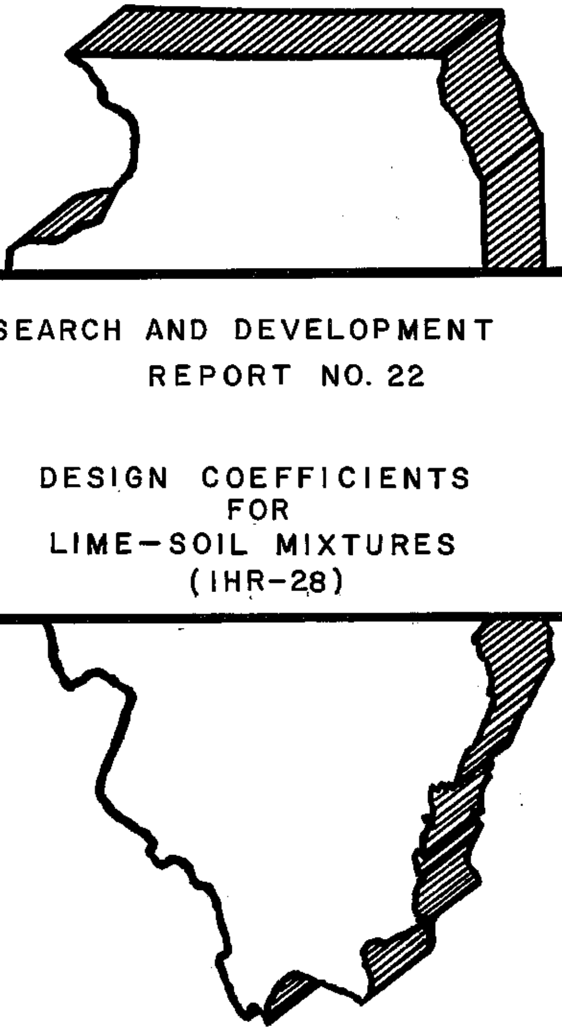
STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
DIVISION OF HIGHWAYS



RESEARCH AND DEVELOPMENT
REPORT NO. 22

DESIGN COEFFICIENTS FOR LIME-SOIL MIXTURES
(IHR-28)

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RESEARCH AND DEVELOPMENT
ADMINISTRATIVE REPORT

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways

DESIGN COEFFICIENTS FOR LIME-SOIL MIXTURES

A Phase of
Research Project IHR-28
AASHO Road Test

A Research Study by
Illinois Division of Highways
Bureau of Research and Development
In Cooperation With
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

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

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DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
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INTRODUCTION

The findings of the research project IHR-76, "Lime Stabilization of Soils for Highway Purposes," conducted by the Department of Civil Engineering, University of Illinois, in cooperation with the Illinois Division of Highways and the Bureau of Public Roads, have indicated that lime-soil mixtures can be used effectively and economically as quality highway construction materials. The work described in this report was undertaken to permit application of the findings of IHR-76 in pavement design by developing tentative strength coefficients and material requirements and limitations for inclusion of the use of lime-stabilized-soil mixtures as base and subbase in the Illinois Flexible Pavement Structural Design Procedure. As more experience is gained in this field, certain revisions should be expected. However, the information included in this report is expected to produce satisfactory results.

Improvements in plasticity, workability, and swell and shrinkage properties are obtained when any fine-grained soil is treated with lime. These improvements occur immediately when the lime is mixed with the soil. However, large strength increases are achieved only if soils display good pozzolanic reactivity. These latter soils are classed as reactive soils and are the only ones that should be considered for use in lime-stabilized-soil subbase and base course construction. The remainder of this report is concerned only with reactive soils.

Information from the IHR-76 study, developed primarily from the results of laboratory tests, and information from published reports based on data obtained from actual roadways constructed with lime-stabilized-soil mixtures have been used in this work.

IHR-76 STUDY

Most of the information developed by the IHR-76 study is the result of analyses of laboratory testing of various lime-stabilized soils which were selected to provide a broad representation of the fine-grained soils commonly encountered during road construction throughout Illinois. Freeze-thaw, fatigue, shrink-swell, mix design, and several other facets of lime-soil stabilization have been investigated.

The findings of the IHR-76 study have indicated that the critical time for a lime-stabilized-soil mixture which has significant strength gain, occurs at the end of the first winter. During cold weather, the pozzolanic reaction is slowed tremendously and ceases completely at temperatures below 40° F. (See Figure 1). However, when the temperature rises, the pozzolanic reaction again continues, resulting in continuing increases in strength for several years. This phenomenon has been observed to occur on various in-service roads constructed of lime-stabilized soils. Tests conducted on lime-flyash mixtures, which rely on the same pozzolanic reaction, also substantiate the finding (See Figure 2).

Another factor which makes the end of the first winter a critical time for lime-stabilized soils are their relatively low resistance to the destructive action of freeze-thaw. Accelerated laboratory freeze-thaw tests on these materials have indicated that strengths are reduced as the number of freeze-thaw cycles is increased (See Figures 3-7). However, if the design allows for this reduction in strength so that the materials do not become overstressed during the critical period, no problems should result.

Fatigue is another durability property which must be considered. Laboratory fatigue tests have indicated that the fatigue behavior of lime-soil mixtures is similar to that of portland cement concrete (See Figure 8). As a result of these test, Swanson and Thompson[1/] suggest that fatigue should not be an important property when considering lime-soil stabilization. Since fatigue is a long-term phenomenon, and since lime-stabilized soils gain strength for an extended period of time, the strength gains should offset the damaging effects of fatigue.

The results of the IHR-76 study indicate that many lime-stabilized soils develop sufficient strength to be used satisfactorily as road-building materials. However, it is necessary to consider the detrimental effects of freeze-thaw to insure that sufficient residual strength exists during the critical "spring thaw" period. Thompson[2/] has established minimum strength requirements for base and subbase material to allow for freeze-thaw losses.

Thompson and Dempsey[3/] have developed and tested a heat-transfer model utilizing 30 years of weather data from five stations representing climatic conditions from northern to southern Illinois that will estimate the number of freeze-thaw cycles in the pavement structure from climatic conditions of the surrounding environment. The results indicate considerable variation in the number of freeze-thaw cycles from year to year and from north to south. The 30-year average number of freeze-thaw cycles was estimated to be about 11 for northern Illinois and about 2 for southern Illinois. For average freeze-thaw conditions in Illinois, designs capable of withstanding seven freeze-thaw cycles are proposed.

For seven freeze-thaw cycles, Thompson suggests that lime-stabilized soils that develop unconfined compressive strengths of 150 psi to 170 psi prior to the onset of cold weather during the first winter will be suitable for base course construction, and that lime-stabilized soils with compressive strengths of 75 psi to 110 psi prior to the first winter following construction will be suitable for subbase construction when at least eight inches of material overlies the lime-stabilized subbase.

IN-SERVICE ROADS

A literature search revealed only a limited amount of information on pavements actually constructed with a lime-stabilized soil as an integral part of the pavement structure. Most published information deals with laboratory tests and pilot studies. However, there was enough information on in-service roads to develop some opinions on lime-soil stabilization.

