ACCELERATED CURING OF LIME AND SALT-LIME MODIFIED

AND STABILIZED COHESIVE OKLAHOMA SOILS

By

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CHAPTER I

INTRODUCTION

In recent years, highway engineers have become more concerned with
the engineering property improvement of existing cohesive subgrade soils.
The use of chemical additives to both modify and stabilize cohesive
soils is now a standard engineering technique. Feasibility of lime and
salt-lime treatment of Oklahoma cohesive soils has already been investi-
gated (Refs 1, 2, 3, 4), thus the purpose of this study was not to
evaluate effects of lime and/or salt-lime treatment but to evaluate ways
of efficiently and quickly determining strength increases caused by lime
and salt-lime treatment.

Statement of the Problem

Rapid design of highway base and subbase courses of lime and salt-
lime treated cohesive soil is hindered by the length of time required to
obtain "strength" values for the treated material. Strength gain with
time is not very fast, and the strength after 28-days of curing is often
taken as a design value, as it is the conventional design procedure used
at Oklahoma State University. Thus, at least a month is required to
develop an adequate design. It would be advantageous, obviously, to
devise a procedure whereby 28-day strengths could be accurately predicted
on the basis of tests that could be completed in a much shorter period
of time.

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Lime and salt-lime reactions with cohesive soil are chemical in nature, and their reaction rate should be increased by curing at elevated temperatures. However, if the curing temperature is too high it is possible that different reactions will occur than those obtained by conventional curing. If the curing temperature is too low, no great decrease in required curing time will exist.

The problem in accelerated curing is, then, to obtain a short-time cure which gives both strength gain and chemical reactions equivalent to those obtained by conventional curing procedures.

Scope of This Investigation

The scope of this investigation was to determine the temperature and time requirements for accelerated curing of two cohesive Oklahoma soils, modified and stabilized with lime and salt-lime additives, which would produce both strength gain and chemical products equivalent to those obtained by 28-day cure in a moist room at 80° F and 100% humidity.

CHAPTER II

MATERIALS AND SAMPLE PREPARATION

This Chapter describes the two cohesive Oklahoma soils used in the
research and the standardized procedure employed in sample preparation,
adopted to minimize errors in test results. A brief description of the
chemical additives used in testing is also presented.

Materials

Permian Red Clay (PRC), of medium plasticity, was one of the cohe-
sive soils chosen for use in this study. PRC is the predominant cohe-
sive soil type of central and western Oklahoma, originating from Permian
marine deposits. The Permian deposits of Oklahoma have a distinctive
red color because of their iron oxide content, and are composed chiefly
of PRC overlying soft, variable red clay shale. Extensive research in
determining feasibility of PRC for salt-lime stabilization has been
completed by Marks and Haliburton (Ref 1). From their study, the author
obtained information pertaining to the physical properties of PRC.

The selection of the second Oklahoma soil, Roger Mills Gray Clay
(RMGC), was made for its differences in both physical characteristics
and geographical origin from that of PRC, and extensive testing of RMGC
salt-lime stabilization feasibility was also conducted by Marks and
Haliburton (Ref 1). RMGC is a highly plastic clay with a distinctive
steel gray color. The material used throughout the study was obtained

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seven miles west of Rollo, in Roger Mills County, Oklahoma.

Table 2.1, taken from Marks and Haliburton (Ref 1), shows the index properties of PRC and RMGC. Grain size distribution curves for the two soils are shown in Fig 2.1. The texture of the two soils, although processed by the same procedure, is quite different. RMGC contains much lower percentages of the fine clay fraction than does PRC; conversely, PRC contains much lower percentages of the coarse clay fraction.

TABLE 2.1

Index Properties of PRC and RMGC

Properties	PRC	RMGC
Specific Gravity	2.72	2.73
Liquid Limit	38.60	60.50
Plastic Limit	17.60	29.80
Plasticity Index	21.00	30.70
Flow Index	3.00	7.70
Toughness Index	7.00	4.00
Liquidity Index	-----	0.33
Lineal Shrinkage	12.0%	17.8%

Lime used throughout the study was supplied by the St. Clair Lime Company of Sallisaw, Oklahoma, in the form of pelletized quicklime (calcium oxide). To prevent formation of carbonates, it was kept tightly sealed in metal containers until used. Moreover, to ensure that carbonated fractions were not mixed with soil, the lime was passed through US No. 40 Sieve before addition.

Rock salt (sodium chloride) was also used as a chemical admixture in the study. The rock salt passed the US No. 40 Sieve and contained not less than 99.0% sodium chloride.

MECHANICAL ANALYSIS CHART

Figure 2.1. Grain Size Distribution Curve for PRC and RMGC.

Sample Preparation

Approximately one thousand to fifteen hundred pounds of each type of soil had been previously obtained and processed. The processing included drying, grinding, sieving, and storing as described by Marks and Haliburton (Ref 1).

A standardized procedure for processing the various mixtures of soil, water, and chemical additives was adopted. A curing time of twenty-four hours was used prior to compaction of chemically treated samples. To produce the desired soil mixtures, the required quantity of dry soil was weighed to the nearest 0.1 gram and placed in a square plastic mixing pan. The chemical additives, at a desired percentage based on dry weight of soil, were then weighed to the nearest 0.1 gram and added. The material was then mixed thoroughly in the dry state and leveled in the plastic pan. Water of desired quantity, optimum moisture content, was sprinkled on the entire surface, and during the 24-hour curing period was allowed to migrate through the sample. The total sample weight was then taken, to the nearest 0.1 gram, and the plastic pan sealed to prevent evaporation. Just prior to sample compaction the total weight was rechecked, and if additional water was needed, it was added at this time. The soil mixture was then mixed thoroughly by hand and resealed to prevent moisture loss during sample compaction.

TESTING PROCEDURE AND RESULTS

Introduction

A minimum of published material exists concerning accelerated cur-
ing of lime-treated soil. The research that has been performed deals
with comparisons between strengths of oven-cured samples and those of
field-cured samples.

Anday (Ref 5), using two soils, a clay gravel and micaceous silty
soil, compared the unconfined compressive strength of field-cured speci-
mens to specimens cured at 140° F and 120° F in the laboratory, both
treated with five percent lime. Field curing times were 30, 45, and
60 days, while laboratory curing times were 0.5, 1, 3, and 5 days. He
concluded from the study that the unconfined compressive strength of
samples field-cured for 45 days at summer temperatures could be predict-
ed by an accelerated laboratory cure of 18 hours at 140° F or 2 days at
120° F. However, Anday recommended the use of 120° F in the laboratory
curing for the following reasons: (a) the lower temperature caused less
moisture loss during curing, (b) the lower temperature was more realis-
tic, (c) the lower temperature created a more convenient curing time and
eased handling of the samples, and (d) the lower temperature increased
the accuracy obtained with small slopes of strength curves.

Anday (Ref 6), in 1961, expanded his research to compare field and
accelerated curing of six different lime-treated soils native to Vir-

ginia. Based on his previous work, 120° F was used exclusively for
laboratory curing. Field curing times remained at 30, 45, and 60 days,
while laboratory curing times were changed to 1, 2, and 3 days. Anday
concluded that soil-lime specimens cured under field conditions would
show an increase in unconfined compressive strength. However, the
amount and rate of strength gain would be functions of soil type and
climatic effects. Basing his field cure on 3000 degree-days, or 40 to
45 days if 0° F is taken as datum, laboratory specimens cured for 2 days
at 120° F should predict the field-cured unconfined compressive strength.

Anday's purpose in both studies was to develop the basis for a
quick laboratory method of determining the suitability of a soil for
lime stabilization under standard conditions.

Thompson (Ref 7), while assisting in development of the Illinois
Highway Department Flexible Pavement Design Manual, performed a study
to determine design coefficients for lime stabilized soils used as high-
way base and subbase courses. His research indicated that laboratory
curing of samples at 120° F for 48 hours produced unconfined compressive
strengths approximately equivalent to those obtained on samples cured
for 30 days at 70° F and recommended that minimum design strength
requirements be based on those results.

Lime and salt-lime treatment of cohesive soil has as a primary
objective the improvement of engineering properties by reduction of
plasticity and/or increase in strength. Small percentages of lime are
usually required to modify or reduce the plasticity of cohesive soils,
with very little strength gain attributable to this addition. The "lime
fixation point" or "modification optimum" is the minimum lime content at
which maximum plasticity reduction occurs. Lime stabilization of cohe-

sive soils is the addition of lime to obtain substantial strength gain. Since obtained strength gains are relatively long-term, a standard curing time of 28 days in a moist room is often used as a basis for design strength evaluations. A procedure to accelerate the rate of long-term strength gain is needed, both for actual field use and rapid laboratory mix design. The use of salt (NaCl) in conjunction with lime, as a catalyst, was evaluated by Marks and Haliburton (Ref 1). However, a curing time of 28 days in a moist room was still used to determine strength behavior.

The use of increased temperature to accelerate chemical reactions and thus decrease required curing time for strength evaluation is the basic concept behind any rapid cure procedure. The problems that arise are control of the rate of strength gain and maximum strength obtained. If the rapid cure procedure increases the strength too quickly, the design value will be higher than strength actually obtained by conventional curing procedures. It is also necessary, for efficiency, to choose one temperature for accelerated curing of different soils, treated with various percentages of lime and salt plus lime. Thus, the prime consideration of the research was to cure different soils with different chemical treatments at the same elevated temperature and achieve the same mineralogical composition and strengths of the various soils and treatments when cured under standard moist room conditions.

The remainder of the Chapter describes testing procedures used and results obtained from a detailed comparison of both accelerated and laboratory moist room curing of lime and salt-lime modified and stabilized cohesive soil samples.

Testing Procedure

The amount of lime and salt necessary to modify and stabilize both PRC and RMGC were previously determined by Marks and Haliburton (Ref 1) in their feasibility study of salt-lime stabilization, and are indicated in Table 3.1.

TABLE 3.1

MODIFICATION AND STABILIZATION PERCENTAGES

FOR PRC AND RMGC

	PRC	RMGC
Lime Modification Optimum	4% CaO	6% CaO
Lime Stabilization Optimum	8% CaO	11% CaO
Lime + Salt Modification Optimum	4% CaO + 1% NaCl	6% CaO + 2% NaCl
Lime + Salt Stabilization Optimum	8% CaO + 1% NaCl	11% CaO + 2% NaCl

The data in Table 3.1 were used in preparation of samples for unconfined compression testing and differential thermal analysis.

Unconfined compression samples were compacted at optimum moisture and density, to values shown in Table 3.2, using a modified Harvard miniature (impact compaction) procedure. The mold used had a length of 2.8125 inches and a diameter of 1.3125 inches. Impact loading was applied with an 0.825 pound hammer in three lifts at 25 blows per lift. Impact energy was reduced in scale proportionally from the Standard Proctor hammer, and equivalent densities were produced. All samples were then sealed with Saran wrap and dipped in melted wax to prevent moisture loss or gain during curing.

TABLE 3.2[*]

MINIATURE STANDARD PROCTOR COMPACTION DATA

FOR PRC AND RMGC

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
PRC + 4% CaO	20.0	95.5
PRC + 4% CaO + 1% NaCl	18.0	100.0
PRC + 8% CaO	25.0	90.0
PRC + 8% CaO + 1% NaCl	24.0	97.5
RMGC + 6% CaO	25.0	92.0
RMGC + 6% CaO + 2% NaCl	24.5	93.7
RMGC + 11% CaO	27.0	92.0
RMGC + 11% CaO + 2% NaCl	23.0	96.0

[*]After Marks and Haliburton (Ref 1)

Two sets of samples for each soil type were compacted for unconfined compression testing, with one set cured in the OSU Soil Mechanics Laboratory moist room, at 80° F and 100% humidity, for 7, 14, 21, and 28 days. The moist room curing temperature of 80° F is similar to average temperatures measured in base, subbase, and subgrade material under Oklahoma highways during the spring/summer construction season (Ref 8) and thus may be taken as a reasonable approximation of field curing temperature. The second set of samples was cured in a Blue M Vapor-Temp Humidity Chamber, at 105° F and 95% humidity, for 12, 24, 36, 48, 60, and 72 hours. Unconfined compression tests were performed on three samples after each of the previously mentioned curing times, at a loading rate of 0.02 inches per minute, equivalent to approximately 5 percent strain in ten minutes. The entire sample was saved and both moisture content and dry density were checked. The average strength of the three samples was used unless one sample gave results much higher

or lower than the other two, then its value was disregarded and the remaining two values averaged.

Differential Thermal Analysis (DTA) of both PRC and RMGC samples was conducted according to a procedure developed in the OSU Soil Mechanics Laboratory (Ref 9). Samples for DTA were compacted and cured by the referenced procedures, using failed samples from strength testing. The DTA samples were air-dried and ground with mortar and pestle. The soil was then sieved and the fraction passing a US No. 80 Sieve and retained on a US No. 200 Sieve was used, to conform to the gradation of the thermally inert reference material, aluminum oxide (Al_2O_3), and thus minimize DTA thermocouple/recorder baseline shift and drift. The sieved soil fraction was then stored over a 1 Normal saturated solution of magnesium nitrate [$Mg(NO_3)_2 \cdot 6 H_2O$], to allow even distribution of moisture in the sample. After four days, 0.15 grams of the sample were prepared for DTA by static compaction at 530 psi in a quartz crucible.

Differential thermal analysis curves were obtained from a Fisher Model 260 Thermalyzer, connected to a 1 mv Texas Instruments Serva/Riter II strip chart recorder. Platinel differential thermocouples were used, with a heating rate of 10° C/min from room temperature to 1200° C and a recorder chart speed of 4 in/hr.

Results

Preliminary studies were made with waxed samples cured in a Blue M Vapor-Temp Humidity Chamber at 95% humidity and 120°, 110°, 105°, and 100° F, to determine the one temperature which would most nearly approximate the strength-time behavior of the moist room-cured samples of both PRC and RMGC under the four levels of lime and salt-lime treatment. The

data shown in Fig 3.1 are typical of the effect of temperature on rate of strength gain for lime and salt-lime treated soils. The plot shows that a decrease in accelerated cure temperature decreases the rate of strength gain. The 120° F curves did not have a shape or slope close to that of the moist room curves, whereas the curves at temperatures of 110°, 105° and 100° F did approximate the moist room cure curve shape. The 110° F curves, although similar in shape, did not appear to level off as the moist room curves do after approximately 28 days of curing. The 100° F curves resemble both the shape and slope of the moist room curves but did not produce strengths equivalent to those obtained by 28-day moist room curing. For both soils and all treatments, the 105° F curves were found to best approximate the slopes and shapes of the moist room curves, and produce strengths equivalent to 28-day moist room cure; thus 105° F was selected as the accelerated curing temperature. Once a single humidity chamber temperature was found to approximate the effects of moist room curing, a correlation between curing time and strength could be developed.

