.3 @ 13.5
	10	120.1 @ 12.4	120.4 @ 12.4	121.1 @ 12.3
	15	120.6 @ 12.0	120.8 @ 12.2	120.9 @ 12.2
Nelson	5	118.4 @ 12.6	118.7 @ 12.7	119.0 @ 13.1
	10	119.1 @ 12.7	119.7 @ 13.1	119.2 @ 13.2
	15	119.8 @ 13.1	121.2 @ 13.0	121.4 @ 12.6

Flyash Source	% Flyash	Percent Lime 2	Percent Lime 4	Percent Lime 6
Cajun	5	119.2 @ 13.0	118.1 @ 13.2	113.6 @ 15.2
	10	118.6 @ 13.3	117.9 @ 13.8	117.9 @ 14.2
	15	118.0 @ 13.2	119.1 @ 12.8	118.7 @ 13.4
Rodemacher	5	114.0 @ 14.4	114.2 @ 14.6	114.2 @ 14.6
	10	115.8 @ 14.2	115.2 @ 14.1	114.4 @ 14.6
	15	116.0 @ 14.4	116.3 @ 14.0	115.6 @ 14.0
Nelson	5	116.4 @ 14.0	116.0 @ 14.2	116.3 @ 14.0
	10	118.4 @ 13.0	116.6 @ 14.0	117.1 @ 13.8
	15	119.0 @ 13.2	118.4 @ 13.1	117.2 @ 14.0

% Flyash	Flyash Source Cajun	Flyash Source Rodemacher	Flyash Source Nelson
15	124.0 @ 10.9	122.3 @ 10.5	120.1 @ 12.4
20	125.8 @ 10.3	122.8 @ 11.5	122.2 @ 11.7
25	126.0 @ 10.3	121.5 @ 12.0	122.4 @ 11.5
30	124.8 @ 11.0	120.5 @ 11.4	122.5 @ 10.9

Table 6

Theoretical Dry Weight Densities and Optimum Moisture Contents

Soil Type -- Sand A-3(0)

Flyash Source	% Flyash	Percent Cement		
		4	6	8
Cajun	5	118.0 @ 9.2	119.5 @ 9.1	121.8 @ 8.5
	10	122.2 @ 8.4	124.0 @ 8.0	127.1 @ 7.6
	15	127.0 @ 7.2	129.0 @ 7.4	129.9 @ 7.2
	20	131.0 @ 6.6	133.4 @ 7.0	133.7 @ 6.0
Rodemacher	5	121.5 @ 8.6	121.5 @ 8.2	121.9 @ 8.5
	10	124.0 @ 8.0	123.8 @ 8.0	125.0 @ 8.0
	15	127.9 @ 7.6	127.3 @ 7.6	130.0 @ 6.7
Nelson	5	118.5 @ 8.9	120.0 @ 8.5	120.9 @ 8.3
	10	122.8 @ 7.9	123.6 @ 7.6	124.6 @ 7.7
	15	126.2 @ 7.2	130.6 @ 6.6	128.7 @ 7.3

Flyash Source	% Flyash	Percent Lime		
		2	4	6
Cajun	5	117.4 @ 9.2	120.6 @ 9.6	122.4 @ 8.6
	10	121.1 @ 8.3	123.4 @ 7.8	123.3 @ 9.0
	15	125.2 @ 7.5	127.4 @ 7.7	126.2 @ 8.4
Rodemacher	5	115.3 @ 9.9	118.0 @ 9.0	120.4 @ 8.5
	10	121.0 @ 7.8	123.0 @ 8.1	125.0 @ 8.5
	15	126.2 @ 8.1	129.2 @ 7.9	127.4 @ 8.5
Nelson	5	117.8 @ 9.5	118.7 @ 9.4	120.7 @ 9.0
	10	120.6 @ 8.9	124.1 @ 8.6	123.8 @ 8.5
	15	124.6 @ 8.4	127.2 @ 7.7	128.0 @ 7.7