Information from sections constructed in Missouri4/ indicates that five inches of lime-stabilized-soil subbase with strengths of 75 psi after seven days curing could be used adequately to replace an equivalent thickness of crushed stone. This same article indicates that a 20 percent reduction in cost would be possible, with no sacrifice in service, in areas where aggregate sources are scarce. Results from another road test in Missouri5/ indicate that six inches of lime-stabilized-soil base covered with 0.5 inches of bituminous seal is performing better than an intervening section constructed with 2.13 inches of gravel topped with 0.95 inches of bituminous seal.

Tests in Nebraska6/ have indicated that lime-treated sections have performed better than an equivalent thickness of granular material. A thickness of seven inches was used for the lime-stabilized-soil subbase, and a thickness of six inches was used for the lime-stabilized-soil base.

The State of Texas has built a number of miles of pavement constructed with lime-stabilized materials. McDowell7/ indicates that satisfactory results have been obtained when a minimum unconfined compressive strength of 50 psi was specified for subbases and 100 psi was specified for bases.

In general, the literature survey indicates that thicknesses of lime-stabilized soils equivalent to those of gravel or crushed-stone materials will provide similar pavement performance. Thicknesses as low as six inches for bases and five inches for subbases have provided satisfactory performance. In areas where the destructive effects of freeze-thaw are not a significant factor, minimum unconfined compressive strengths of 100 psi for bases and 50 psi for subbases have been adequate. Lime-soil stabilization is economical, and substantial savings in costs can be realized where ready sources of aggregate are not available.

STRENGTH COEFFICIENTS FOR LIME-STABILIZED SOILS

Since lime-stabilized soils were not used as base or subbase on the AASHO Road Test Project, no reference point has been established for this material from which coefficient values can be directly correlated with strength characteristics for use in pavement structural design based on Road Test results. The assignment of coefficient values for lime-stabilized soils as base course and subbase for use in the Illinois flexible pavement design manual, therefore, must be made by indirect procedures. Information from the IHR-76 study suggests that unconfined compressive strengths can be used as meaningful measures of strength or stability of lime-stabilized-soil mixtures, and that estimates of coefficient values may be made by relating these compressive strengths to those obtained for cement-aggregate mixtures. The pozzolanic reaction produces a cementing similar to that of cement-treated mixtures, and lime-stabilized and cement-stabilized plastic soils are similar in flexural strength, modulus of elasticity, failure strains, and Poisson's ratio. The major difference is that cement-stabilized soils gain strength rapidly while lime-stabilized soils increase in strength at much slower rates and over longer periods of time.

Coincidental with the establishment of coefficient values for lime-stabilized-soil mixtures is the need to establish minimum strength requirements for the mixtures. As previously discussed, minimum strength requirements were established for lime-stabilized soils as base and as subbase in the IHR-76 study. These requirements were based on compressive strengths of the mixtures at termination of field curing following the onset of cold weather during the first winter following construction. Additional studies of the effect of curing temperatures on strength have shown that the laboratory method of curing samples at 120° F. for 48 hours produces unconfined compressive strengths approximately equivalent to those obtained on samples cured for 30 days at 70° F. This indicates that the 48-hour curing at 120° F. should provide realistic estimates of field strengths at the onset of cold weather during the first winter following construction for lime-stabilized-soil mixtures completed immediately prior to a recommended September 15 cutoff date. Thus, for the purpose of incorporating the permissive use of lime-stabilized soils as base course and as subbase in the Illinois flexible pavement structural design procedure, minimum strength requirements should be based on the results of tests conducted on specimens cured for 48 hours at 120° F.

<u>Base Course Coefficient, a_2</u>: From the information obtained from the IHR-76 study, a minimum unconfined compressive strength of 150 psi for lime-stabilized soil as a base course appears to be realistic. This should provide sufficient residual strength following the first winter to adequately serve as base course on light-traffic roads, for which its use is intended, and many fine-grained plastic soils in Illinois will be suitable for use in this construction.

Figure 9[8/] shows the relationship between a_2 and seven-day compressive strength for cement-treated base course. As previously mentioned, lime-stabilized and cement-stabilized soils are similarly cemented, with the only major difference being that lime-stabilized soils gain in strength at much slower rates and over longer periods of time. Thus, it would appear reasonable to expect that the relationship between a_2 and compressive strength for lime-stabilized soils is similar to that shown in Figure 9, and that the seven-day compressive strength of cement-stabilized soils would compare favorably with the compressive strength of lime-stabilized soils at the onset of cold weather during the first winter following construction (estimated from samples cured for 48 hours at 120° F.). Assuming this, the value of a_2 obtained from Figure 9 for a compressive strength of 150 psi is 0.11.

In a preliminary study of lime-soil base course coefficients, Thompson[9/] developed relationships between a_2 and compressive strength (Figure 10) utilizing layered elastic theory analysis and ultimate strength considerations, and comparing crushed stone base thicknesses with equivalent lime-stabilized soil base thicknesses. This work suggests that values of a_2 for lime-stabilized soil could range from 0.12 to 0.26 for compressive strengths of 100 to 400 psi.

Information obtained from published reports on in-service roads suggests that lime-stabilized soil base courses are equivalent in performance to granular base courses. This suggests coefficient values for lime-stabilized soils ranging from 0.10 (uncrushed gravel) to 0.13 (crushed stone).

A value of $a_2 = 0.11$ is recommended for use in the Illinois flexible pavement design procedure as the design coefficient for lime-stabilized soils as base course. This value was selected with the intention of being somewhat conservative at this time since field data are not now available to validate the selection. It is, however, within the range suggested by the limited information on in-service roads. This value compares with a value of a_2 = 0.15 assigned to soil-cement mixtures designed for a minimum seven day compressive strength of 300 psi.

Subbase Coefficient, a_3: Following the recommendations of the IHR-76 study, a minimum unconfined compressive strength of 100 psi is suggested for lime-stabilized soil when used as the subbase for flexible pavements.

Heretofore, only granular materials have been used as subbase for flexible pavements in Illinois and the CBR value is the only strength measure in the design procedure related to the subbase coefficient a_3. In addition, correlations are not available for direct comparison of performance of cemented materials to granular materials based on their relative strengths as measured by unconfined compression and CBR, respectively, Thus, the comparison must be made by indirect procedure.

Referring to Figure 9, a lime-stabilized soil with a minimum compressive strength of 100 psi when used as base course would be assigned a coefficient value, a_2, of 0.095. From the relationships shown in Illinois flexible pavement design procedure, a granular base course equivalent to the 100 psi lime-stabilized soil (a_2 = 0.095) would have a CBR of 44. This same granular material (CBR = 44) when used as a subbase would be assigned a coefficient a_3 equal to 0.12.

A value of a_3 = 0.12 is recommended for lime-stabilized soil (100 psi minimum compressive strength) when used as subbase. This compares favorably with the range in a_3 of 0.11 to 0.14 for granular subbase materials.

DESIGN LIMITATIONS

The Illinois flexible pavement design procedure contains minimum thickness and material strength requirements for each layer of the pavement structure which have been established in consideration of construction and maintenance problems to avoid the possibility of developing impractical designs. The minimum strength requirements are increased as the structural design requirements increase. It is equally important that such minimum requirements be established for use of lime-stabilized soils as base course and as subbase.