Figures 3.2 through 3.9 are plots of unconfined compressive strength vs curing time for PRC and RMGC at lime and salt-lime modification and stabilization optimums, cured in the OSU Soil Mechanics Laboratory moist room at 80° F and 100% humidity and in a Blue M Vapor-Temp Humidity Chamber at 105° F and 95% humidity. The strengths obtained from the 28-day moist room cure curves were projected to the equivalent strength curves from the humidity chamber-cured samples and the curing times required to produce the equivalent 28-day strengths were recorded.

Figures 3.2 and 3.3 are plots of PRC and RMGC treated with their respective lime modification optimum percentages. Although the 28-day
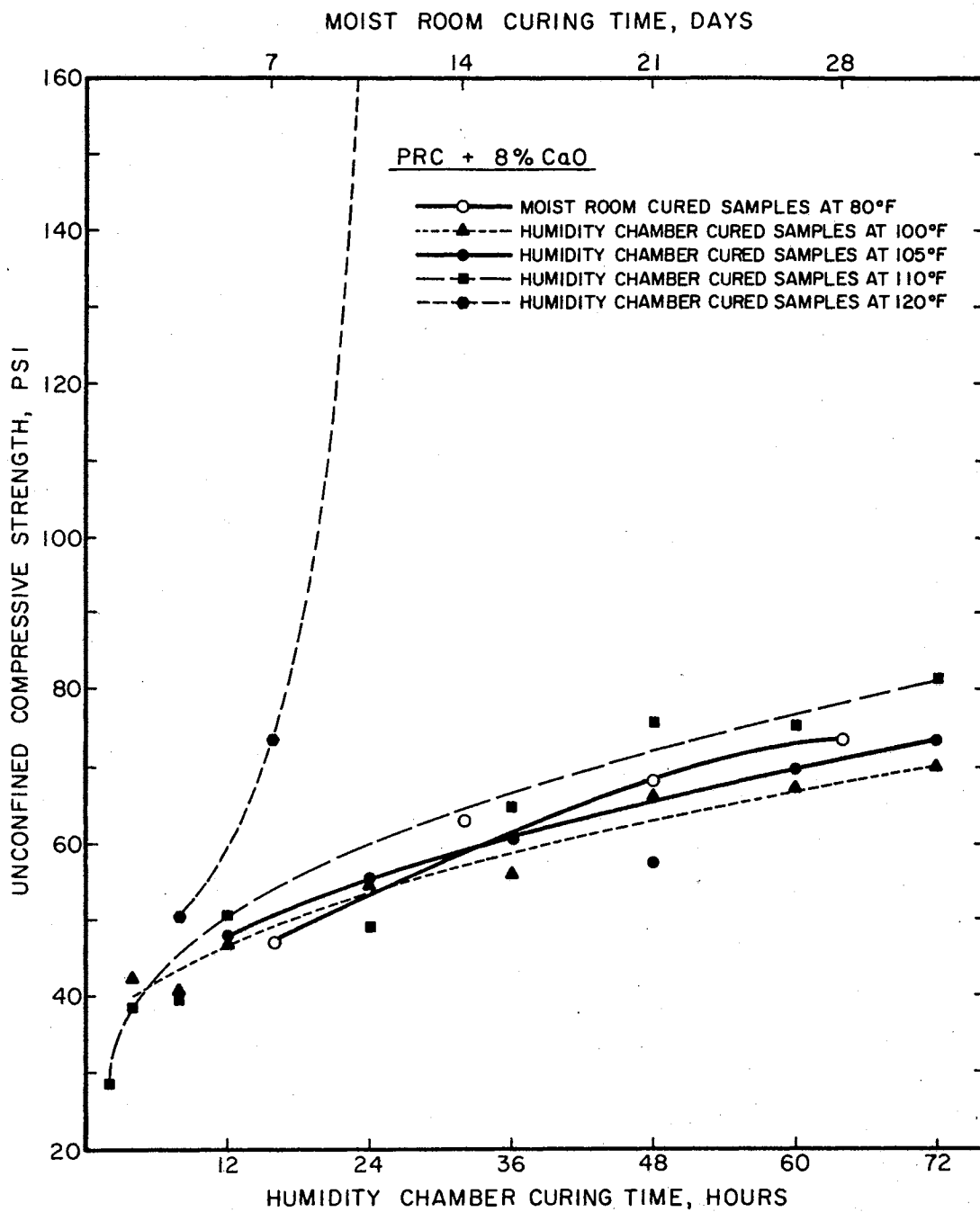
MOIST ROOM CURING TIME, DAYS

Figure 3.1. Strength-Time Behavior of Lime Stabilized PRC at
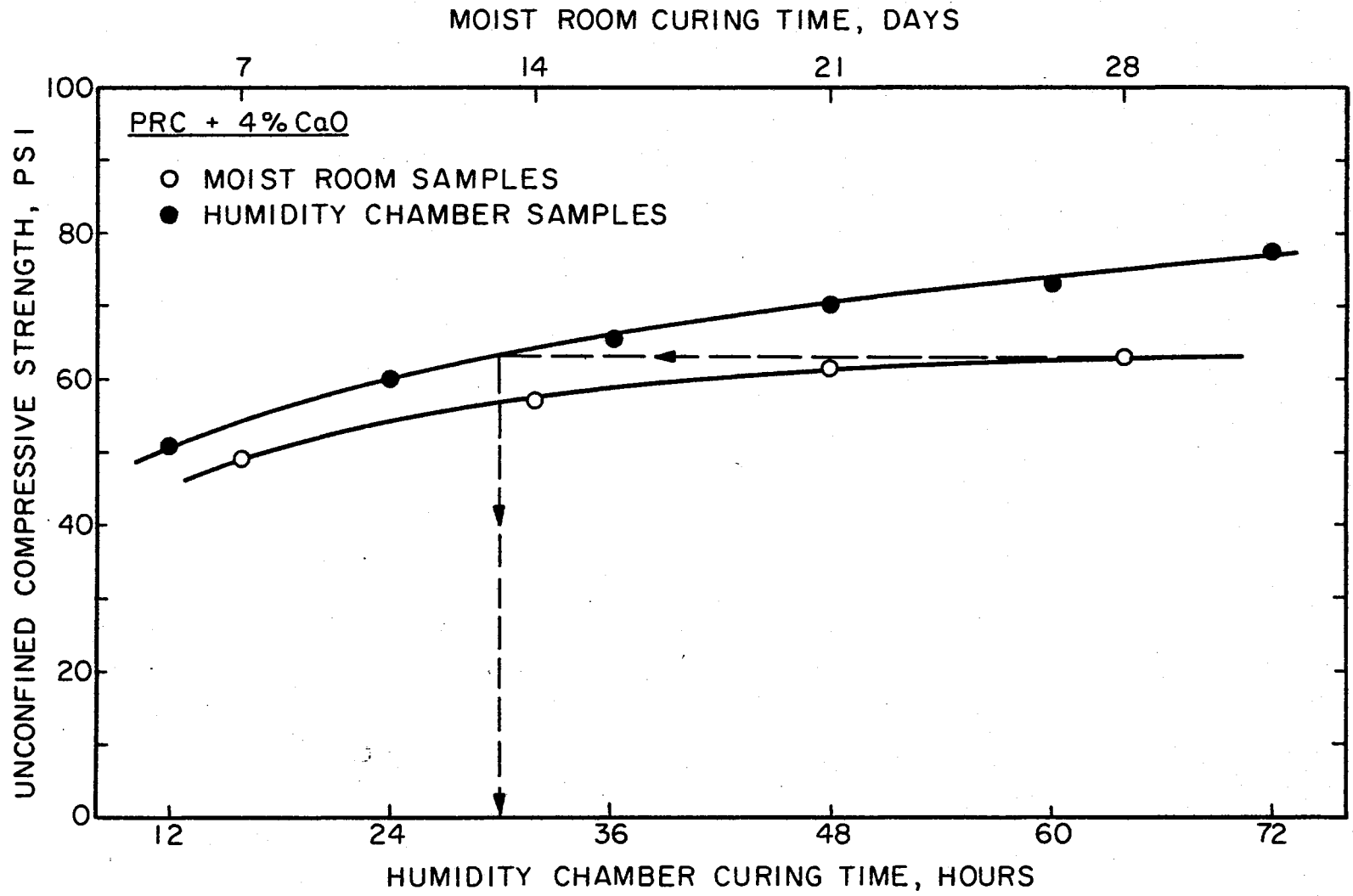Various Accelerated Curing Temperatures.

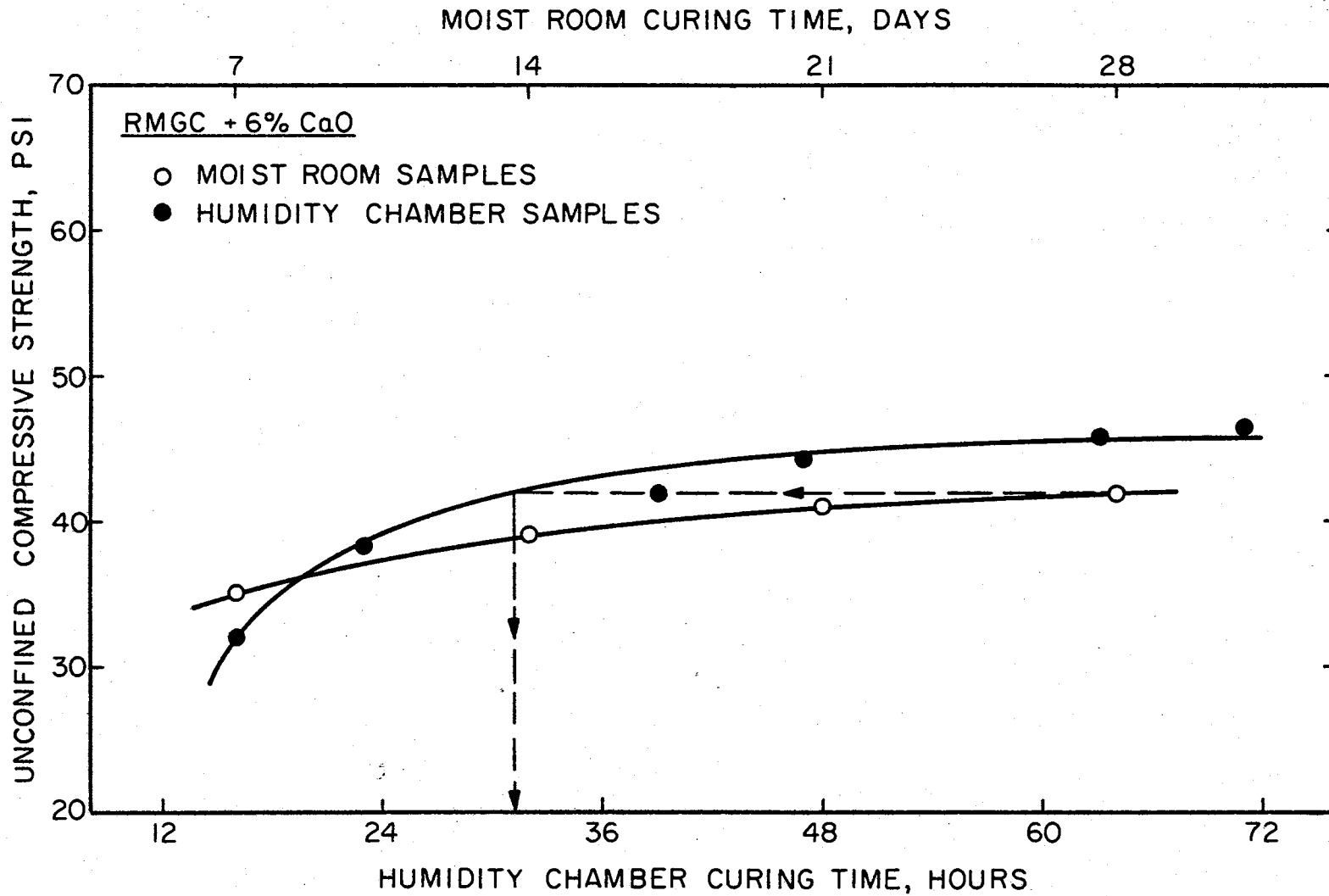Figure 3.2.   Strength-Time Behavior of Lime-Modified PRC.

Figure 3.3.   Strength-Time Behavior of Lime-Modified RMGC.

moist room cured sample have a marked difference in strength, 62 psi for PRC and 42 psi for RMGC, the required accelerated curing time to produce this equivalent strength was approximately equal for both samples. PRC needed an accelerated curing time of 30 hrs, whereas RMGC required 31.8 hrs. The error which would result in rounding the curing to 30 hrs for lime-modification of RMGC would be 1.2% or 0.5 psi to the conservative side. Therefore, the accelerated curing time for lime-modified samples cured at 105° F and 95% humidity would be 30 hours.

Figures 3.4 and 3.5 are plots of PRC and RMGC at lime stabilization optimum. The percentage of lime necessary for optimum stabilization is generally unknown, but for Oklahoma cohesive soils has been found to be approximately twice the lime-modification optimum (Ref 1). The accelerated curing of samples at the lime stabilization optimum required approximately 72 hours of rapid curing. The time of 72 hours is based on the results shown in Fig 3.4 and 3.5, as both PRC and RMGC required 72 hours to achieve equivalent 28-day moist room strengths of 74 psi for PRC and 44 psi for RMGC.