% Flyash	Flyash Source		
	Cajun	Rodemacher	Nelson
10	118.7 @ 8.7	119.2 @ 7.0	119.4 @ 8.5
15	124.3 @ 7.0	122.2 @ 8.0	124.2 @ 7.2
20	131.1 @ 6.8	126.9 @ 7.2	126.9 @ 6.8
25	132.8 @ 5.7	132.6 @ 5.1	130.2 @ 6.7

Table 7

Unconfined Compression and Vacuum Saturation Strengths-PSI

Additive -- Portland Cement

Test	Cement	SAND			SANDY LOAM		
		Age in Days			Age in Days		
	%	7	28	56	7	28	56
COMPRESSION	4	104	143	142	321	435	535
	6	231	290	331	496	651	719
	8	363	593	619	507	779	913
	10	665	843	1021	718	934	1032
		7	28	56	7	28	56
VACUUM	4	90	151	138	283	411	375
	6	222	304	325	378	464	604
	8	338	556	597	509	704	732
	10	647	742	936	569	735	716

Table 8

Unconfined Compressive Strengths -PSI

Additive -- Flyash

% Fly Ash	Soil Type	Cajun 7	Cajun 28	Cajun 56	Rodemacher 7	Rodemacher 28	Rodemacher 56	Nelson 7	Nelson 28	Nelson 56
10	S	28	31	31	79	76	62	53	52	63
15	A	75	81	107	136	160	199	105	136	154
20	N	226	251	333	265	323	454	183	241	319
25	D	556	693	637	494	654	705	322	410	580
15	SANDY SILT	59	114	58	49	39	90	80	81	91
20		99	109	103	85	81	96	150	130	146
25		142	115	148	98	106	127	131	210	280
30		152	210	260	160	137	178	216	268	323

Vacuum Saturation Strengths - PSI

Additive -- Flyash

% Fly Ash	Soil Type	Cajun 7	Cajun 28	Cajun 56	Rodemacher 7	Rodemacher 28	Rodemacher 56	Nelson 7	Nelson 28	Nelson 56
10	S	27	32	35	63	69	63	42	54	51
15	A	72	115	83	146	172	177	108	133	136
20	N	188	244	244	239	302	424	197	308	272
25	D	582	694	653	457	464	714	264	442	488
15	SANDY LOAM	45	139	62	64	43	75	72	74	80
20		71	77	86	63	73	100	131	115	158
25		108	106	158	90	91	123	159	192	250
30		113	182	191	150	147	150	202	202	271

Table 9

Unconfined Compressive Strengths

Soil Type -- Sand A-3 (0)

Additives--- Flyash and Portland Cement

Flyash Source	% Fly ASH	4 % Cement			6 % Cement			8 % Cement		
		7	28	56	7	28	56	7	28	56
none		104	143	142	231	290	331	363	593	619
Cajun	5	190	298	404	330	597	702	498	714	1019
	10	333	431	704	447	808	954	810	1053	1552
	15	477	761	1093	741	1069	1233	1212	1806	2149
Rod	5	228	284	445	396	525	716	520	801	789
	10	320	524	621	515	838	944	784	1363	1554
	15	434	875	1198	657	1205	1359	1150	2093	2101
Nel	5	192	302	421	387	670	593	639	907	993
	10	306	492	638	523	976	1013	748	1133	1273
	15	337	813	1215	831	1144	1464	981	1935	2082

Fly Ash and Lime Combinations

Flyash Source	% Fly ASH	2 % Lime			4 % Lime			6 % Lime		
		7	28	56	7	28	56	7	28	56
Cajun	5	28	33	31	41	46	64	75	89	121
	10	106	122	150	148	169	196	169	209	207
	15	242	278	349	349	431	469	375	421	454
Rod	5	34	38	50	53	68	96	105	104	142
	10	128	140	324	166	184	459	232	277	452
	15	254	339	383	367	475	886	379	456	909
Nel	5	27	28	30	38	45	59	66	81	105
	10	81	100	112	116	151	234	172	232	259
	15	160	222	267	277	341	378	323	356	492