As previously stated, it is recommended that only lime-stabilized-soil mixtures developing at least 150 psi compressive strength when cured at 120° F. for 48 hours be used as base course, and only those developing at least 100 psi be used as subbase. Design coefficients of $a_2 = 0.11$ and $a_3 = 0.12$ have been recommended as base course and subbase, respectively.

The Illinois design manual includes a minimum of eight inches of Aggregate Base Course, Type B, for pavement designs requiring Structural Numbers less than 2.50. The assigned coefficient value, a_2, of this material ranges from 0.10 to 0.13. The suggested value of $a_2 = 0.11$ for lime-stabilized-soil mixtures is within this range; and thus, it is recommended that a minimum of eight inches of lime-stabilized soil be permitted as the base course for pavements requiring Structural Numbers less than 2.50.

The Illinois flexible pavement design manual makes optional the use of a subbase for pavement designs with Structural Numbers less than 5.00. If used, however, it must be at least four inches of pit-run gravel ($a_3 = 0.11$). For pavements requiring Structural Numbers of 5.00 and greater a granular subbase is required, with the minimum being four inches of processed uncrushed gravel ($a_3 = 0.12$).

Since the recommended coefficient value for lime-stabilized soil as subbase is 0.12, it is reasonable that this material be permitted as subbase whenever a flexible pavement is designed with a subbase. The minimum thickness should be increased to six inches. A four-inch thickness is considered impractical from a construction standpoint since lime-soil mixtures are processed in place.

REFERENCES

1/ Swanson and Thompson, "Flexural Fatigue Strength of Lime-Soil Mixtures," Highway Research Record No. 198, 1967.

2/ Thompson, Marshall R., "Mixture Design for Lime-Treated Soils," Civil Engineering Studies, Highway Engineering Series No. 26, 1968.

3/ Thompson and Dempsey, "A Report of the Investigation of Durability Testing of Stabilized Materials," paper offered for presentation at 1970 Annual Meeting of the Highway Research Board.

4/ Thomas, Jones, and Davis, "Lime and Phosphoric Acid Stabilization in Missouri," Highway Research Record No. 92, 1965.

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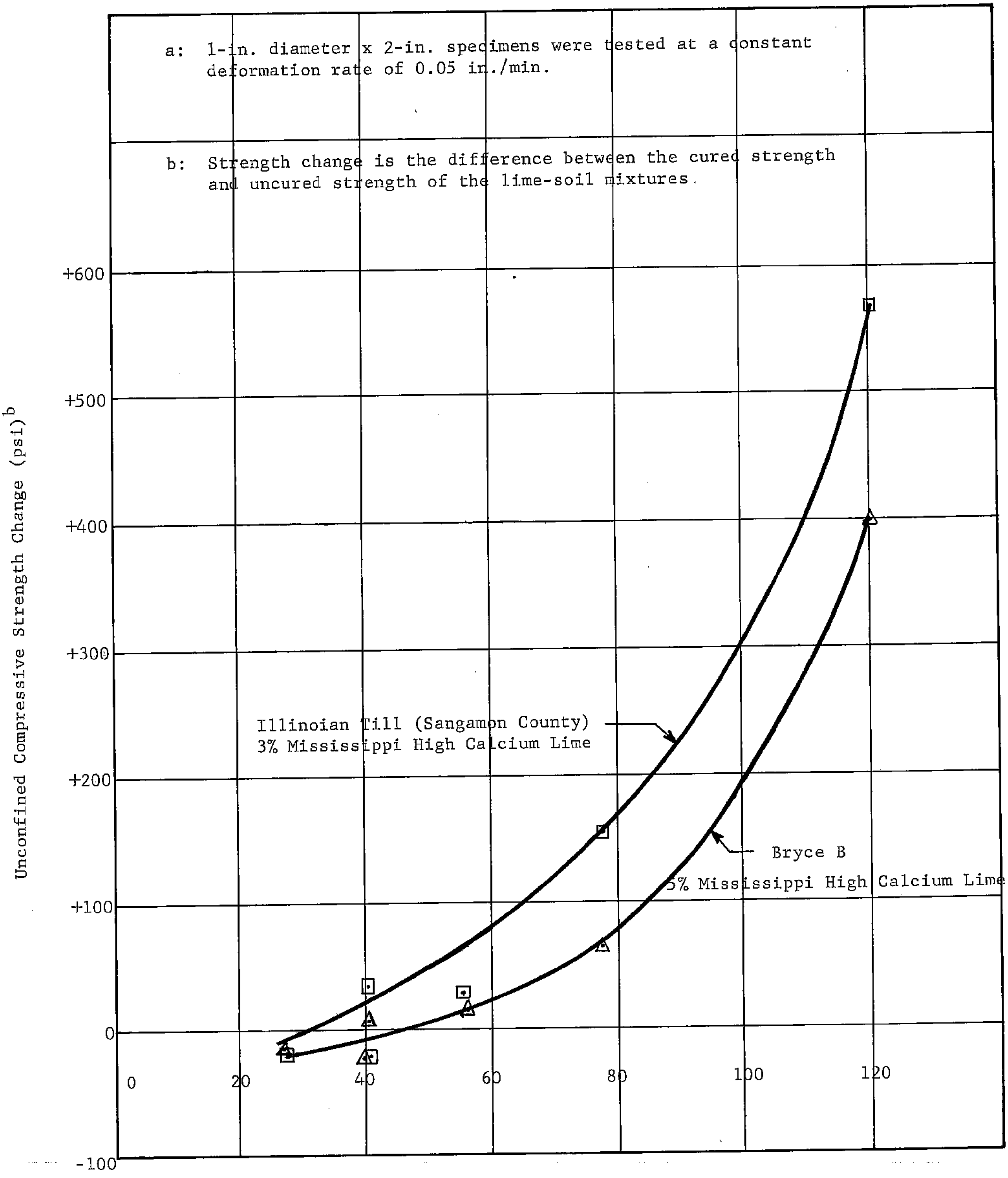
6/ Lund and Ramsey, "Experimental Lime Stabilization in Nebraska," Highway Research Board Bulletin No. 231, 1959.

7/ McDowell, Chester, "Evaluation of Lime-Soil Stabilization Mixtures," Highway Research Record No. 139, 1966.

8/ Chastain, W. E. Sr. and Schwartz, D. R., "AASHO Road Test Equations Applied to the Design of Bituminous Pavements in Illinois," Highway Research Record No. 90, 1965.

9/ Thompson, Marshall R., "A Preliminary Study of Lime-Soil Coefficients," Unpublished Report.



a: 1-in. diameter x 2-in. specimens were tested at a constant deformation rate of 0.05 in./min.

b: Strength change is the difference between the cured strength and uncured strength of the lime-soil mixtures.

Figure 1. Influence of curing temperature on unconfined compressive strength change (28-day curing)^a.