Figures 3.6 and 3.7 are plots of PRC and RMGC at the respective salt-lime modification optimums. The strength of both PRC and RMGC has increased slightly over that obtained by modification with lime alone. However, the time required for accelerated curing was not changed markedly, as is to be expected since there is little free lime available for pozzolanic reaction at modification optimum. The required time for PRC has actually decreased to 28 hours where the time for RMGC has increased to 38 hours. The error that would result from rounding the accelerated curing time to 30 hours for both soils is 1.5% or 1 psi for PRC and 11.6% or 6 psi for RMGC, on the conservative side.
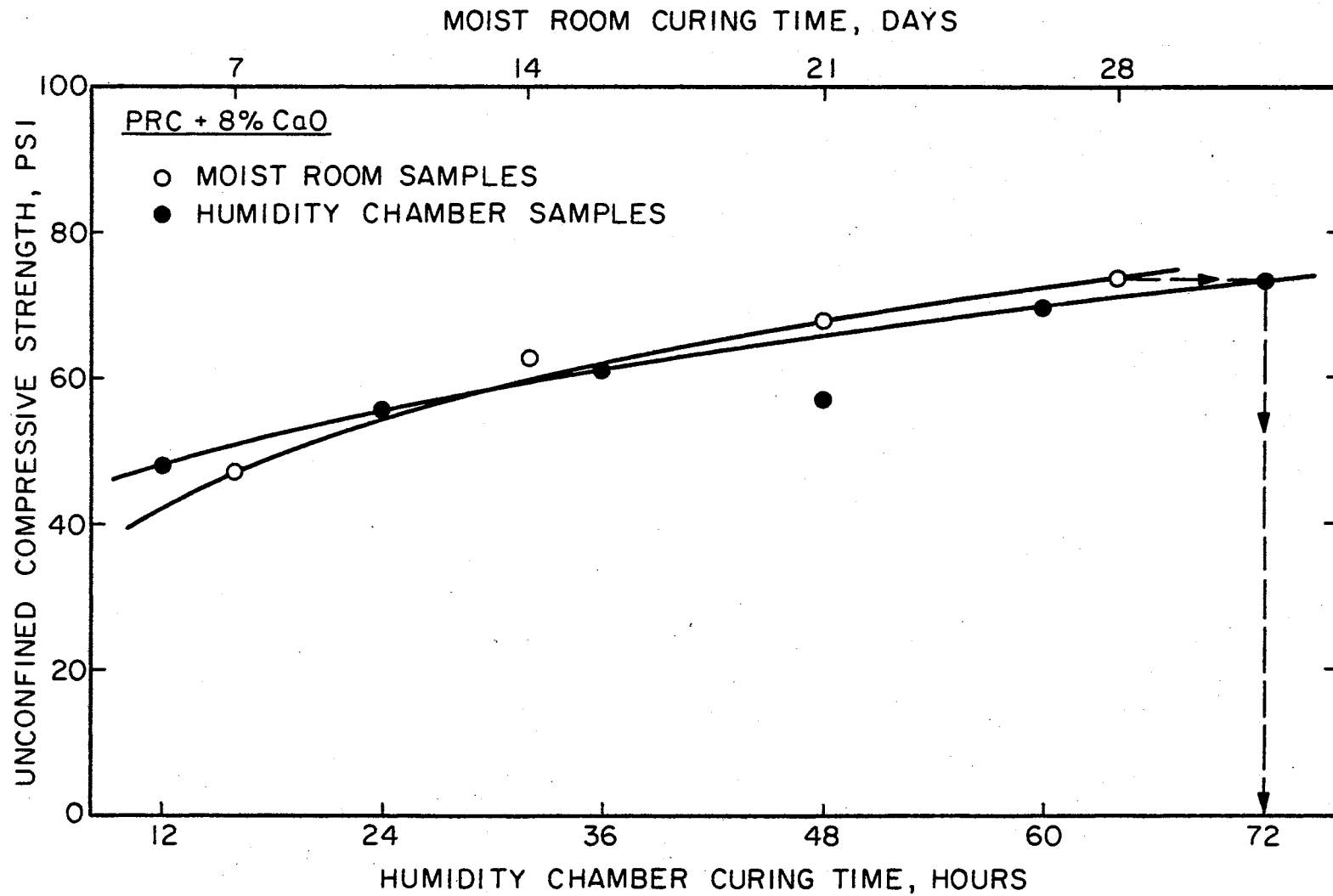
Figure 3.4. Strength-Time Behavior of Lime-Stabilized PRC.
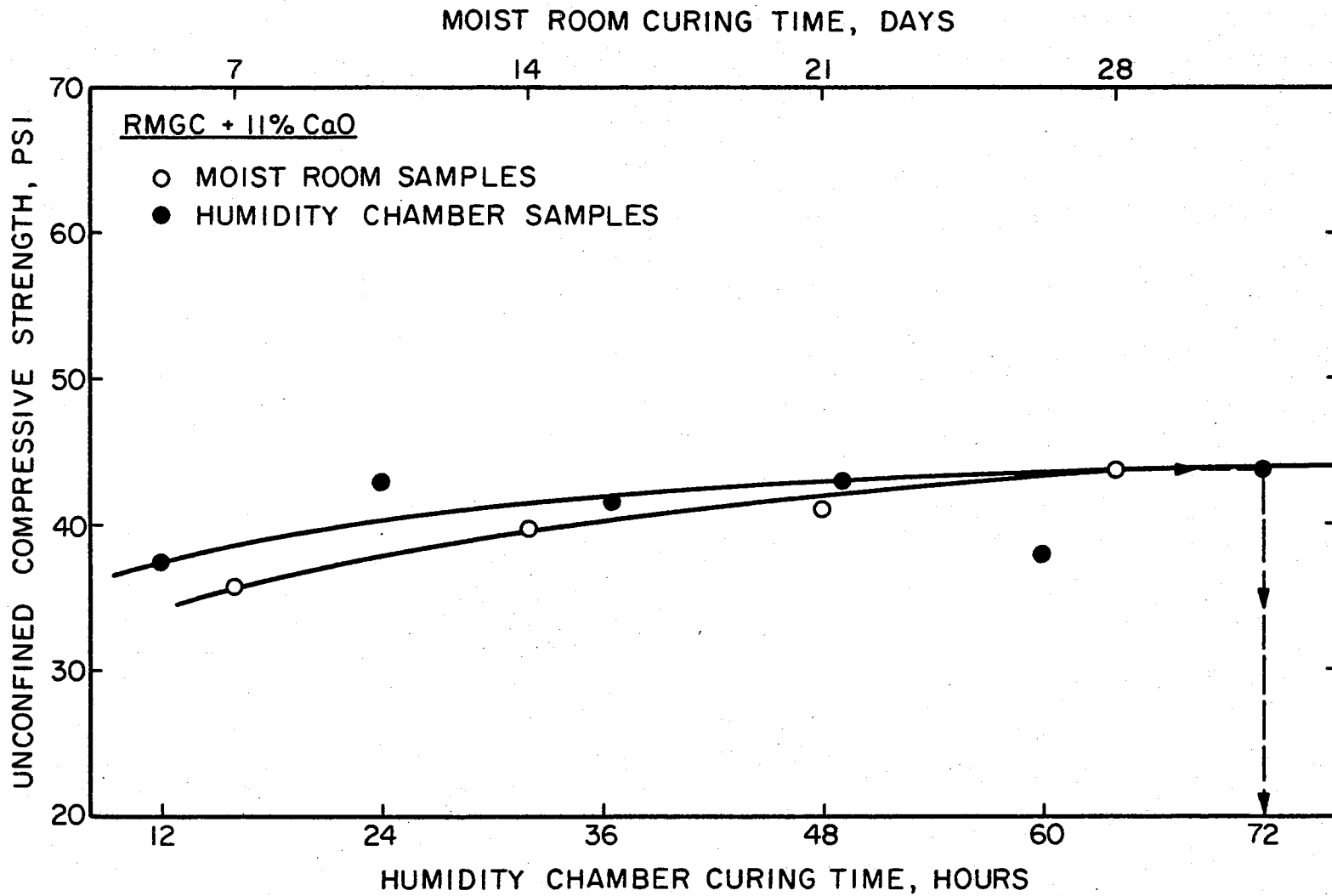
Figure 3.5. Strength–Time Behavior of Lime–Modified RMGC.
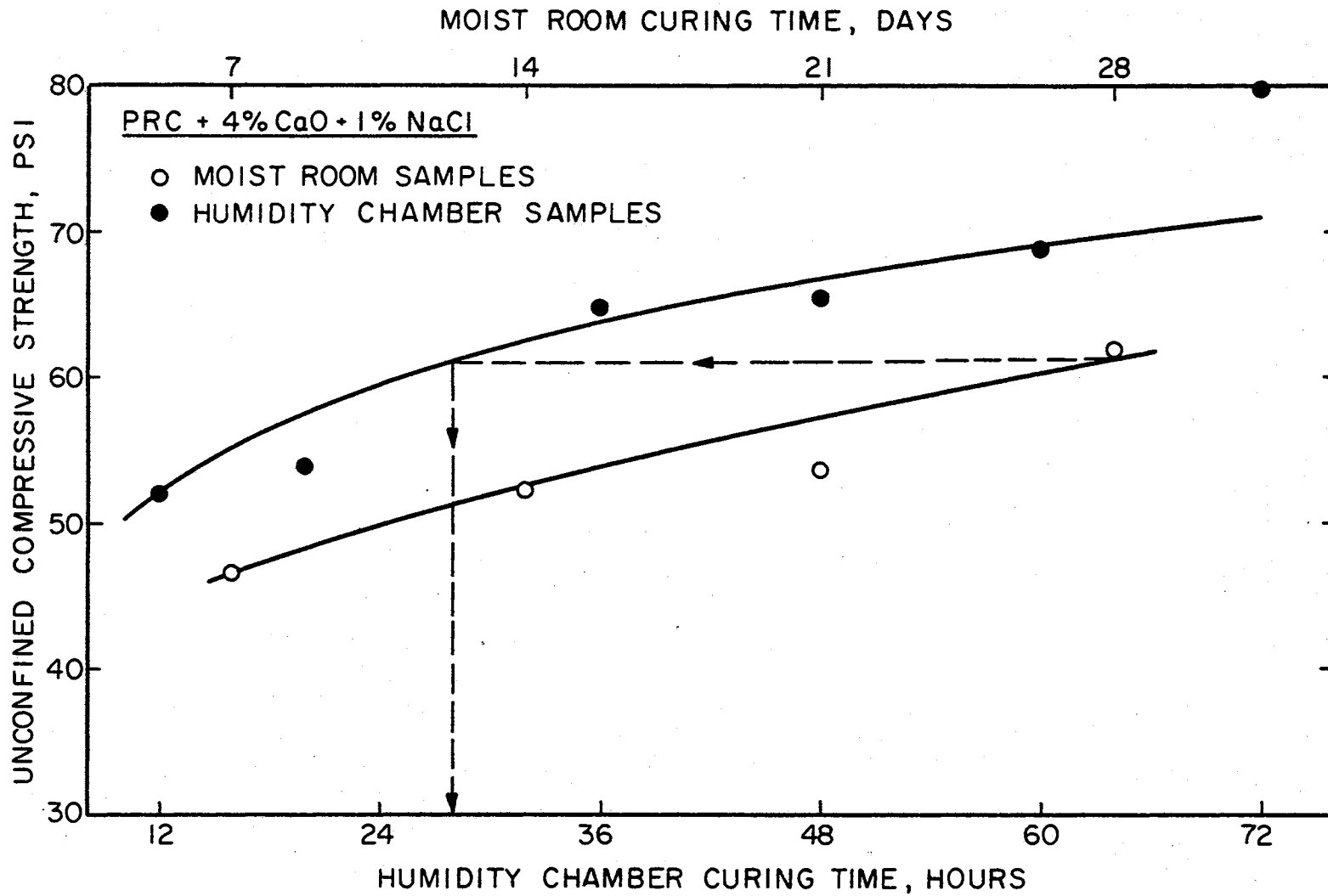
Figure 3.6. Strength-Time Behavior of Salt-Lime Modified PRC.
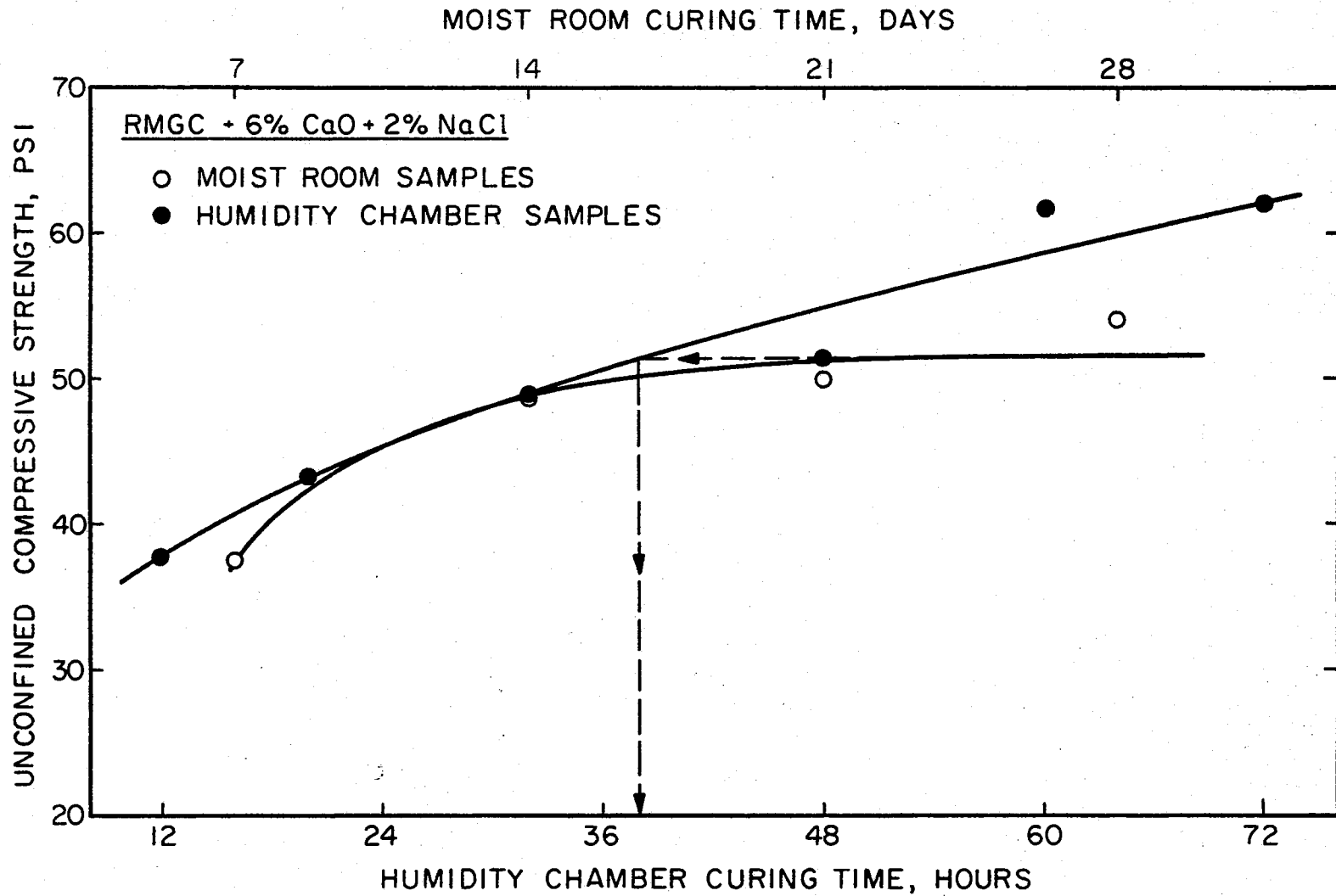
Figure 3.7.   Strength-Time Behavior of Salt-Lime Modified RMGC.