Table 10

Unconfined Compressive Strengths - PSI

Soil Type --- Sandy Silt A-2-4(0)

Additives -- Flyash and Portland Cement

Flyash Source	% Fly ASH	4 % Cement			6 % Cement			8 % Cement		
		7	28	56	7	28	56	7	28	56
none		321	435	535	496	651	719	507	779	913
Caj	5	473	705	753	599	812	1021	852	1066	1237
	10	537	615	910	743	917	1296	906	1158	1402
	15	530	531	676	623	1135	1413	1024	1298	1459
Rod	5	393	418	522	462	613	684	656	905	1021
	10	489	581	684	619	866	1061	764	960	1199
	15	500	650	629	694	918	1178	870	1148	1313
Nel	5	281	587	609	372	757	641	504	823	1119
	10	335	618	659	467	729	888	562	877	1143
	15	363	624	698	528	791	1095	632	1042	1332

Fly Ash and Lime Combinations

Flyash Source	% Fly ASH	2 % Lime			4 % Lime			6 % Lime		
		7	28	56	7	28	56	7	28	56
Caj	5	19	83	90	35	90	149	32	103	176
	10	33	57	150	49	46	142	75	87	138
	15	82	106	152	108	107	192	101	138	173
Rod	5	51	69	85	57	102	100	70	103	154
	10	85	116	136	93	132	156	97	135	155
	15	102	137	143	118	182	223	117	190	236

Table 11

Vacuum Saturation Strengths - PSI

Soil Type -- Sand A-3(0)

Additives -- Flyash and Portland Cement

Flyash Source	% Fly ASH	4 % Cement			6 % Cement			8 % Cement		
		7	28	56	7	28	56	7	28	56
none		90	151	138	222	304	325	338	556	597
Cajun	5	178	279	345	303	569	718	495	869	997
	10	308	522	747	515	913	1044	833	1122	1615
	15	438	719	1008	693	1120	1395	1294	1419	2295
Rodemacher	5	179	281	398	426	544	695	554	696	894
	10	310	439	503	531	851	1020	764	1320	1745
	15	437	816	1247	647	1267	1519	1148	1907	2208
Nelson	5	184	334	281	394	598	589	597	933	964
	10	274	516	694	646	809	934	755	1243	1292
	15	316	775	1028	718	1104	1283	917	1609	2135

Additives -- Flyash and Lime

Flyash Source	% Fly ASH	2 % Lime			4 % Lime			6 % Lime		
		7	28	56	7	28	56	7	28	56
Cajun	5	20	27	32	33	39	54	63	97	132
	10	90	106	136	143	160	187	155	195	207
	15	235	233	328	338	398	430	322	421	465
Rodemacher	5	34	40	45	46	63	79	94	94	120
	10	128	146	175	165	195	439	217	262	504
	15	238	282	414	381	451	846	388	495	814
Nelson	5	28	23	29	34	44	55	53	71	102
	10	73	96	122	108	119	243	163	211	284
	15	171	212	294	231	316	489	322	390	483

Table 12

Vacuum Saturation Strengths - PSI

Soil Type -- Sandy Silt A-2-4(0)

Additives -- Flyash and Portland Cement

Flyash Source	% Fly ASH	4 % Cement			6 % Cement			8 % Cement		
		7	28	56	7	28	56	7	28	56
none	0	283	411	375	378	464	604	509	704	732
Cajun	5	445	613	650	562	781	950	741	947	1185
	10	461	559	803	641	887	1148	799	1050	1417
	15	488	501	719	574	755	1395	859	1123	1426
Rodemacher	5	379	369	469	462	597	631	560	849	862
	10	412	535	631	550	687	926	707	890	1210
	15	465	586	602	615	796	1146	759	993	1174
Nelson	5	239	538	512	363	703	600	453	764	955
	10	281	505	583	422	560	901	509	664	1074
	15	305	490	668	475	721	952	576	961	1194