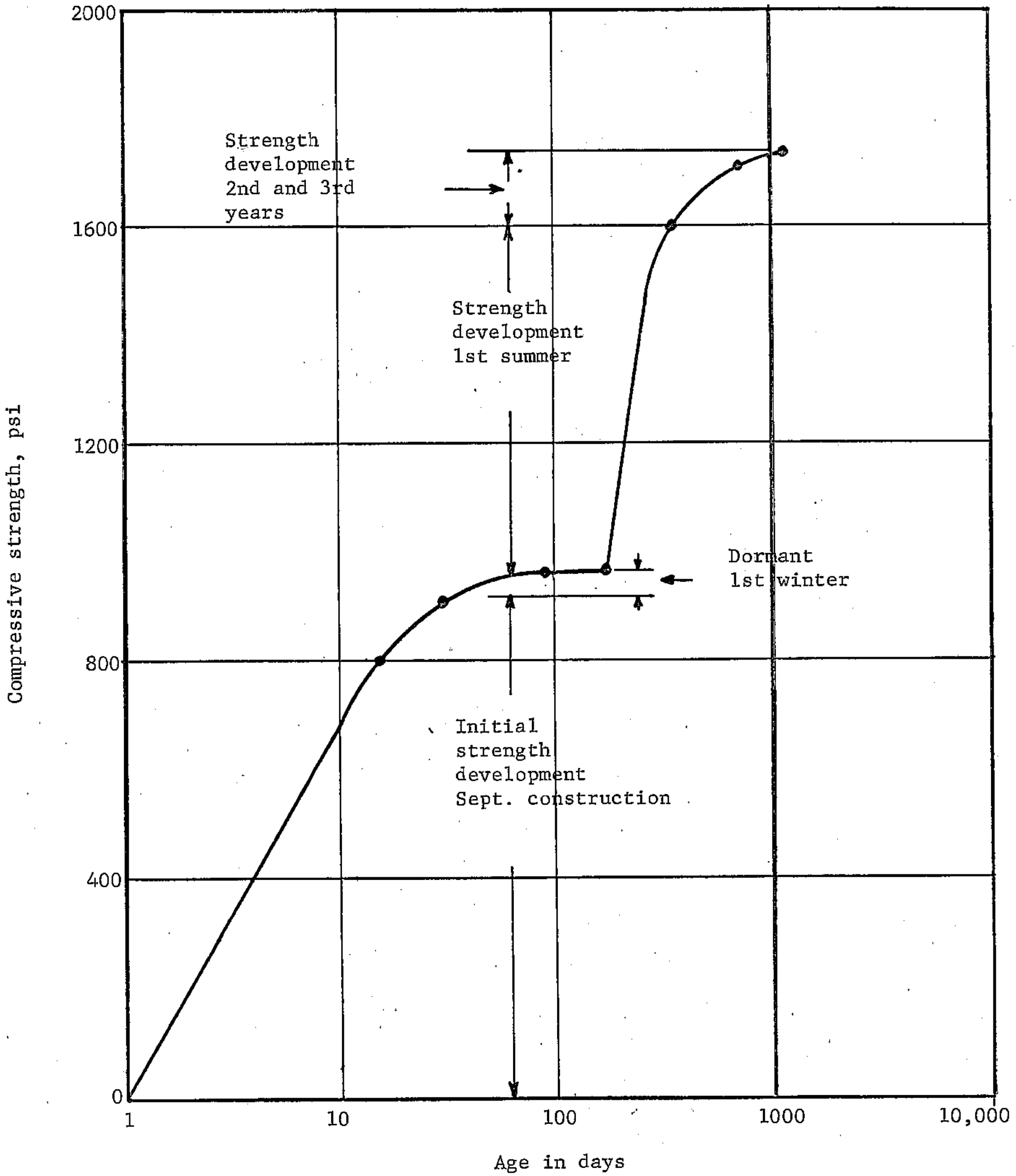


Figure 2. Compressive strength development of in-service pavement with lime-flyash stabilization, Harlem Ave., Chicago, Illinois.

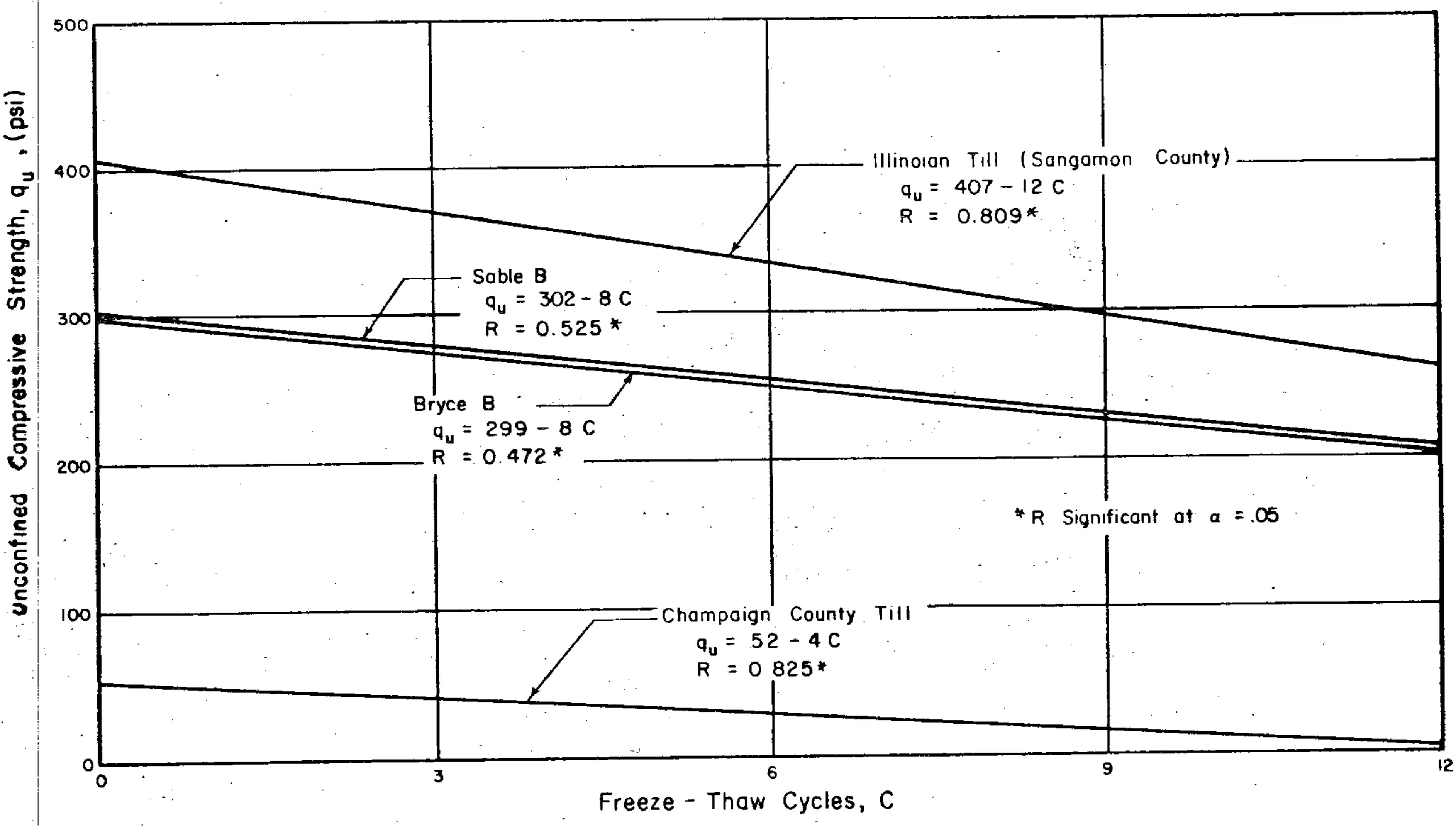


Figure 3 -Influence of Freeze-Thaw Cycles On Unconfined Compressive Strength (48 Hour Curing)