Figures 3.8 and 3.9 are plots of PRC and RMGC at the salt-lime stabilization optimum. Again this percentage is generally not known, but is approximately twice the modification optimum. Although the strengths of both soils have increased, the accelerated curing time required to produce the equivalent 28-day moist room strength has decreased markedly. Marks and Haliburton (Ref 1) hypothesized that the addition of NaCl to lime-treated soils would act as a catalyst, and allow achievement of long-term strength gains more rapidly. This decrease from 72 hours accelerated curing substantiates their hypothesis. The error resulting from rounding the curing times required to 30 hours would be 2.6% or 2 psi for PRC and 5.3% or 2.5 psi for RMGC, both on the conservative side. Thus, the accelerated curing times for both salt-lime modification and salt-lime stabilization are approximately the same; further proof that salt increases the rate of lime-soil reaction.

Table 3.3 summarizes the times required to obtain equivalent 28-day strength by accelerated curing at 105° F for PRC and RMGC and standard times the author thinks acceptable in developing an accelerated mix design procedure for lime and salt-lime modified and stabilized cohesive soils.

TABLE 3.3

28-DAY EQUIVALENT 105° F ACCELERATED

CURING TIMES IN HOURS

	PRC	RMGC	Standard
Lime Modification	30	31.8	30
Lime Stabilization	72	72	72
Lime + Salt Modification	28	38	30
Lime + Salt Stabilization	28	36	30
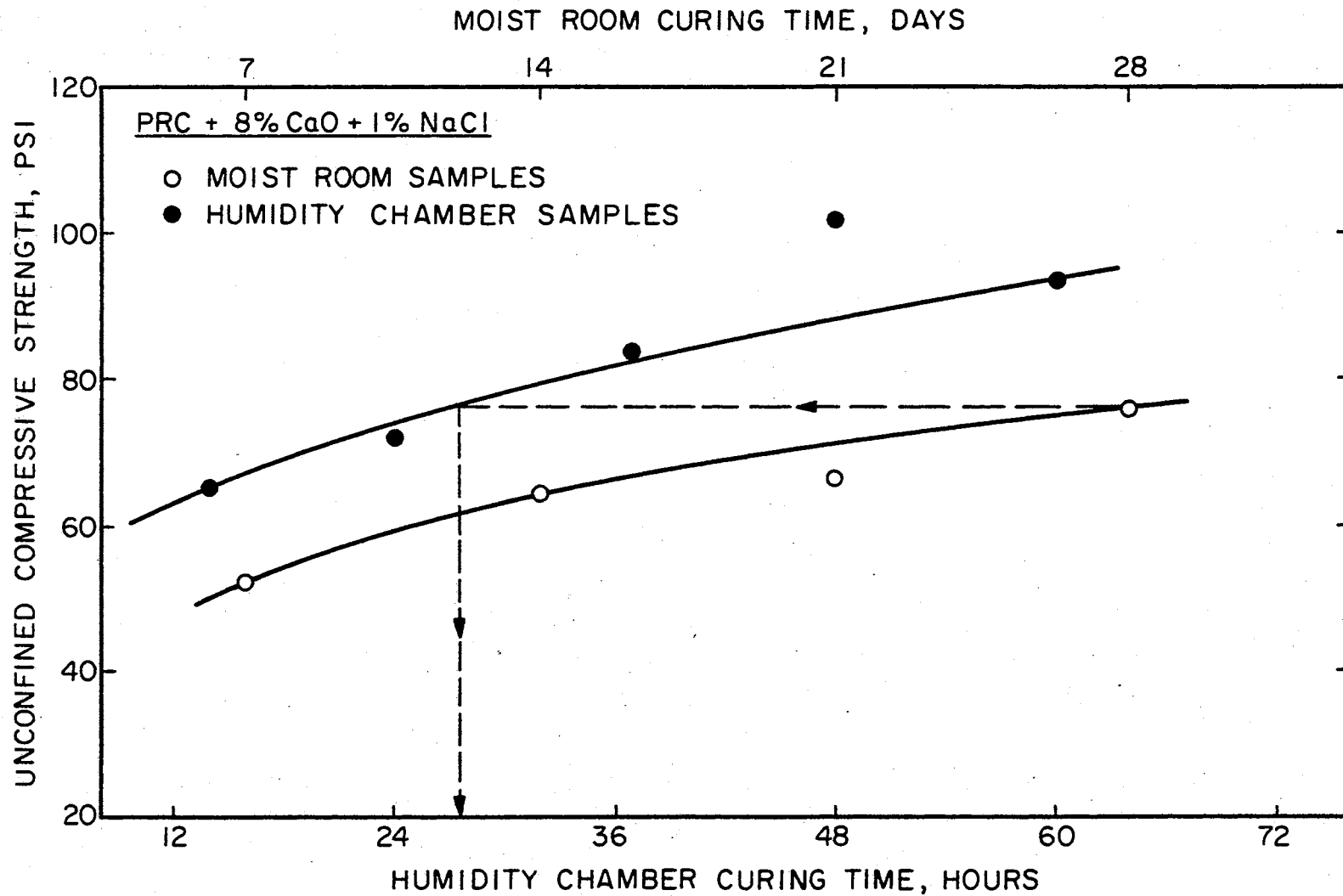
Figure 3.8. Strength-Time Behavior of Salt-Lime Stabilized PRC.
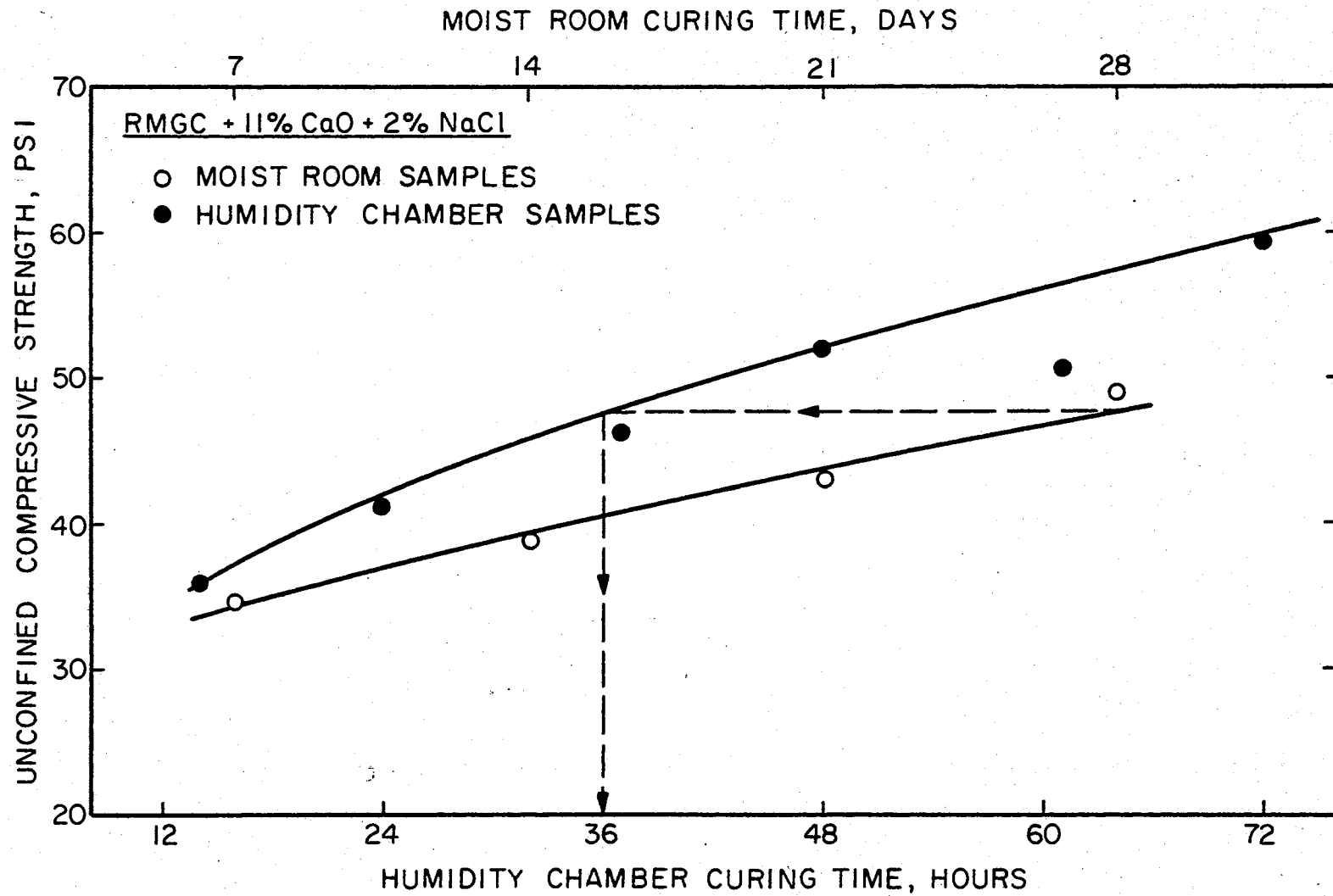
Figure 3.9. Strength-Time Behavior of Salt-Lime Stabilized RMGC.

Since lime and salt-lime reactions with cohesive soils are chemical and thus temperature-dependent, some method to determine the effects of accelerated curing on the treated soil's mineralogical composition was necessary. It is not enough to produce an equivalent 28-day moist room curing strength, if this is done through a change in mineralogical composition and reaction products rather than by simply accelerating the change that takes place naturally during moist room cure.

Differential thermograms for the two raw soils used throughout the study (PRC and RMGC) are shown with pure samples of illite and chlorite in Fig 3.10. It is obvious from analysis of these curves that both soils are composed mainly of illite and chlorite. RMGC appears to contain more chlorite than PRC since double peaks around 600° C are more pronounced in this material.

Differential thermal analysis was not used to determine the exact chemical composition of the treated soil samples, but merely as a means of mineralogically fingerprinting the moist room and humidity chamber samples, to determine if their mineralogical characteristics after respective curing procedures were similar.

Differential thermograms of PRC and RMGC at lime and salt-lime modification and stabilization optima are presented in Fig 3.11 through 3.18. Differential thermal analysis was run on moist room samples cured 7, 14, 21, and 28 days and humidity chamber samples cured the number of hours equivalent to 28-day strengths, and also plus and minus 12 hours. The endothermic peak at 100° C common to all samples is from the moisture present.

Figure 3.11 shows thermograms of lime-modified PRC. Both the moist room samples and humidity chamber samples show typical 570° C and 900° C
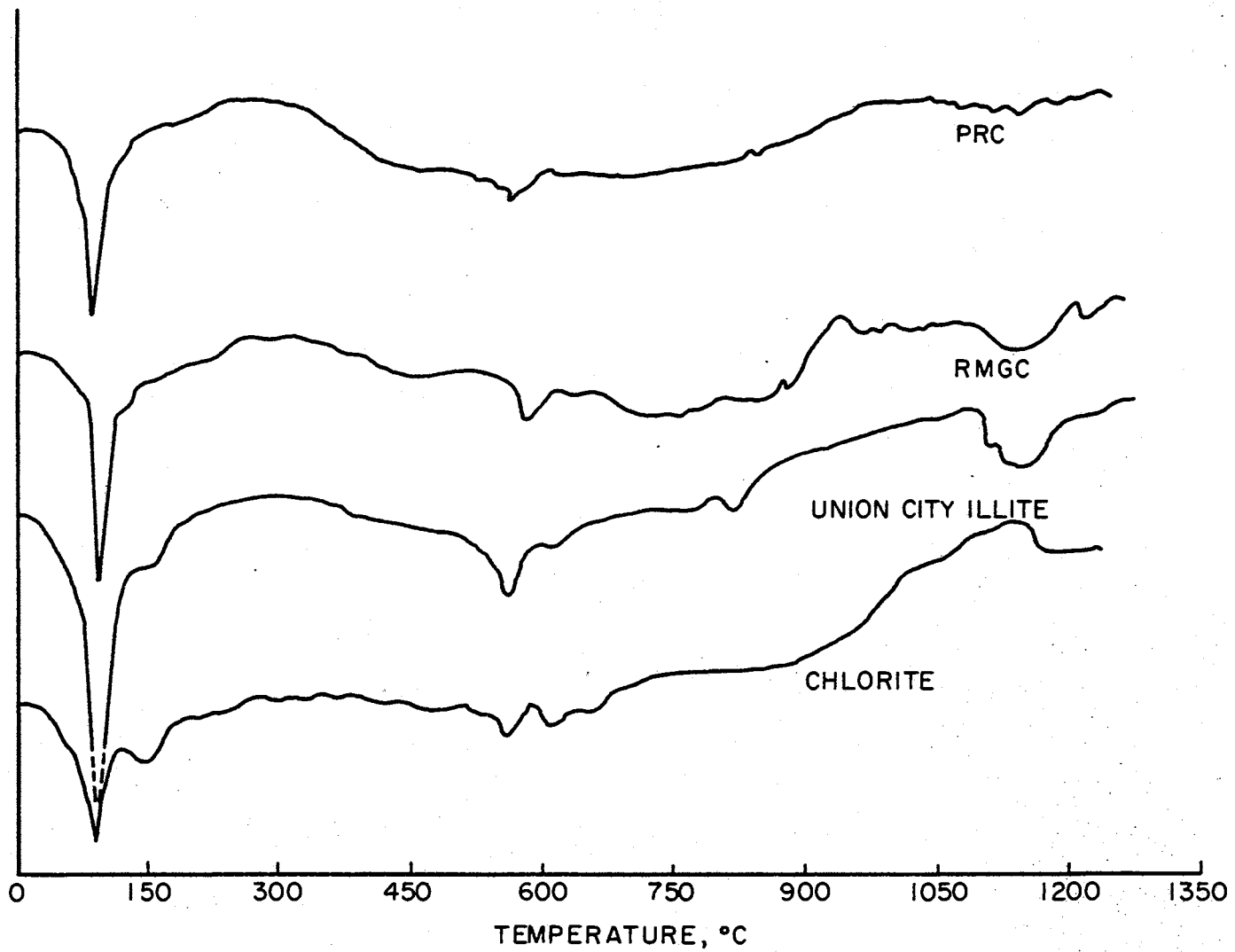
Figure 3.10. Differential Thermograms of PRC, RMGC, Illite, and Chlorite.