Additives -- Flyash and Lime

Flyash Source	% Fly ASH	2 % Lime			4 % Lime			6 % Lime		
		7	28	56	7	28	56	7	28	56
Cajun	5	13	69	68	23	71	127	22	81	147
	10	34	45	128	32	38	124	48	56	118
	15	107	86	132	73	69	143	79	108	131
Rodemacher	5	45	60	68	39	88	81	39	97	131
	10	72	103	115	79	111	125	83	119	129
	15	85	115	128	101	147	174	111	154	211

SOURCE=BOYCE

VARIABLE	N	MEAN	RANGE	CV	STD	MIN	MAX
% RETAINED ON THE #325	37	15.8838	10.50	17.354	2.75646	11.00	21.5
POZZALANIC ACTIVITY INDEX	31	87.0032	10.00	2.359	2.05272	83.00	93.0
AUTOCLAVE EXPANSION	31	0.0874	2.01	408.970	0.35752	-0.01	2.0
SPECIFIC GRAVITY	29	2.5590	0.35	2.815	0.07203	2.35	2.7
LOSS ON IGNITION	37	1.3730	2.70	55.593	0.76327	0.30	3.0
SULFUR TRIOXIDE CONTENT	37	2.7784	4.00	36.480	1.01356	1.50	5.5
TOTAL OXIDES	37	66.1081	15.60	4.931	3.25939	55.90	71.5
CALCIUM OXIDES	37	22.9297	12.20	13.781	3.15998	18.00	30.2
MAGNESIUM OXIDES CONTENT	37	4.1054	2.70	16.269	0.66789	3.10	5.8
MOISTURE CONTENT	31	1.3226	3.00	61.137	0.80858	0.00	3.0

SOURCE=CAJUN

VARIABLE	N	MEAN	RANGE	CV	STD	MIN	MAX
% RETAINED ON THE #325	45	11.2978	16.00	30.114	3.40217	5.00	21.00
POZZALANIC ACTIVITY INDEX	30	86.8300	11.50	2.497	2.16829	81.50	93.00
AUTOCLAVE EXPANSION	30	0.0370	0.11	118.160	0.04372	0.00	0.11
SPECIFIC GRAVITY	30	2.7010	0.20	1.848	0.04992	2.58	2.78
LOSS ON IGNITION	47	1.3277	4.70	66.349	0.88088	0.20	4.90
SULFUR TRIOXIDE CONTENT	48	2.5437	6.30	35.403	0.90057	1.50	7.80
TOTAL OXIDES	48	66.3729	13.40	3.924	2.60423	58.10	71.50
CALCIUM OXIDES	48	23.0250	12.70	10.292	2.36971	18.00	30.70
MAGNESIUM OXIDES CONTENT	47	4.0915	4.30	20.256	0.82878	1.10	5.40
MOISTURE CONTENT	37	1.0459	3.00	79.532	0.83186	0.00	3.00

SOURCE=NELSON

VARIABLE	N	MEAN	RANGE	CV	STD	MIN	MAX
% RETAINED ON THE #325	41	18.1561	20.00	23.358	4.24088	11.60	31.6
POZZALANIC ACTIVITY INDEX	26	85.3885	4.50	1.692	1.44453	81.40	85.9
AUTOCLAVE EXPANSION	28	0.0314	0.12	137.119	0.04309	-0.02	0.1
SPECIFIC GRAVITY	28	2.5761	0.30	3.046	0.07847	2.40	2.7
LOSS ON IGNITION	41	1.6317	3.20	45.625	0.74446	0.10	3.3
SULFUR TRIOXIDE CONTENT	41	3.4756	31.50	138.596	4.81704	1.50	33.0
TOTAL OXIDES	41	65.6829	25.20	8.164	5.36218	50.00	75.2
CALCIUM OXIDES	41	22.8780	10.30	11.966	2.73756	18.40	28.7
MAGNESIUM OXIDES CONTENT	41	3.7707	4.80	24.957	0.94107	1.00	5.8
MOISTURE CONTENT	38	1.6263	2.80	41.794	0.67970	0.10	2.9