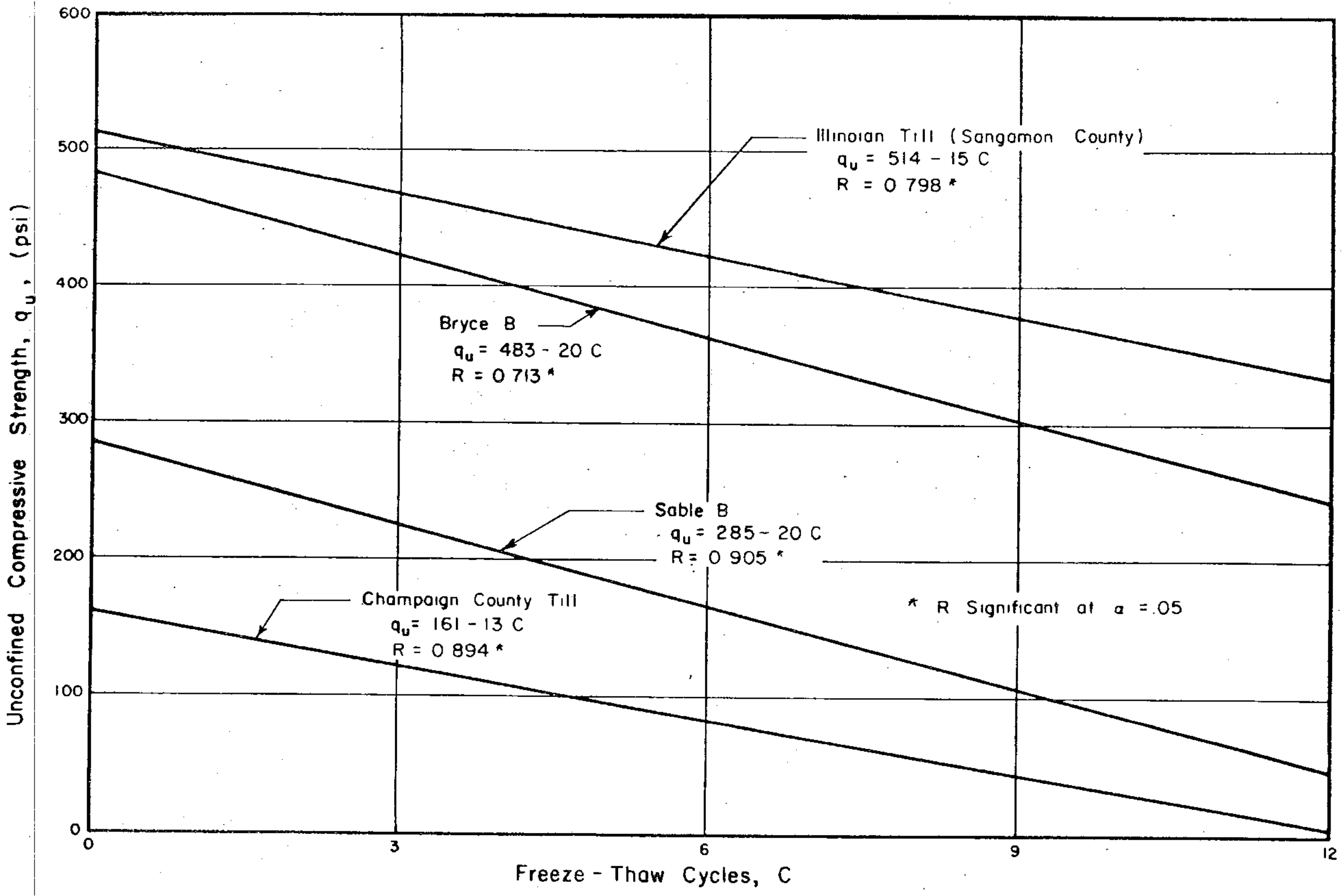


Figure 4 - Influence of Freeze-Thaw Cycles On Unconfined Compressive Strength (96 Hour Curing)