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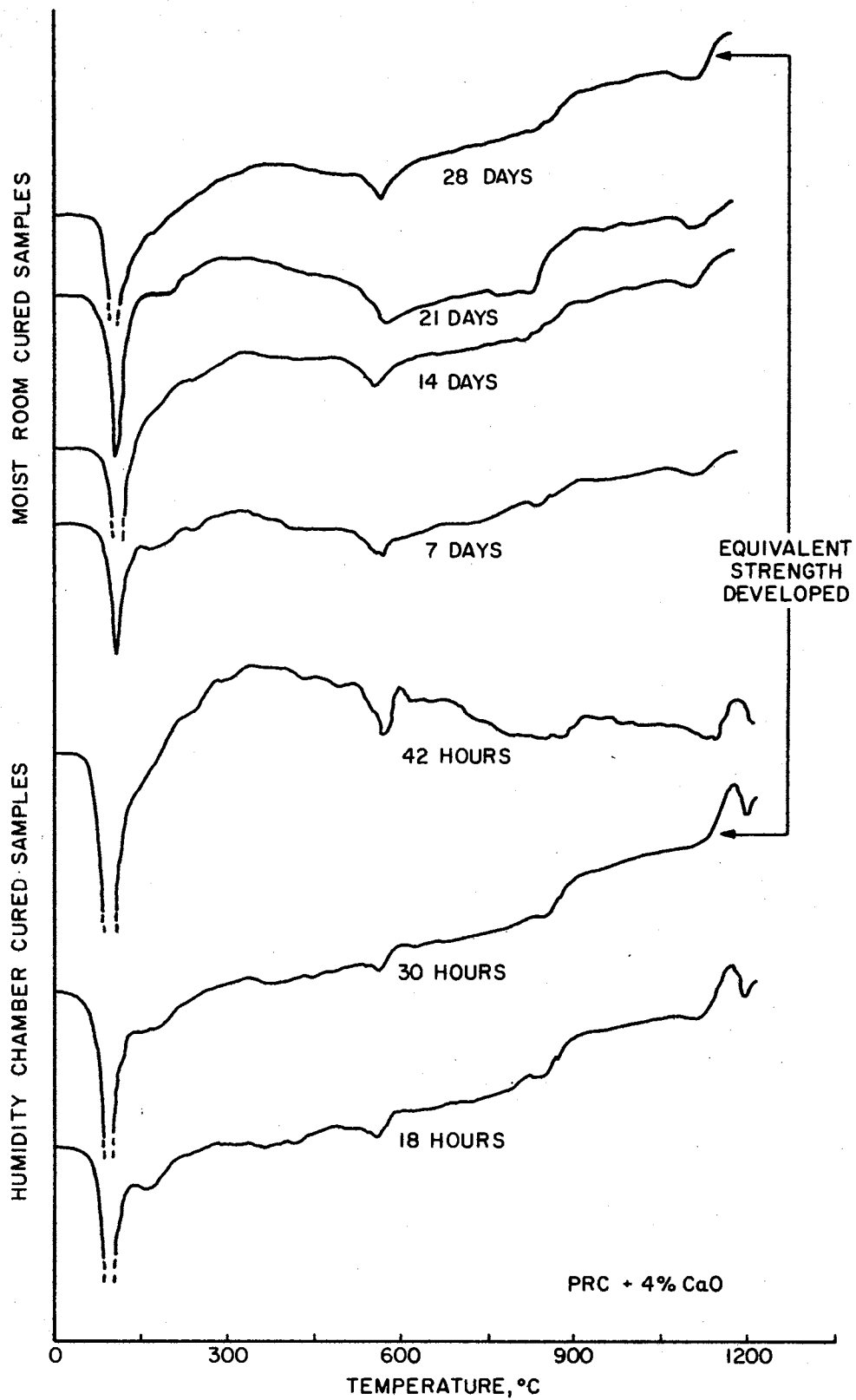
Figure 3.11. Differential Thermograms of Lime-Modified PRC.

endothermic peaks, which could be attributed to free lime. However, as can be seen in Fig 3.12, which shows thermograms of salt-lime modified PRC, the 570° C peak is still present but the 900° C peak has become exothermic, which would tend to show that some chemical reaction at modification optimum is caused by addition of salt.

Both Figs 3.13 and 3.14 are differential thermograms of lime and salt-lime modified RMGC. Figure 3.13 shows that common endothermic peaks at 570° C and 1100° C and also a slightly developed exothermic peak at 900° C exist for both moist room and humidity chamber cured samples, while Fig 3.14 shows the absence of the 570° C peak and a greater development of the 900° C peak. This 900° C exothermic peak again tends to show some chemical reaction occurs when salt is added.

Figures 3.15 and 3.16 show differential thermograms of lime and salt-lime stabilized PRC, respectively. Figure 3.15 shows a common 570° C and 900° C endothermic peak with a slightly developed exothermic peak at 1100° C for both moist room cured and humidity chamber cured samples. Again, as can be seen in Fig 3.16, when salt is added the 570° C and 1100° C peaks remain, but the 900° C peak changes to an exothermic reaction.

Figures 3.17 and 3.18 are differential thermograms of lime and salt-lime stabilized RMGC respectively. Again, as in all the previous thermograms of lime-treated soils, Fig 3.17 shows the typical 570° C, 900° C, and 1100° C endothermic peaks. The peaks are common to both moist room and humidity chamber cured samples. Figure 3.18 further emphasizes the change of the 900° C peak from endothermic to exothermic when salt is added. This is a common occurrence in all the thermograms of salt-lime treated soils.
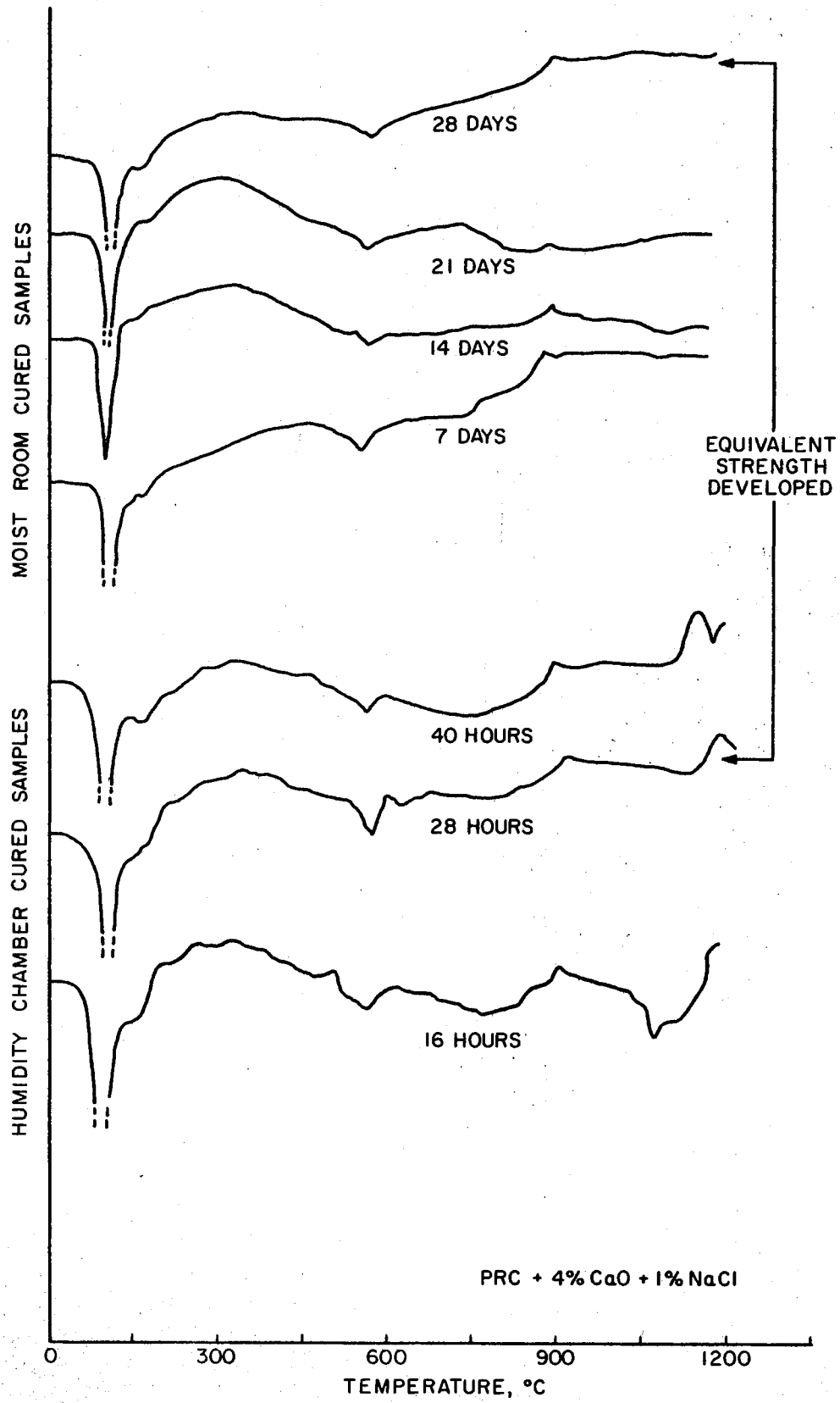
Figure 3.12. Differential Thermograms of Salt-Lime Modified PRC.
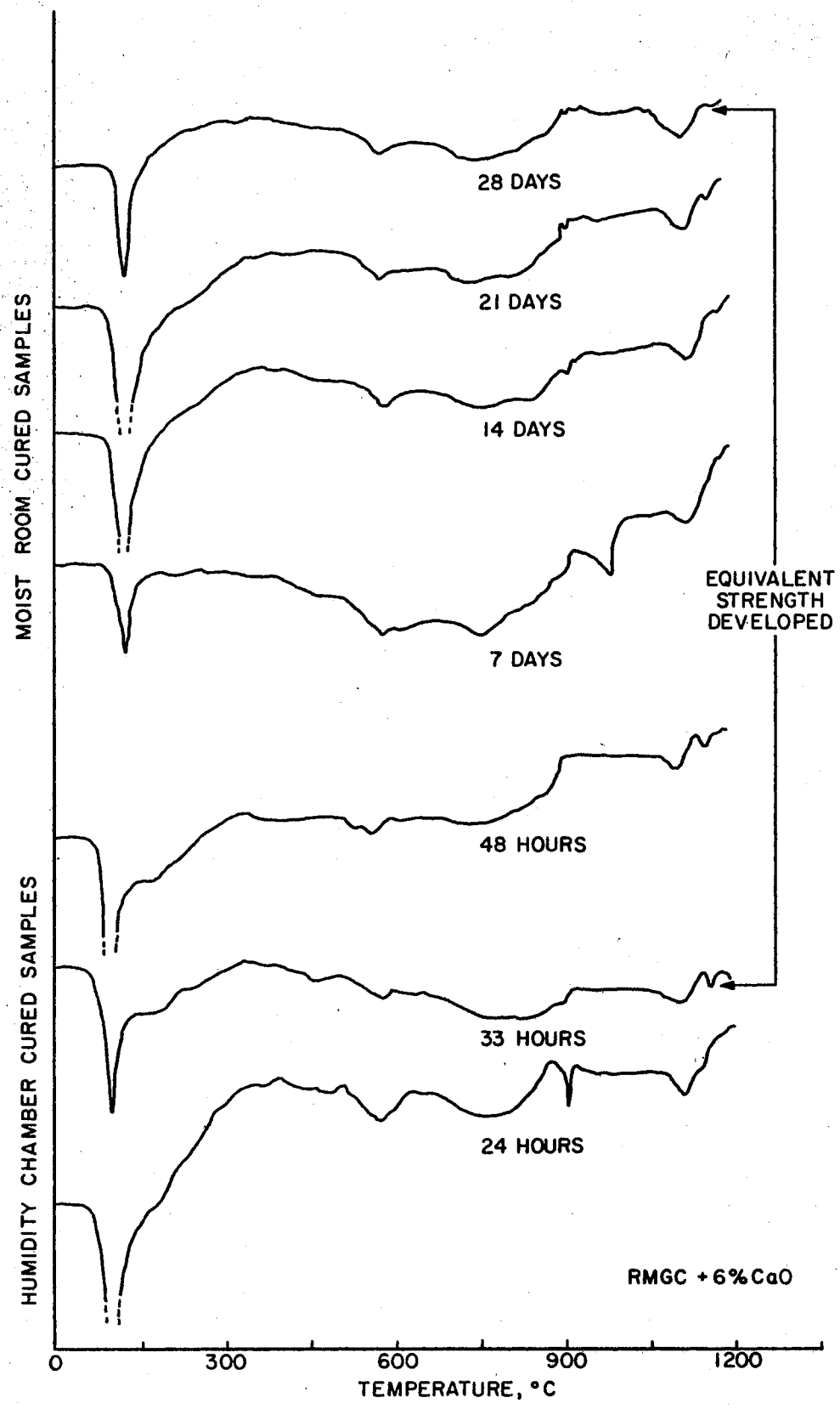
Figure 3.13. Differential Thermograms of Lime-Modified
RMGC.
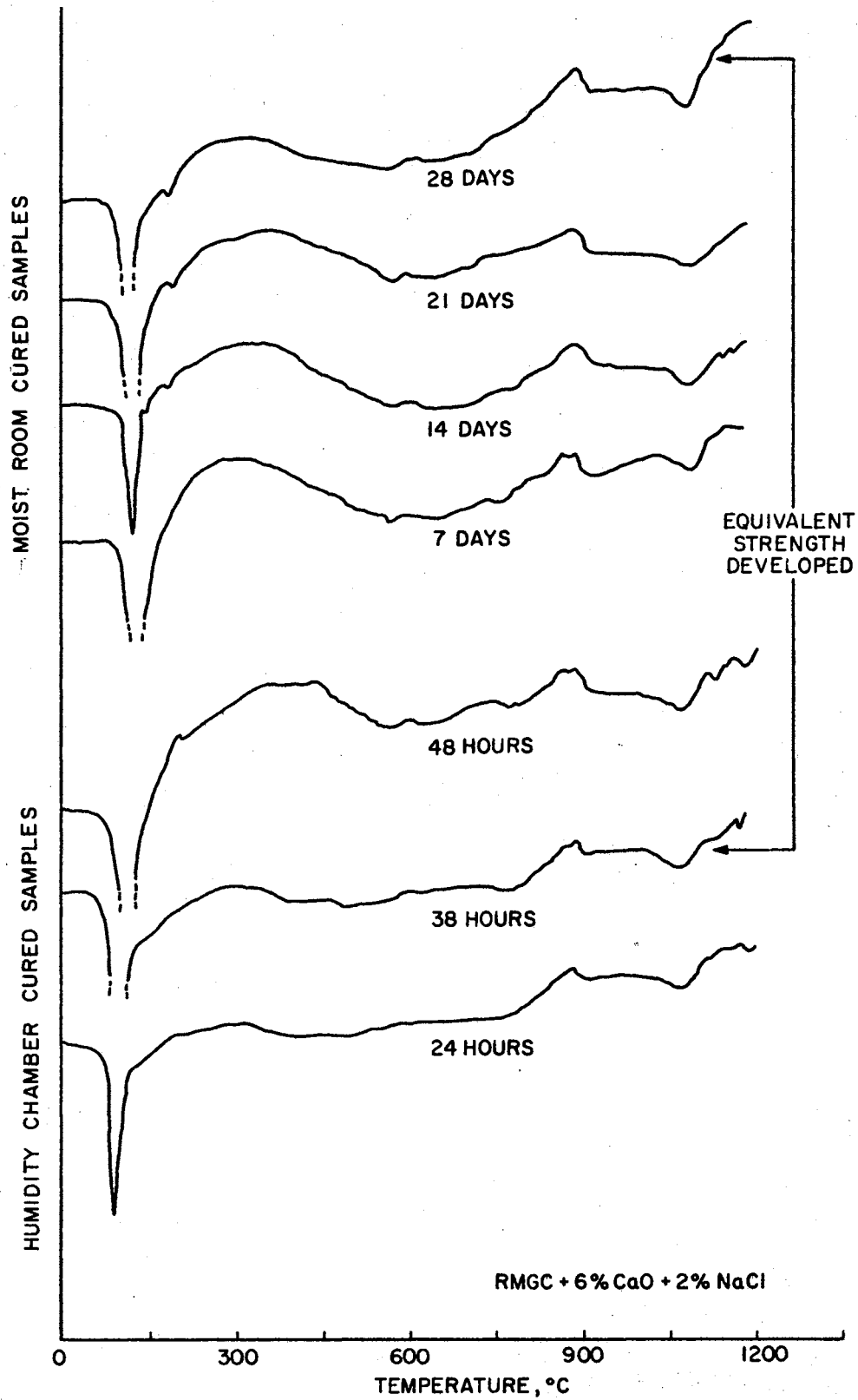
Figure 3.14. Differential Thermograms of Salt-Lime Modified RMGC.
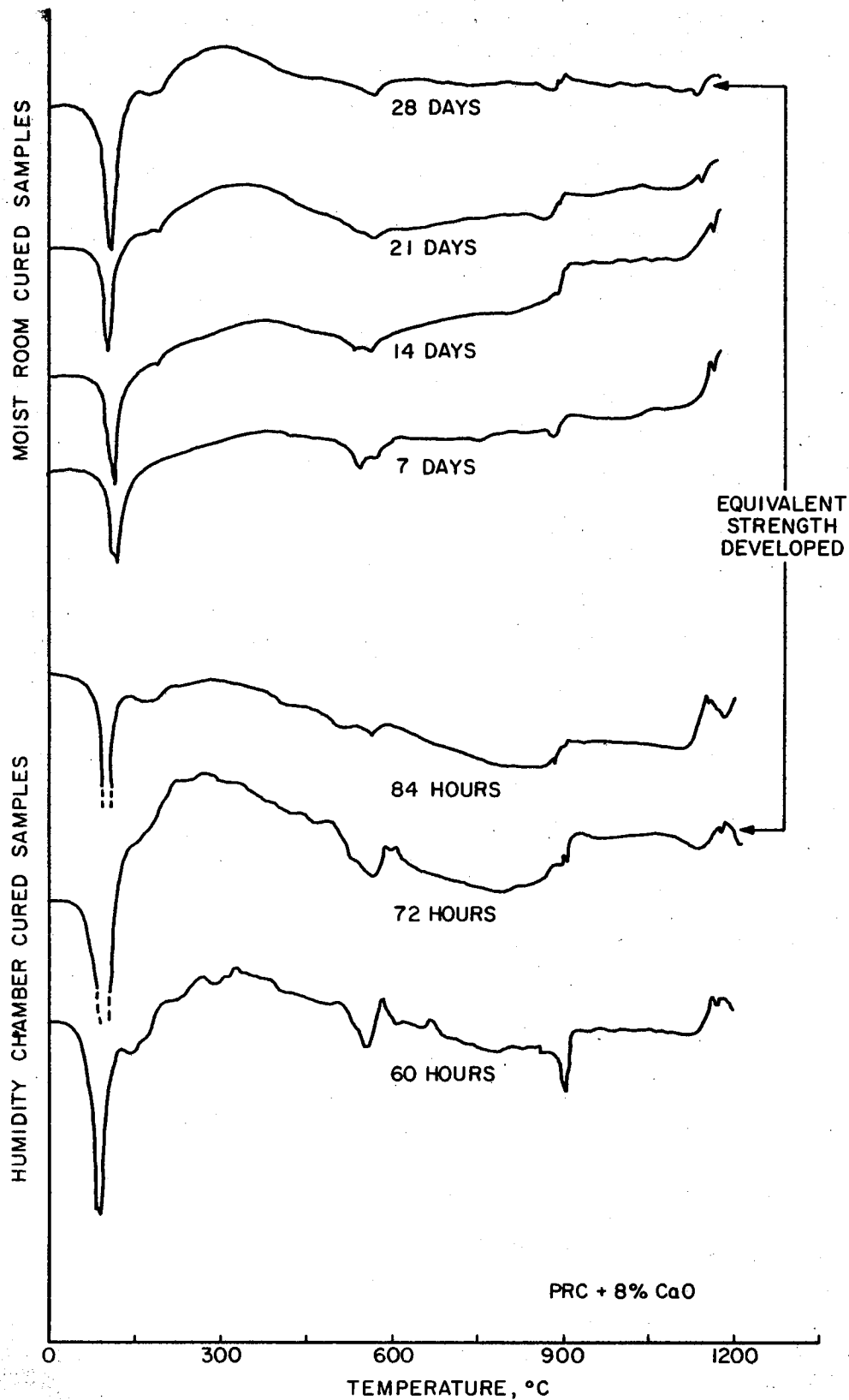
Figure 3.15. Differential Thermograms of Lime Stabilized PRC.
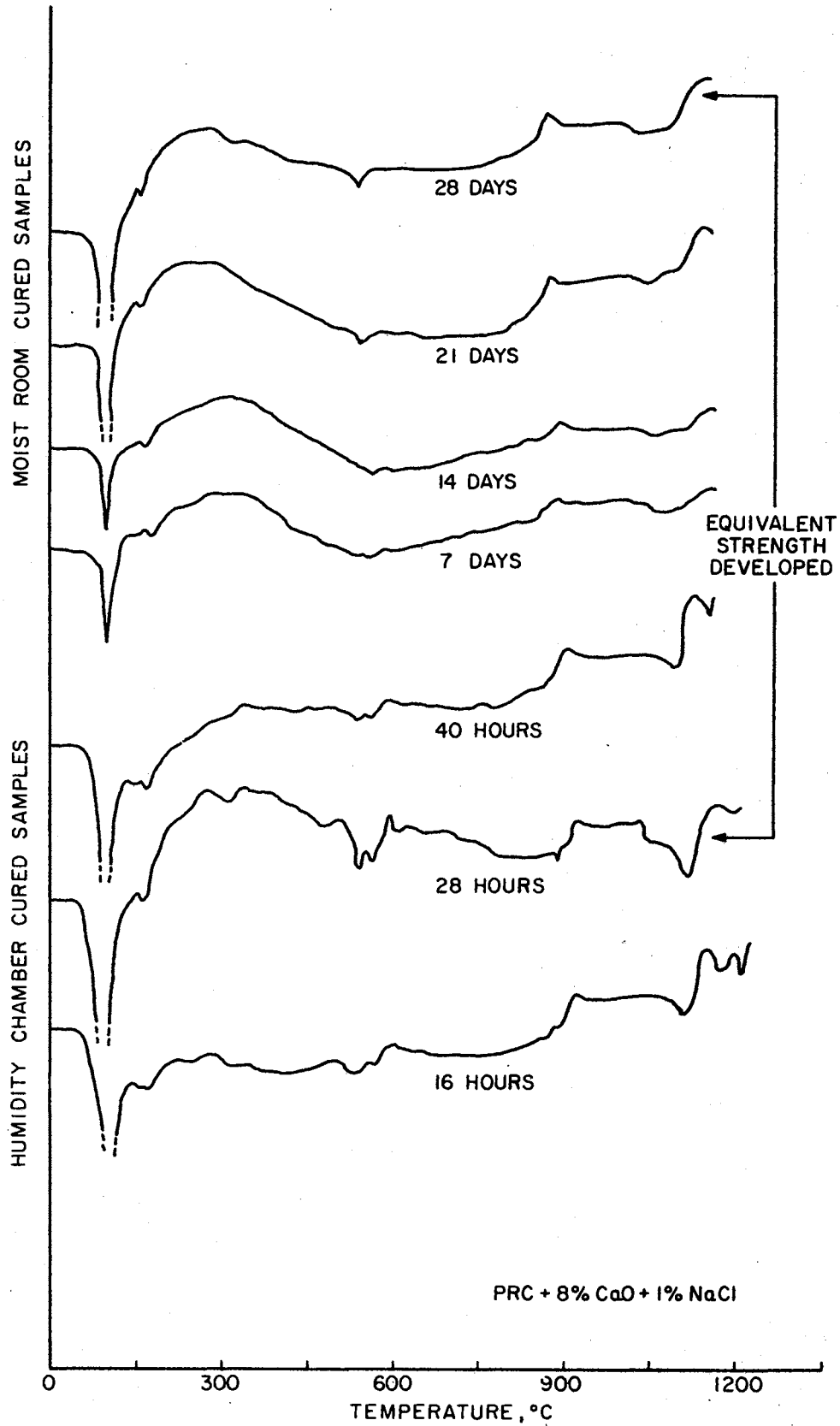
Figure 3.16. Differential Thermograms of Salt-Lime Stabilized PRC.

Axis labels and content within figure:

MOIST ROOM CURED SAMPLES

HUMIDITY CHAMBER CURED SAMPLES

28 DAYS

21 DAYS

14 DAYS

7 DAYS

EQUIVALENT STRENGTH DEVELOPED

40 HOURS

28 HOURS

16 HOURS

PRC + 8% CaO + 1% NaCl

TEMPERATURE, °C

0   300   600   900   1200
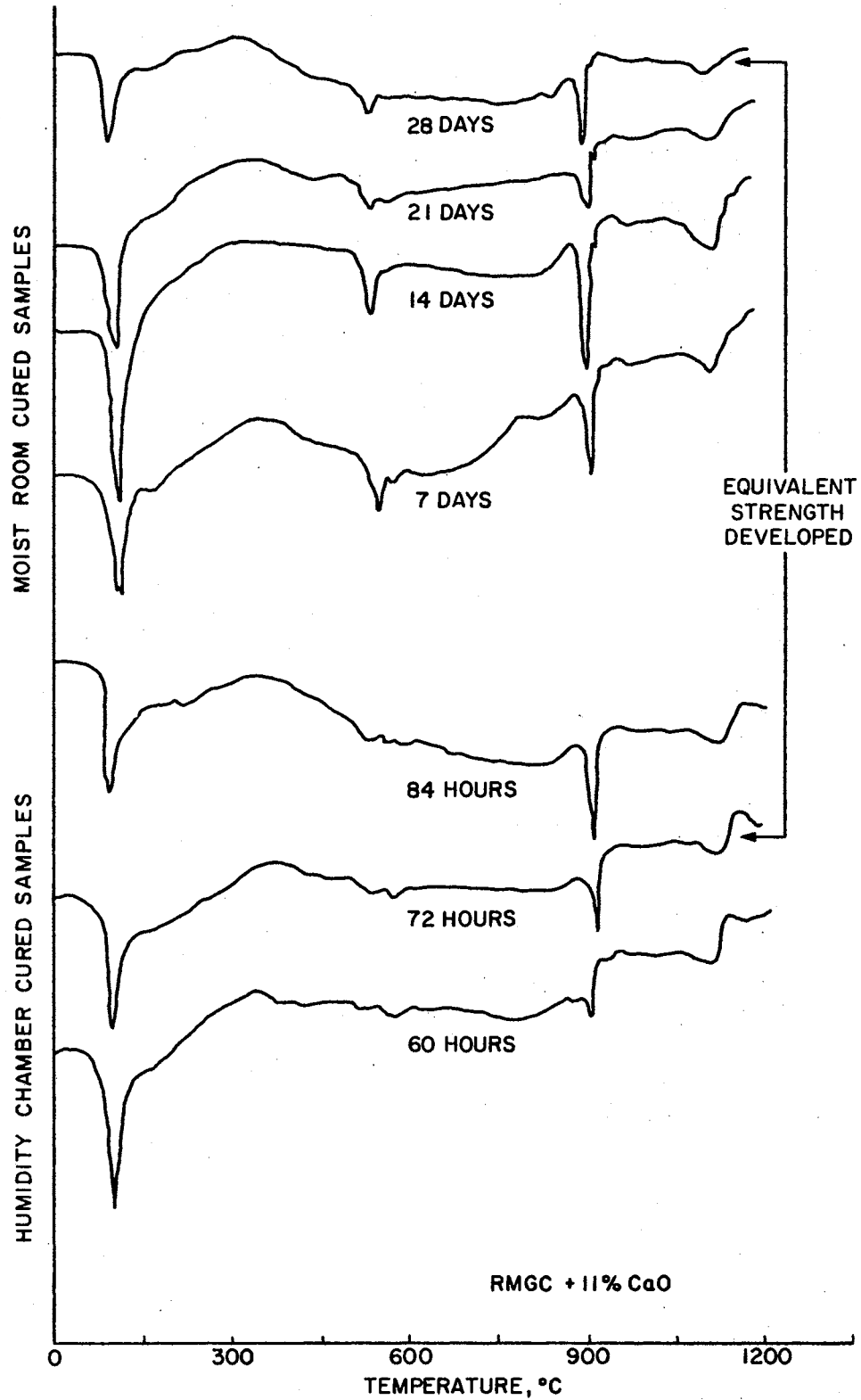
Figure 3.17. Differential Thermograms of Lime Stabilized RMGC.
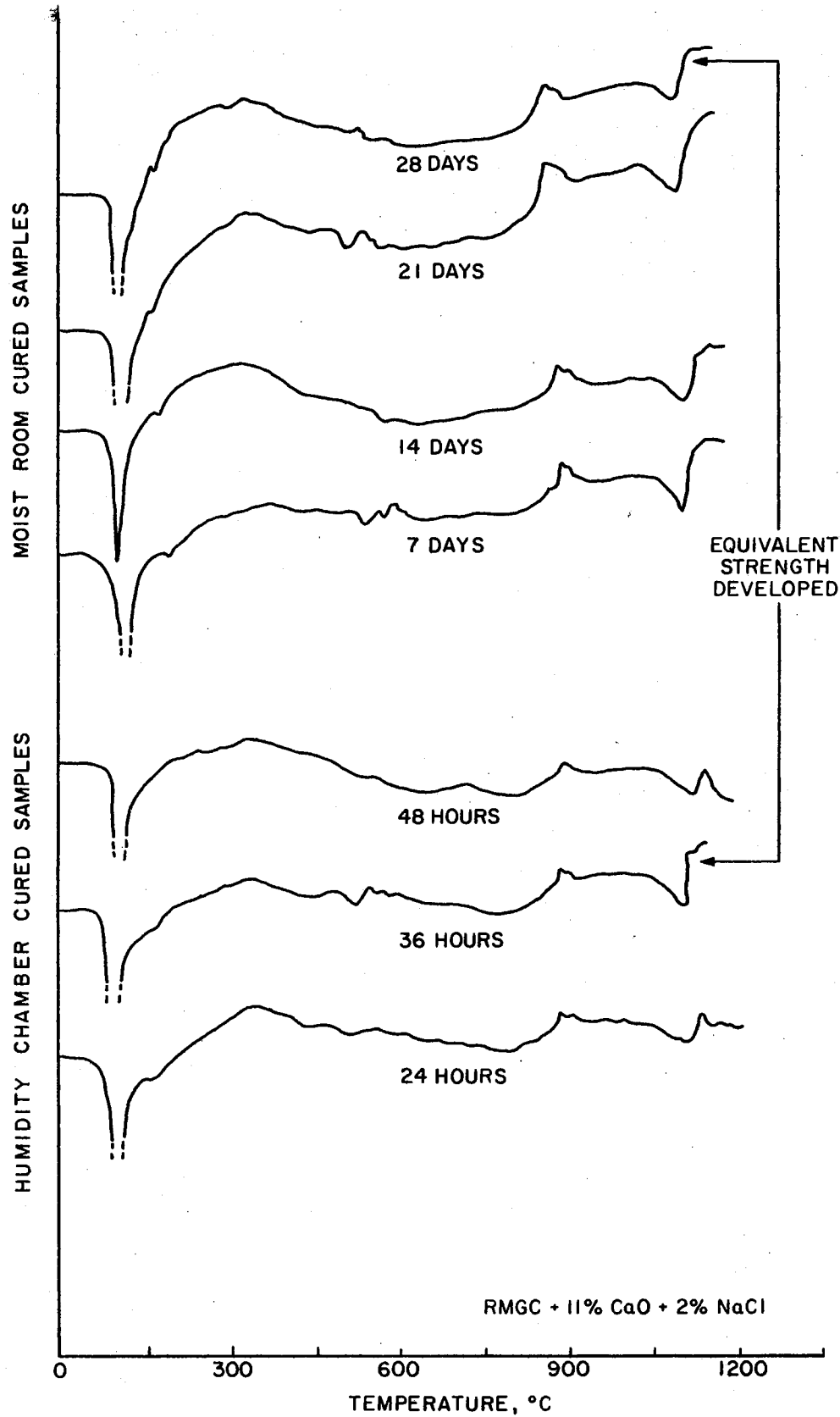
Figure 3.18.   Differential Thermograms of Salt-Lime
Stabilized RMGC.