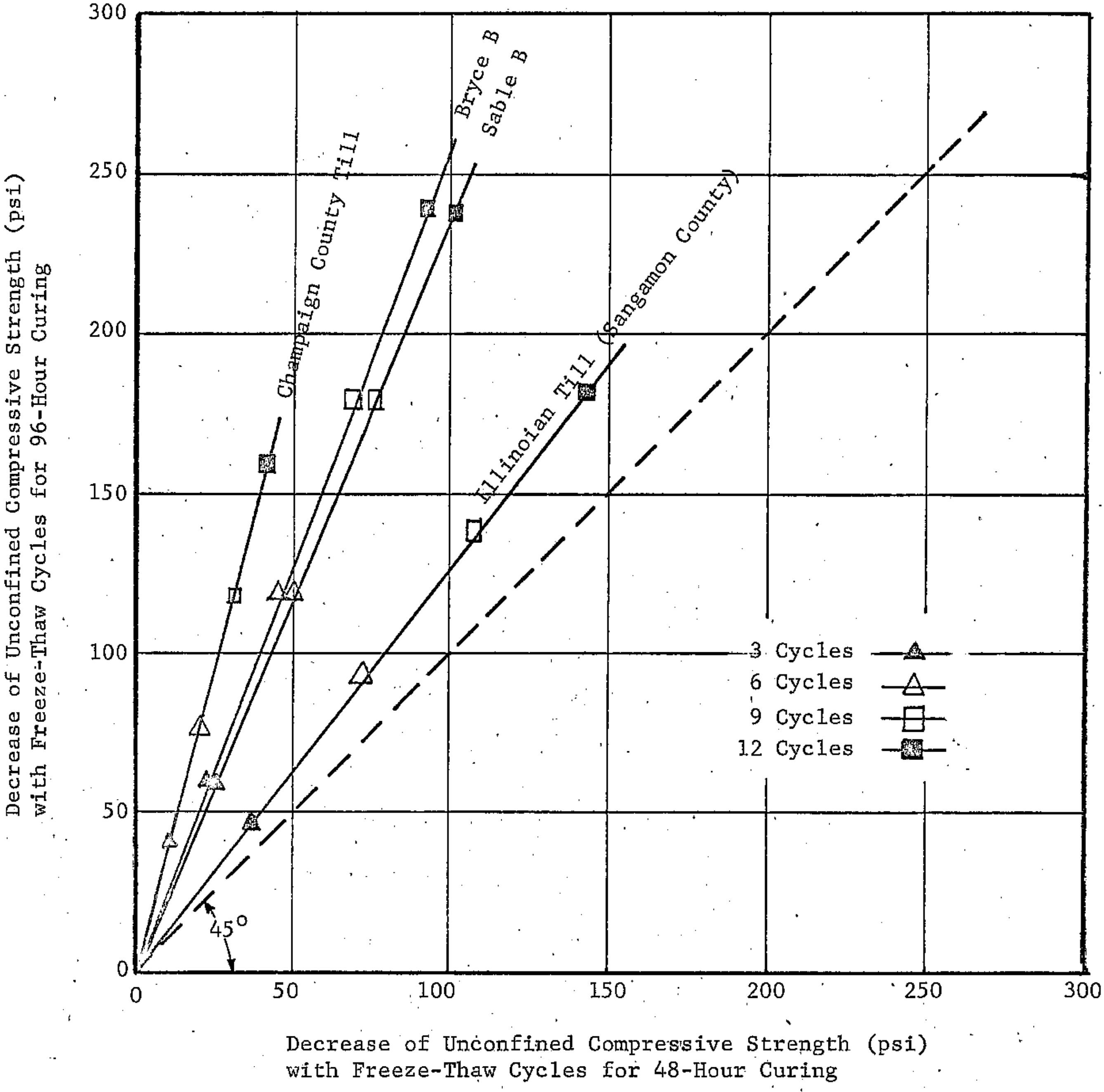


Figure 5. Effect of Curing Period on Decrease of Unconfined Compressive Strength with Freeze-Thaw Cycles

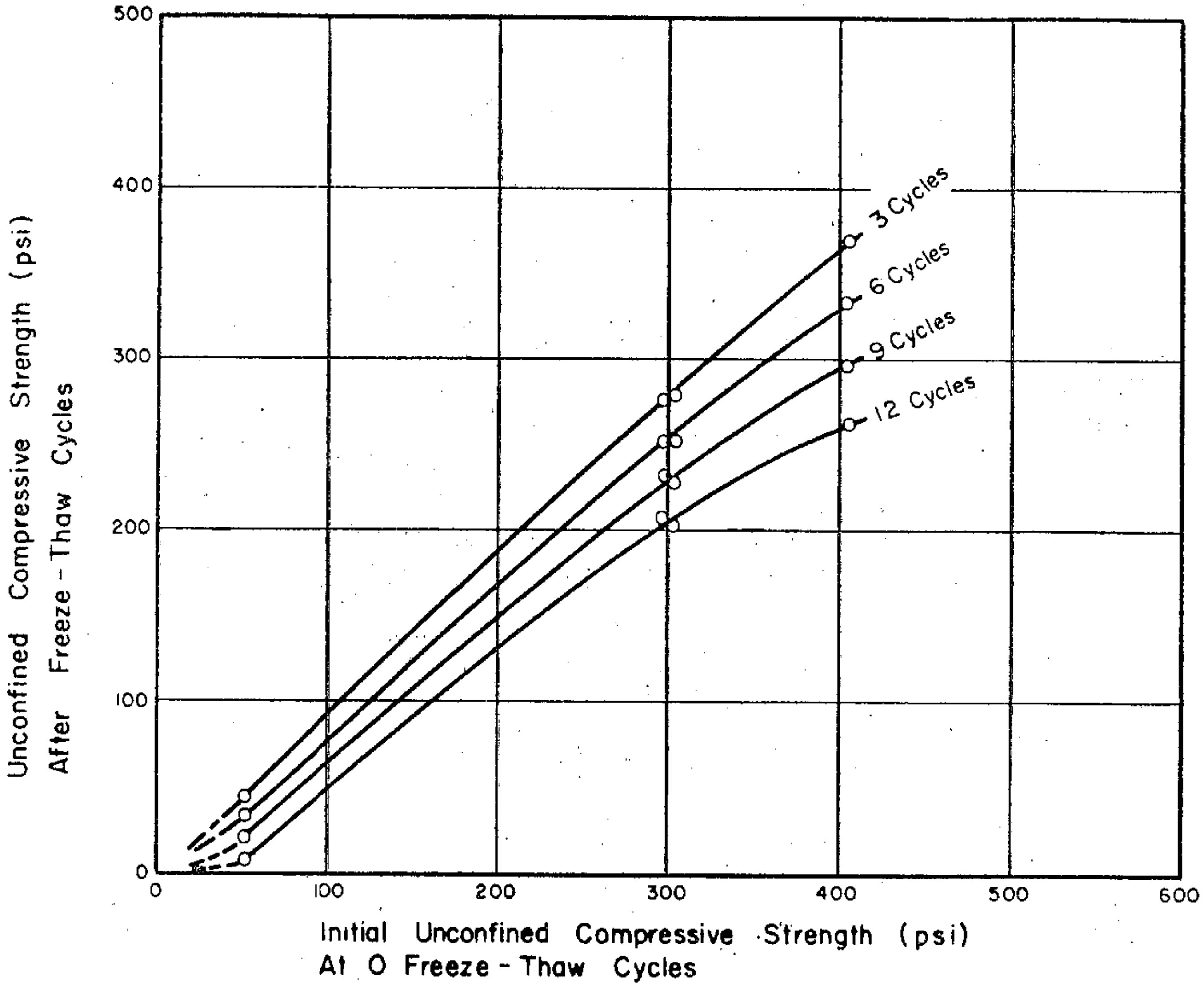


Figure 6 - Influence of Initial Unconfined Compressive Strength On the Residual Strength After Freeze-Thaw Cycles (48 Hour Curing)