Figures 3.19 and 3.20 summarize comparative thermograms of 28-day strength moist room cured samples and those at the equivalent accelerated curing time. As may be seen in both Figures, the mineralogical finger-prints of moist room and humidity chamber samples are very similar in nature. With this agreement of DTA thermograms for the two types of curing to reinforce the previous strength correlation, it is believed the two curing procedures are, for all practical purposes, equivalent.

The accelerated curing correlation obtained in this study is valid for samples cured in the OSU Soil Mechanics Laboratory moist room. It may be extended to other curing conditions by following the procedure used to determine the initial strength correlation and then checking obtained mineralogy by DTA. While the basic intent of this study was to study the feasibility of an accelerated curing porcess for use at Oklahoma State University, nevertheless the procedures employed may be used by other agencies to establish valid accelerated curing procedures which simulate their particular conventional curing conditions. The study has also enabled the author to propose a mix design procedure to obtain equivalent 28-day strength properties of lime and salt-lime treated soils, for use as base and subbase materials. With proper equipment and adequately trained personnel, the following design proce-dure should take from 5-7 working days after the raw soil samples are received:

1. Using the sample preparation techniques described in Chapter II, run miniature Standard Proctor compaction test with 0, 0.5, 1.0, 1.5, and 2.0% NaCl content to determine the optimum salt content (usually between 1-2%).

2. Run pH test for lime modification optimum, as described by Eades
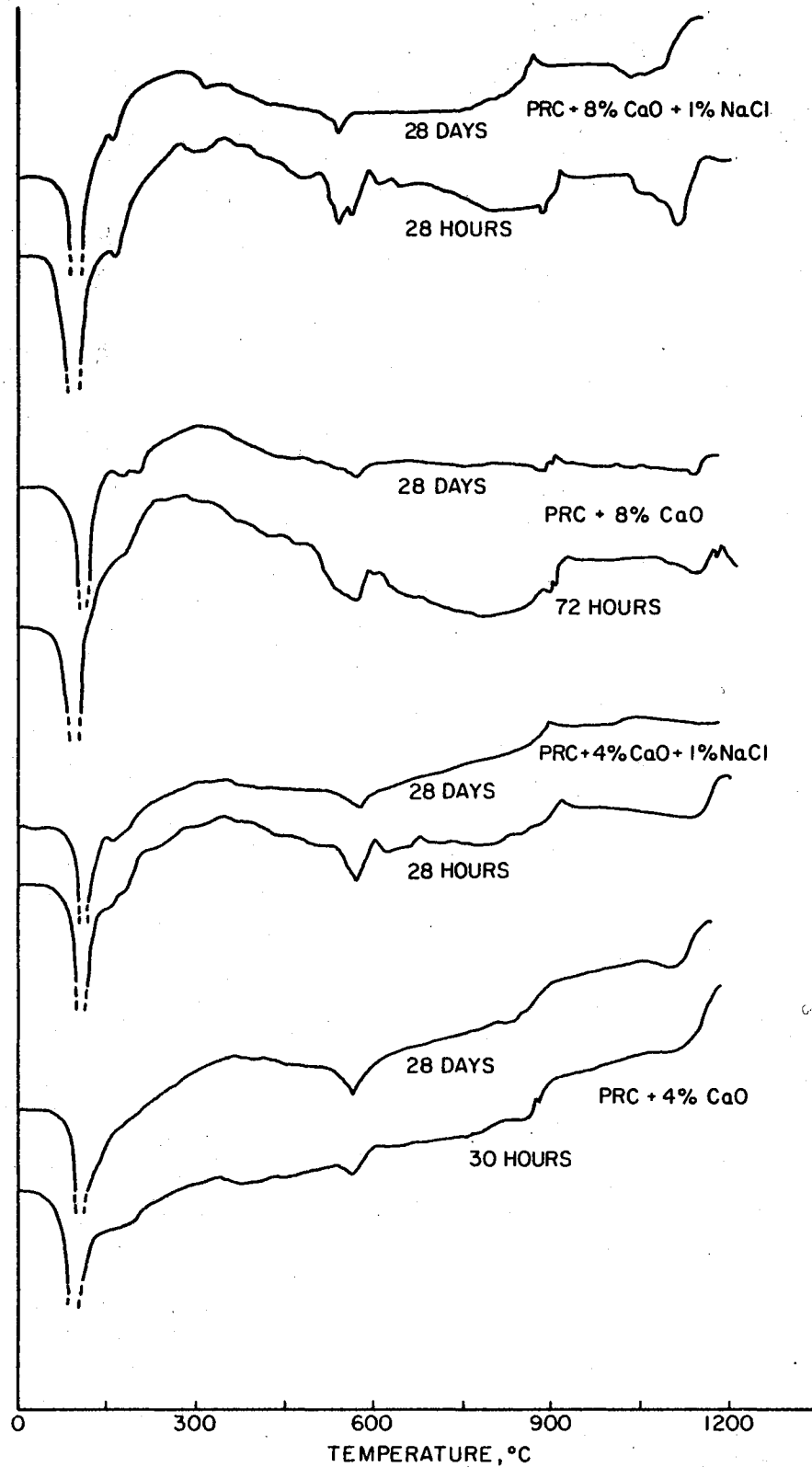
Figure 3.19. Summary of Differential Thermograms of 28-
Day Moist Room and 28-Day Equivalent
Humidity Chamber Strengths for Lime and
Salt-Lime Treated PRC.
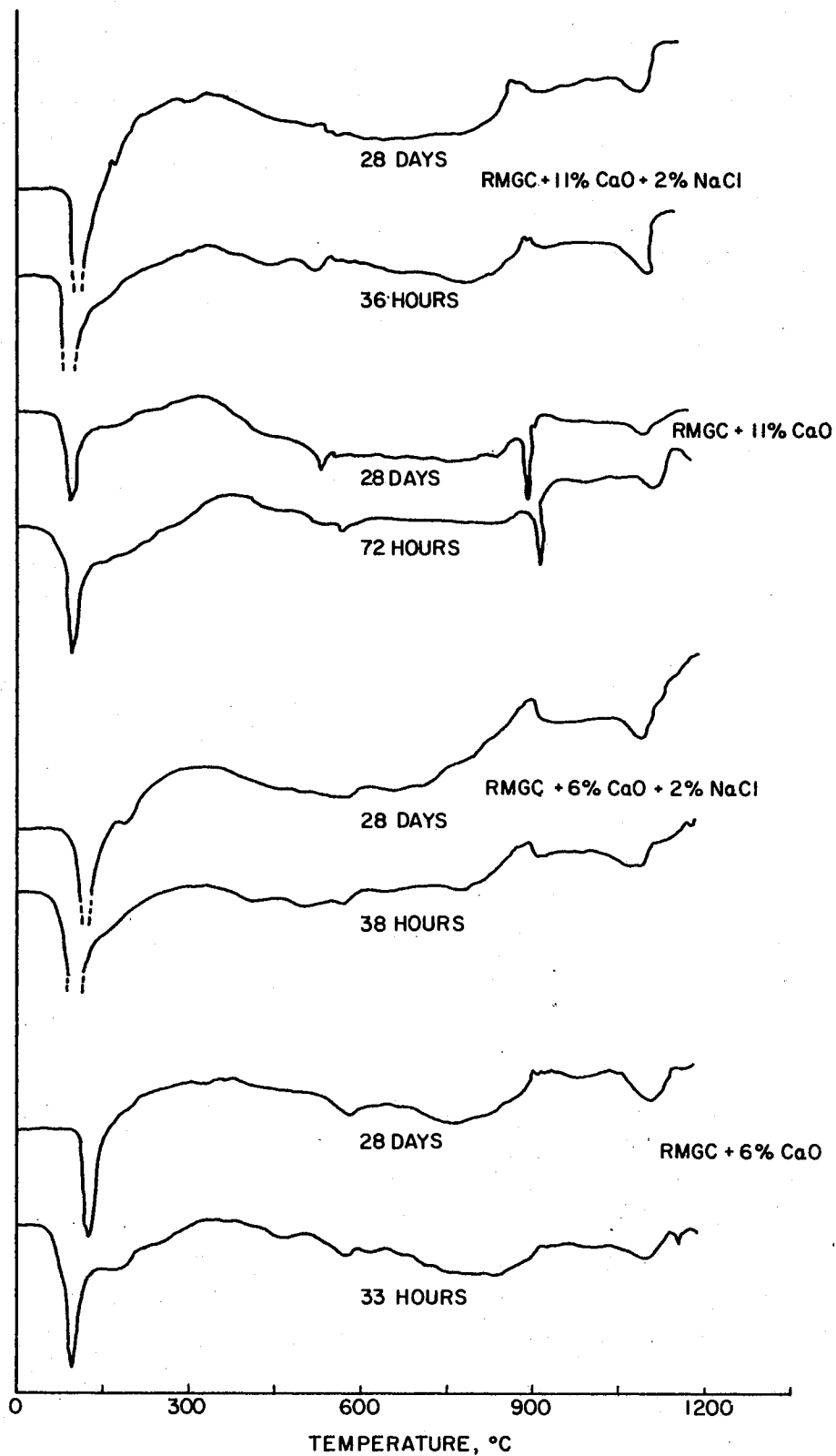
Figure 3.20. Summary of Differential Thermograms of 28-Day Moist Room and 28-Day Equivalent Humidity Chamber Strengths of Lime and Salt-Lime Treated RMGC.

and Grim (Ref 9), using increments of 1% CaO or $Ca(OH)_2$ until pH

peaks.

3. Using the sample preparation techniques described in Chapter II,

   run miniature Standard Proctor compaction at optimum NaCl content

   and lime contents from modification optimum to twice modification

   optimum, generally considered as upper bound for stabilization

   optimum, in 1% lime content increments. Compact three samples at

   each lime percentage to Standard Proctor compaction maximum density

   at optimum moisture.

4. For lime treatment alone, omit the steps pertaining to salt treat-

   ment. However, salt-lime treatment is preferred to lime treatment

   alone for various reasons (Ref 1).

5. Cure lime and/or salt-lime samples by rapid curing procedure at

   $105°$ F and 95% relative humidity to equivalent 28-day strength

   using times of

   a. Lime modification   30 hours

   b. Lime stabilization   72 hours

   c. Salt-lime modification   30 hours

   d. Salt-lime stabilization   30 hours

   To determine equivalent 28-day strengths for lime treated samples

   at lime percentages above modification optimum, assume twice modi-

   fication optimum as the stabilization optimum and equally divide

   the number of whole percentages of lime between the 42 hours

   difference in rapid curing time. For example,

   PRC + 4% CaO = Modification optimum = 30 hours rapid curing

   PRC + 5% CaO = 40.5 hours rapid curing

   PRC + 6% CaO = 51.0 hours rapid curing

PRC + 7% CaO = 61.5 hours rapid curing

PRC + 8% CaO = Stabilization optimum = 72 hours rapid curing

6. Run unconfined compression test on rapid cured samples, using procedure described in Chapter III.

   a. For subbase use the minimum lime content that will produce q_u = 50 psi. This material should be tentatively considered equivalent to typical "select" material subbase (Ref 11).

   b. For base material use the minimum lime content that will produce q_u = 100 psi. This material should be tentatively considered equivalent to the "equivalent base" used in the Oklahoma Subgrade Index (OSI) design procedure (Ref 11, 12).

7. Add 1% CaO or $Ca(OH)_2$ and 0.5% NaCl to design values to compensate for field procedures.

8. Place additives in field wet or dry, in any order, mix together and compact at optimum moisture to at least 95% Standard Proctor compaction maximum density for original design values. If reasonable inspection of field mixing procedure and mixing moisture content is done, only field tests for compacted density will be needed. Failure to obtain required density after reasonable rolling time will be indicative (usually) of insufficient mixing, as field compacted density values cannot usually be obtained without proper mixing of the NaCl.

It should be possible to use cohesive materials for all portions of the highway structure beneath the wearing surface, often reducing construction cost and allowing better job-site control of material properties than for "transported" materials. It is suggested that this

procedure be evaluated for routine use in design of low-traffic highways and as a design option in high-traffic highways.

CHAPTER IV

CONCLUSION

Summary and Conclusions

The temperature and time required for accelerated curing of two
cohesive Oklahoma soils, modified and stabilized with lime and salt-
lime additives, which produced a strength equivalent to that obtained by
curing in a moist room at 80° F and 100% humidity, was determined. The
following conclusions are indicated or inferred from analysis of data
collected throughout the study:

1. An accelerated curing process can be used to achieve 28-day uncon-
   fined compressive strengths of moist room cured samples.

2. A humidity chamber curing temperature of 105° F was found to pro-
   duce the closest approximation of unconfined compressive strength
   curing time behavior for moist room cured samples of PRC and RMGC.

3. Comparison of DTA thermograms for the accelerated and moist room
   cure samples indicated that both types of curing produced similar
   mineralogical conditions.

4. The humidity chamber accelerated curing times required to simulate
   28-day unconfined compressive strength of moist room samples of
   PRC and RMGC are:

   a. Lime modification   30 hours

   b. Lime stabilization   72 hours

   c. Salt-lime modification   30 hours

    d. Salt-lime stabilization   30 hours

5. A design procedure for lime and salt-lime stabilization of cohesive soil has been proposed, which reduces the time required to obtain design values from about one month to between five and seven working days after raw soil samples have been received.

Recommendations for Further Study

The following recommendations should be considered in further testing involving the accelerated curing of lime and salt-lime treated soils.

1. Further evaluation of the accelerated curing process should be undertaken, using additional soils at their lime and salt-lime modification and stabilization optima.

2. Strengths obtained through actual field curing should be correlated with humidity chamber accelerated curing for PRC, RMGC, and other treated cohesive soils.

3. The mix design procedure for lime and salt-lime stabilization of cohesive soils should be preformance-evaluated by its use in the design, construction, and evaluation of highway test sections.

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APPENDIX

LISTING OF COMPUTER PROGRAM USED IN

DATA REDUCTION AND SAMPLE OF COMPUTER OUTPUT

```
        $JOR *****,***-**-****, J. A. DRAKE
        C******* THIS COMPUTER PROGRAM REDUCES UNCONFINED COMPRESSION TEST DATA
   1              DIMENSION    AN1(80),   AN2(35),   CAREA(20),   XLOAD(20),        BDM19J69
              1                RDL(20),   TS(20),   STRN(20),   PSTRN(20),          BDM19J69
              2                S1(20),   S2(20),   TERM(20),                        BDM20J69
              3            PMO(20),NSO(20),DDE(20),CTI(20),S3(20)                   RLC15A70
   2          1   FORMAT    (I2,39A2)
   3          2   FORMAT    ( F5.1, F5.1, 35A2 )
   4          3   FORMAT    (  I5,   5X,  F7.4,   3X,  F7.4,   3X,  F7.4,   3X, F7.4)BDMS1569
   5          4   FORMAT    (  3X,   F7.4,   3X,  F7.4  )                           BDM19J69
   6          5   FORMAT    (  2X,   40A2  )                                        BDM19J69
   7          6   FORMAT    (  //, 10X, 9HSHEET NO., I5, //, 15X,   35A2  )         BDM19J69
   8          7   FORMAT    (  //, 12X, 10HNO. POINTS, 3X,   8HDIAMETER,  3X,       BDM19J69
              1               6HHEIGHT, 13X,  18HPROVING RING CONST  )             BDM19J69
   9          8   FORMAT    (  /, 13X,  I5,  6X,  F7.4,  4X,  F7.4,  10X,  F7.4  ,BDM15S69
              1               5X,  F7.4  )                                         RLC15A7C
  10          9   FORMAT    (//,10X,15HSTRAIN, PERCENT,  5X,  11HSTRESS, PSI,       BDM19J69
              1               5X,  11HSTRESS, TSF  )                               BDM19J69
  11         10   FORMAT    (  /, 15X,  F6.2,  10X,  F6.2,  11X,  F6.2  )           BDM19J69
  12         11   FORMAT    (  1H1,  2H-I,  82X, 10HI-----TRIM  )                   RLC15A70
  13         12   FORMAT    (1H1)
  14         13   FORMAT    (I5,F5.1,F5.1,10A1)                                     RLC15A70
  15         14   FORMAT    (     //////,19X,42HLIME-SOIL STABILIZATION WORK/SUMMARRLC15A70
            1Y SHEET)                                                              RLC15A70
  16         15   FORMAT    (/////,10X,35A2,/////)
  17         16   FORMAT    (/,7X,I5,10X,F5.1,10X,F5.1,8X,10A1,7X,F6.2)             RLC15A70
  18         17   FORMAT    (22X,5H-----,10X,5H-----,26X,5H-----)                   RLC15A70
  19         18   FORMAT    (18X,4HAVG ,F5.1,6X,4HAVG ,F5.1,21X,4HAVG ,F6.2,////)   RLC15A70
  20         19   FORMAT    (7X,24HVALUES FROM SHEET NUMBER,I5,42H ARE BEING DELERLC15A70
            1TED BECAUSE THE MAX UCC FOR,/,7X,43HTHAT SAMPLE IS + OR - 10.0 PSIRLC15A70
            2 FROM THE AVG,/)
  21        101   FORMAT    (7X,5HSHEET,10X,6HACTUAL,8X,7HAPPROX.,9X,6HCURING,   RLC15A70
            18X,7HMAXIMUM,/,8X,3HNO.,13X,2HWT,8X,11HDRY DENSITY,8X,4HTIME,10X,  RLC15A70
            26HSTRESS,/,37X,5H(PCF),25X,5H(PSI))                                 RLC15A70
  22        102   FORMAT    (8X,11HDESIGN WT =,F5.1,10X,16HDESIGN DENSITY =,     RLC15A70
            1F5.1,////)
  23         20   READ 1,   NSA, (AN1(N),  N = 1, 78)                              RLC15A70
  24         21   READ 2,   DMO, DDD, (AN2(N),  N = 1,  35  )                      RLC15A70
  25              STR = 0.                                                         RLC15A70
  26              TDD =0.                                                          RLC15A70
  27              TMO =0.                                                          RLC15A70
  28         52 DO  53  J = 1,  NSA                                                RLC15A70
  29              READ 13, NSO(J),PMO(J),DDE(J),(CTI(N),N=1,10)                    RLC15A70
  30              IF (NSO(J) .EQ. 0 ) GO TO 100                                    RLC15A70
  31         22   READ 3,  NPTS,  DIAM,  HT,  CONST1,  CONST2                      BDM19J69
  32         36   PRINT 11                                                         BDM20J69
  33         30   PRINT 5, ( AN1(N),  N = 1, 80 )                                  BDM19J69
  34         31   PRINT 6,  NSO(J),  (AN2(N),  N = 1,  35  )                       RLC15A70
  35         32   PRINT 7                                                          BDM19J69
  36         33   PRINT 8,  NPTS,  DIAM,  HT,  CONST1,  CONST2                     BDM15S69
  37              DO 24  I = 1,  NPTS
  38         23   READ 4,  RDL(I),  TS(I)                                          BDM19J69
  39         24 CONTINUE
  40         34   PRINT 9                                                          BDM19J69
  41         40         AREA  = ( 3.1416  *  DIAM  *  *  2 )  /  4.0               BDM19J69
  42              S3(J) =0.00
  43         41      DO  50  I = 1,  NPTS                                          BDM19J69
  44         42          STRN(I)  =  TS(I)  /  HT                                  BDM19J69
  45         43          TERM(I)  =  1.0  -  STRN(I)                               BDM19J69
  46         44          CAREA(I)  =  AREA  /  TERM(I)                             BDM19J69
```

```
 47                             IF  ( RDL(I) .GT. 0.0420 )  GO  TO  49      BDM15S69
 48                             GO  TO  45                                  BDM15S69
 49      49              XLOAD(I)  =  CONST2  * (RDL(I)-0.0420) * 10000.0 +  BDM15S69
         1CONST1 * 0.0420 * 10000.0                                          BDM15S69
 50                             GO  TO  46                                  BDM15S69
 51      45              XLOAD(I)  =  CONST1 *  RDL(I)  *  10000.0           BDM19J69
 52      46              PSTRN(I)  =  STRN(I)  *  100.0                      BDM19J69
 53      47              S1(I)  =  XLOAD(I)  /  CAREA(I)                     BDM20J69
 54      48              S2(I)  =  ( S1(I)  *  144.0  )  /  2000.0           BDM20J69
 55      35      PRINT 10,  PSTRN(I),  S1(I),  S2(I)                         BDM19J69
 56              IF  ( I .EQ. 1 )  GO TO 50
 57              M = I - 1
 58              IF ( S1(I) .LT. S1(M))  GO TO 51                            RLC15A70
 59              GO TO 61
 60      51      IF ( S3(J) .GT. 0 )  GO TO 50
 61              S3(J) = S1(M)                                              RLC15A70
 62              STR = S1(M) + STR                                          RLC15A70
 63              TMO = PMO(J) + TMO                                         RLC15A70
 64              TDD = DDE(J) + TDD                                         RLC15A70
 65              GO TO 50                                                   RLC15A70
 66      61      IF ( S3(J) .GT. 0 )  GO TO 50                              RLC15A70
 67              IF ( I .EQ. NPTS )  GO TO 59                               RLC15A70
 68              GO TO 50
 69      59      S3(J) = S1(I)                                              RLC15A70
 70              STR = S1(I) + STR                                          RLC15A70
 71              TMO = PMO(J) + TMO                                         RLC15A70
 72              TDD = DDE(J) + TDD                                         RLC15A70
 73      50              CONTINUE                                          BDM19J69
 74      53 CONTINUE                                                        RLC15A70
 75              PRINT 11                                                   RLC15A70
 76              PRINT 14                                                   RLC15A70
 77              PRINT 15,       (AN2(N), N = 1,  35)                       RLC15A70
 78              PRINT 101                                                  RLC15A70
 79          DO 54 J = 1,  NSA                                              RLC15A70
 80              PRINT 16,   NSO(J),PMO(J), DDE(J),(CTI(N),N=1,10),S3(J)    RLC15A70
 81      54 CONTINUE                                                        RLC15A70
 82              PRINT 17                                                   RLC15A70
 83              AMO = TMO/NSA                                              RLC15A70
 84              AST = STR/NSA                                              RLC15A70
 85              ADD = TDD/NSA                                              RLC15A70
 86              PRINT 18,       AMO,ADD,AST                                RLC15A70
 87              PRINT 102, DMO, DDD
 88              QRT = 0                                                    RLC15A70
 89          DO 56 J = 1,  NSA
 90              IF (AST - S3(J) .GT. 10.00 )  GO TO 55                     RLC15A70
 91              IF (AST - S3(J) .LT. -10.00 )  GO TO 55                    RLC15A70
 92              QRT = QRT + 1                                             RLC15A70
 93              GO TO 56                                                   RLC15A70
 94      55      STR = STR - S3(J)                                         RLC15A70
 95              TMO = TMO - PMO(J)                                        RLC15A70
 96              TDD = TDD - DDE(J)                                        RLC15A70
 97              PRINT 19,       NSO(J)
 98      56 CONTINUE                                                        RLC15A70
 99              IF ( QRT .EQ. 0 )   QRT = 1                               RLC15A70
100              ASP = STR/QRT                                             RLC15A70
101              IF (ASP-AST)  57,58,57                                    RLC15A70
102      57      ADP = TDD/QRT                                             RLC15A70
103              AMP = TMO/QRT                                             RLC15A70
104              PRINT 18,    AMP,ADP,ASP                                  RLC15A70
105      58      GO TO 21                                                  RLC15A70
106     100      PRINT 12
107              CALL EXIT                                                 RLC15A70
108              END                                                       RLC15A70

        $ENTRY
```

THIS COMPUTER PROGRAM REDUCES DATA OBTAINED FROM UNCONFINED COMP. TEST
DATA PUNCHED AND RUN BY JOHN A. DRAKE

SHEET NO.   4

RMGC + 6% CAO + 2% NACL   HUM. CHM.   @ 105 F

NO. POINTS	DIAMETER	HEIGHT	PROVING RING CONST	
6	1.3125	2.8125	0.3180	0.7550

STRAIN, PERCENT	STRESS, PSI	STRESS, TSF
0.36	5.62	0.40
0.71	12.84	C.92
1.07	20.70	1.49
1.42	25.72	1.85
1.78	27.24	1.96
2.13	25.76	1.85

THIS COMPUTER PROGRAM REDUCES DATA OBTAINED FROM UNCONFINED COMP. TEST
  DATA PUNCHED AND RUN BY JOHN A. DRAKE

        SHEET NO.   5

            RMGC +   6% CAO + 2% NACL   HUM. CHM. @ 105 F

        NO. POINTS   DIAMETER   HEIGHT   PROVING RING CONST

            8   1.3125   2.8125   0.3180   0.7550

STRAIN, PERCENT   STRESS, PSI   STRESS, TSF

        0.36   5.39   0.39

        0.71   12.60   0.91

        1.07   21.39   1.54

        1.42   29.89   2.15

        1.78   36.94   2.66

        2.13   41.63   3.00

        2.49   42.86   3.09

        2.84   40.88   2.94

THIS COMPUTER PROGRAM REDUCES DATA OBTAINED FROM UNCONFINED COMP. TEST
DATA PUNCHED AND RUN BY JOHN A. DRAKE

SHEET NO.   6

RMGC +   6% CAO + 2% NACL   HUM. CHM.   @ 105 F

NO. POINTS	DIAMETER	HEIGHT	PROVING RING CONST	
7	1.3125	2.8125	0.3180	0.7550

STRAIN, PERCENT	STRESS, PSI	STRESS, TSF
0.36	5.62	0.40
0.71	13.54	0.97
1.07	22.79	1.64
1.42	31.74	2.29
1.78	39.94	2.88
2.13	42.78	3.08
2.49	42.17	3.04

LIME-SOIL STABILIZATION WORK/SUMMARY SHEET

RMGC + 6% CAO + 2% NACL   HUM. CHM. @ 105 F

SHEET NO.	ACTUAL W%	APPROX. DRY DENSITY (PCF)	CURING TIME	MAXIMUM STRESS (PSI)
4	22.3	85.4	12 HRS	27.24
5	24.6	85.6	12 HRS	42.86
6	23.7	86.9	12 HRS	42.78
AVG	23.5	AVG 86.0		AVG 37.63

DESIGN W% = 24.5   DESIGN DENSITY = 93.0

VALUES FROM SHEET NUMBER   4 ARE BEING DELETED BECAUSE THE MAX UCC FOR
THAT SAMPLE IS + OR - 10.0 PSI FROM THE AVG

AVG 24.1   AVG 86.2   AVG 42.82

VITA

John Albert Drake

Candidate for the Degree of

Master of Science

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