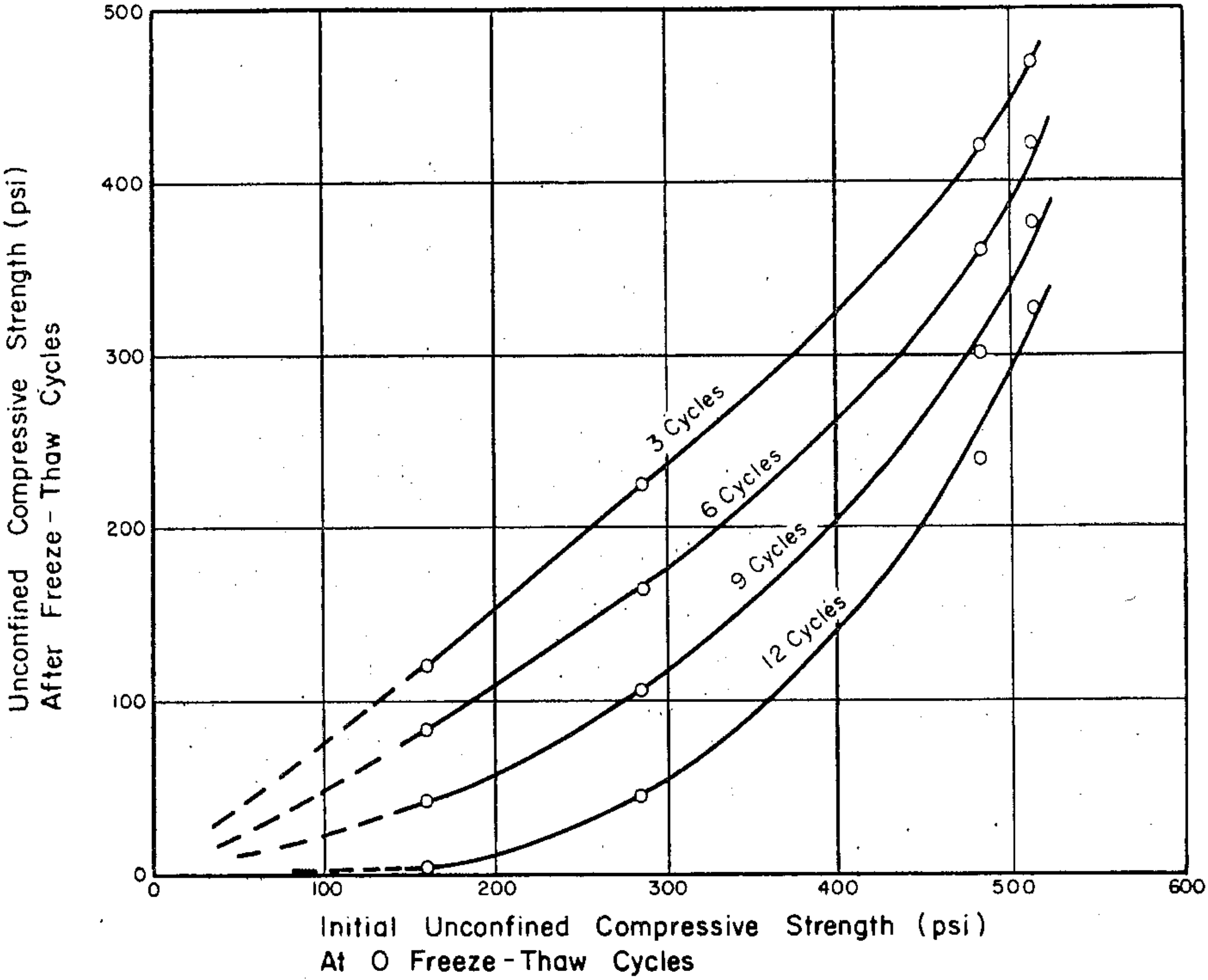


Figure 7 - Influence of Initial Unconfined Compressive Strength On the Residual Strength After Freeze-Thaw Cycles (96 Hour Curing)

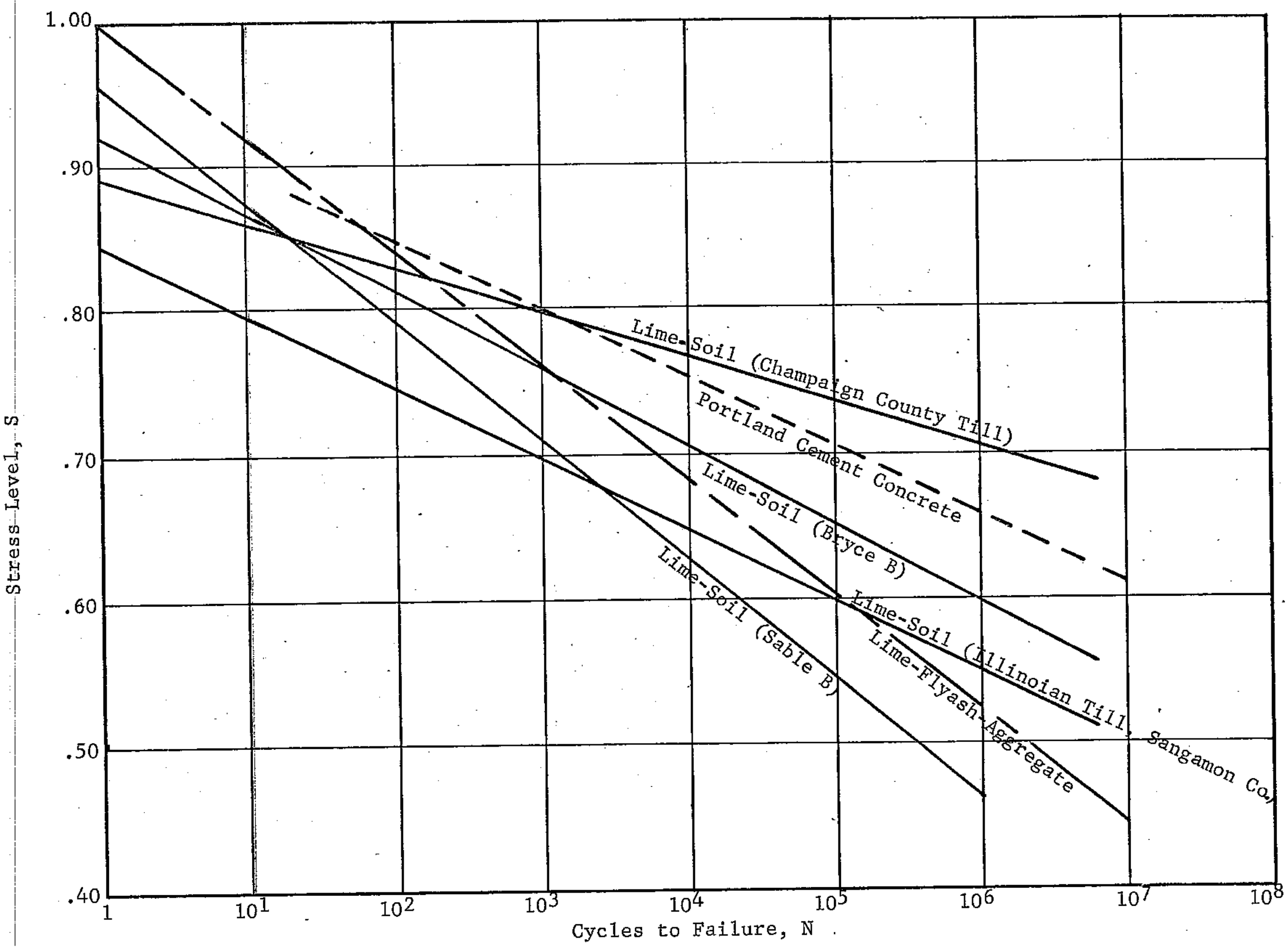


Figure 8. Flexural fatigue response curves.

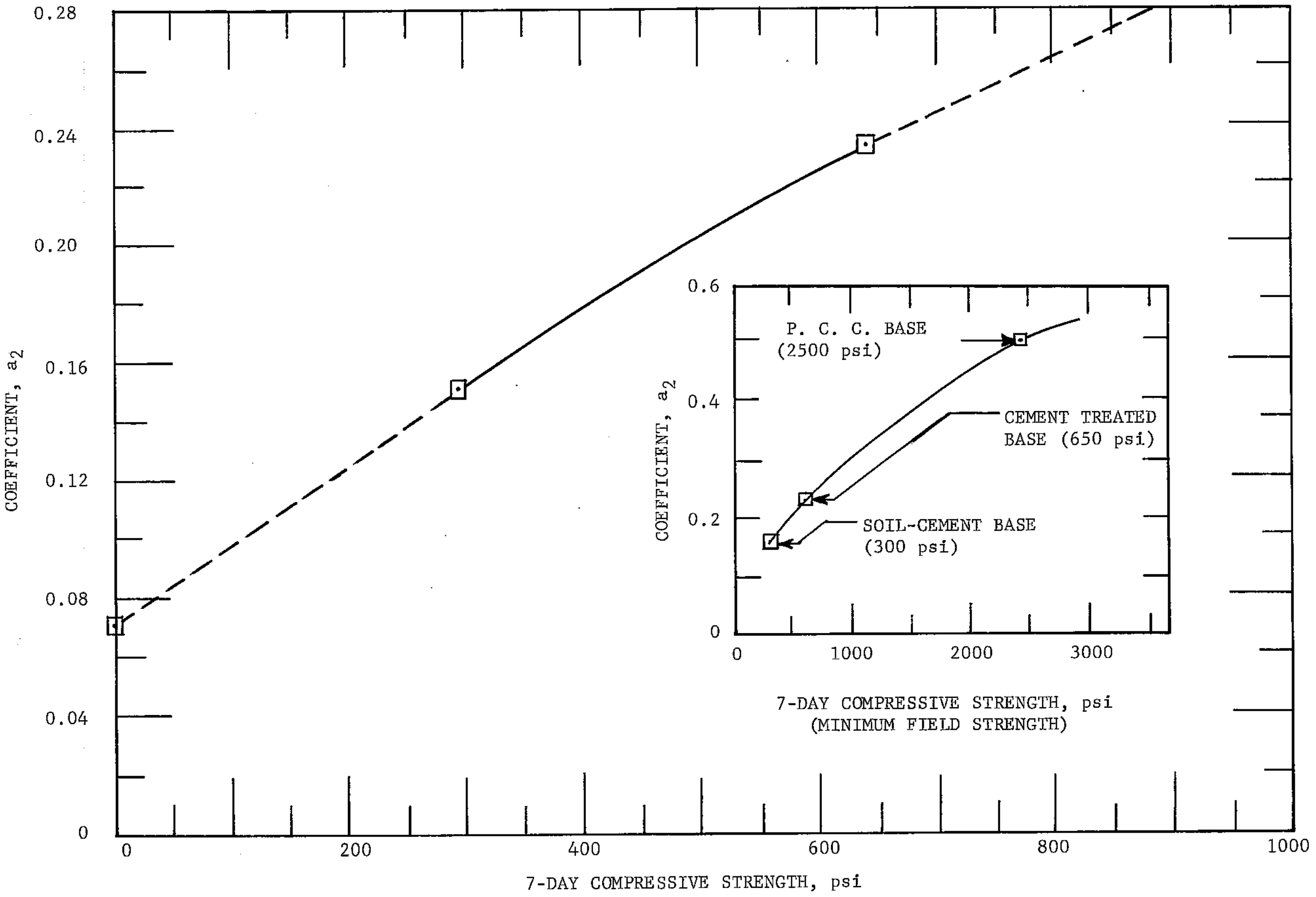
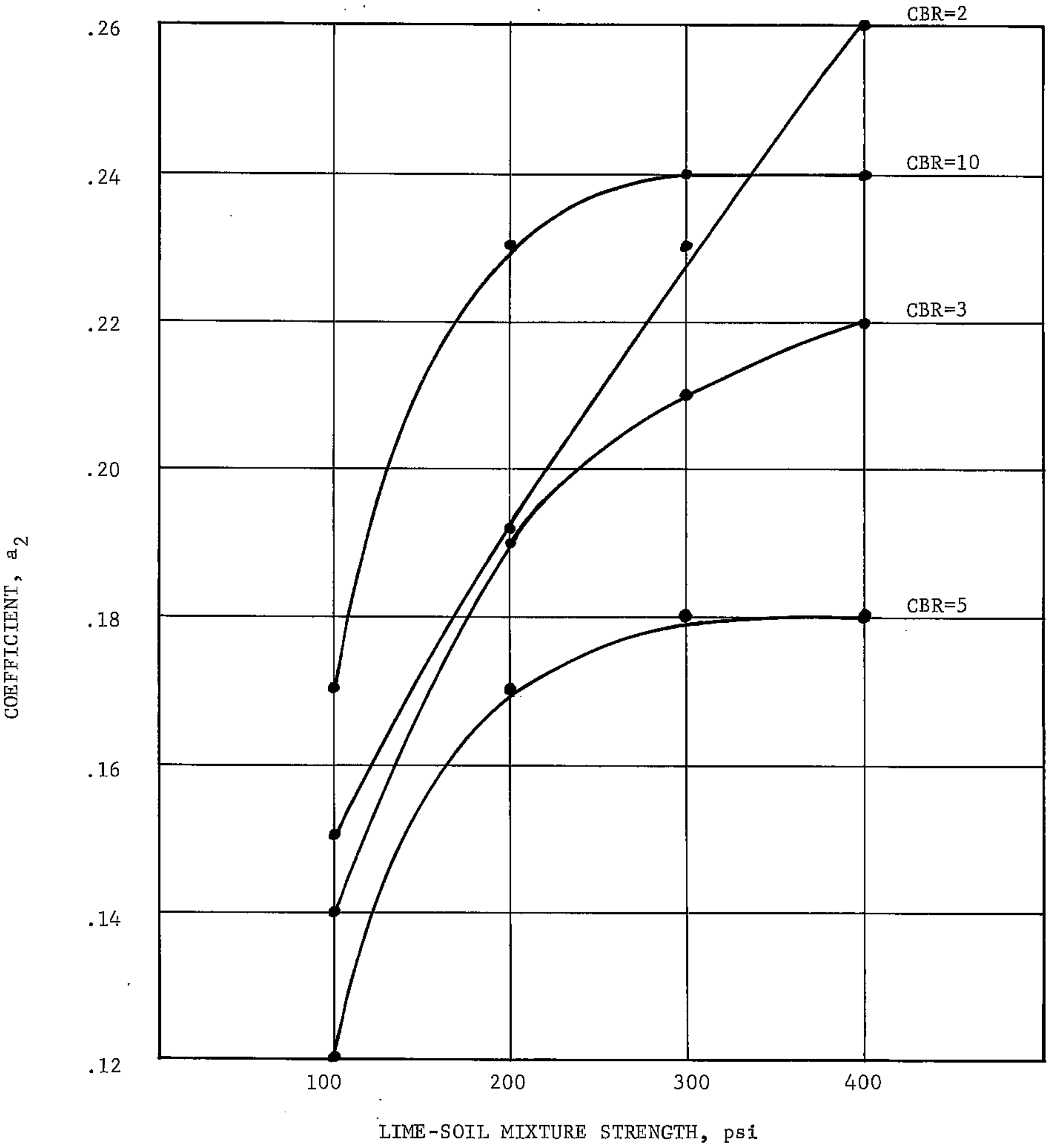

0.28
0.24
0.20
0.16
0.12
0.08
0.04
0
COEFFICIENT, a_2
0
200
400
600
800
1000
7-DAY COMPRESSIVE STRENGTH, psi
0.6
0.4
0.2
0
COEFFICIENT, a_2
0
1000
2000
3000
P. C. C. BASE
(2500 psi)
CEMENT TREATED
BASE (650 psi)
SOIL-CEMENT BASE
(300 psi)
7-DAY COMPRESSIVE STRENGTH, psi
(MINIMUM FIELD STRENGTH)

FIGURE 9



COEFFICIENT-STRENGTH RELATIONS FOR LIME-SOIL MIXTURE BASE COURSES.
(CLASS III - 700 ADT)

FIGURE 10