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ENGINEERING CHARACTERISTICS OF SOME SOUTHEAST ASIAN SOILS

James L. Post

The Eric H. Wang Civil Engineering Research Facility
University of New Mexico
Albuquerque, New Mexico

Contract F29601-68-C-0009

TECHNICAL REPORT NO. AFWL-TR-67-143

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

May 1968

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FOREWORD

This report was prepared by the Eric H. Wang Civil Engineering Research Facility, University of New Mexico, Albuquerque, New Mexico, under Contract F29601-68-C-0009. The research was performed under Program Element 6.44.15.06.4, Project 1559, Task 113, and was funded by the Aeronautical Systems Division (ASD).

Inclusive dates of research were 26 June 1967 to 28 November 1967. The report was submitted 19 April 1968 by the AFWL Project Officer, Lt J. R. Salley, (WLDC).

The help of Lt Salley and Lt John Trierweiler (WLDC) in securing samples and providing assistance in this investigation is greatly appreciated by the author.

This report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement No. 2)

The physical characteristics and the chemical and mineralogical compositions of soils from selected sites in Southeastern Asia were investigated to determine soil properties and effective chemical stabilants. The effect of additives on soil-cement was determined, and the ' fluence of the grain-size distribution of the soil gradation on soil-cement compressive strength was investigated. The unconfined compressive strengths of the cured soil-cements, compacted at ASTM standard optimum moisture-densities, were determined and correlated with mineralogical and chemical soil characteristics. The soil samples were mostly sandy soils and lateritic soils, composed mainly of quartz, perthite, kaolinite, illite, and goethite, or some combination of these minerals. Portland cement proved to be the most effective soil stabilization agent that gave adequate compressive strength to the soil-cement mixtures. Thailand portland cement and lime products were found to be of good quality, comparable to U.S. products. Aluminous cement additive was effective with some soils but was not very reliable, and lime additive proved to be of little value. The compressive strength of the soil-cements depended mainly on gradation of the soils and was not affected adversely by the sesquioxides in the lateritic soils. Additional tests are required to more accurately delineate the most beneficial soil gradations for soil-cements.

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

TABLES

TABLES (Cont'd)

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SECTION I

LABORATORY PROCEDURE

1. Introduction.

The purpose of this investigation was to determine the physical characteristics and composition of soils found near air traffic facilities in Southeast Asia (SEA). Soil stabilization procedures are also given for the soil samples which have been secured. The term "soil stabilization," as used in this study, refers to the process by which the physical properties of the soils may be improved to provide an adequate foundation material for support of loads transmitted to it.

Thirty-four soil samples were secured from ten sites, representing some of the more common types of soils to be found in Vietnam and Thailand. A general soil map of Vietnam assembled by Moormann is available in reference 1. The soils were classified according to soil types and tested with chemical stabilants which are available in that part of the world. Thailand lime and portland cement were tested and compared with analogous products manufactured in the United States.

Procedures were developed for the preparation of acceptable soil-cement material from the soils of Southeast Asia. Many of the soils used in construction are referred to as "lateritic" soils, or "latosols." Lateritic soils may be defined as soils possessing concretionary formations or sesquioxide-rich crusts in at least one of their horizons (ref. 2).

2. Mechanical Analyses.

Each soil sample, consisting of 6 to 10 kilograms of partially saturated soil, was tested for moisture content, was air-dried, and then broken down with a mortar and rubber pestle. The lateritic soils contained nodules of weakly indurated material. These nodules were formed mainly of concentric layers of goethite and kaolinite and when air-dired could often retain as much moisture as the soil fraction passing the No. 10 U.S. Standard sieve. The soil moisture data are given in the appendix.

The following standard test procedures were used for soil classification purposes as given in the ASTM *Procedures for Testing Soils* (ref. 3).

Liquid limit	ASTM Designation: D423-61T
Plastic limit and Plasticity Index	ASTM Designation: D424-59
Specific gravity	ASTM Designation: D854-58
Grain-size analysis	ASTM Designation: D422-63

An ASTM 152-H hydrometer was used for the fines portion of the grain-size analysis, and the hydrometer test was generally allowed to run for only 250 minutes, this being sufficient to show the amount of clay-size material in the soil samples. The range of the silt-size material was taken to be from 0.05 millimeter (mm) to 5 microns (μ); the grain-size distribution curves were plotted on 6-cycle semilog paper. The results of the soil tests are included in the appendix by site.

The soils are classified according to the Unified Soil Classification System and the American Association of State Highway Officials (AASHO) Classification System, using the appropriate grain-size limits in each case. These classifications are also given on the data sheets in the appendix.

From two to five bulk soil samples were taken from separate pits at each site, except at Phan Rang where three soil samples were taken across one soil column. The plasticity characteristics of all the soils tested are shown on the plasticity chart in figure 1 where the number of nonplastic soils is also indicated. Most of these soils are quite inactive, the activity (Plasticity Index/[-2 μ] clay fraction) being less than 0.75 in every case. Nearly every type of inorganic soil is represented by the soil samples received; however, the two most common soil types received were sandy soils (15 samples) and lateritic soils (9 samples). Because of the small soil samples received and the large portion of nodules in the lateritic soils, the indurated material in those soils was pulverized and used for testing.

3. Soil Stabilization.

The hygroscopic moisture of the soil fraction passing the No. 20 sieve was determined for each of the 33 samples, and the samples were subsequently thoroughly mixed and stored in sealed plastic bags. One soil sample from Nakhon Phanom consisted of heavily indurated laterite. This sample was reduced to material that was less than 1 mm in size by a mechanical pulverizer.

A Harvard miniature compaction apparatus (ref. 4) was used because of the small amount of soil sample material, and time, available. The material was compacted in five layers using 25 blows per layer with a 25-pound tamper spring.

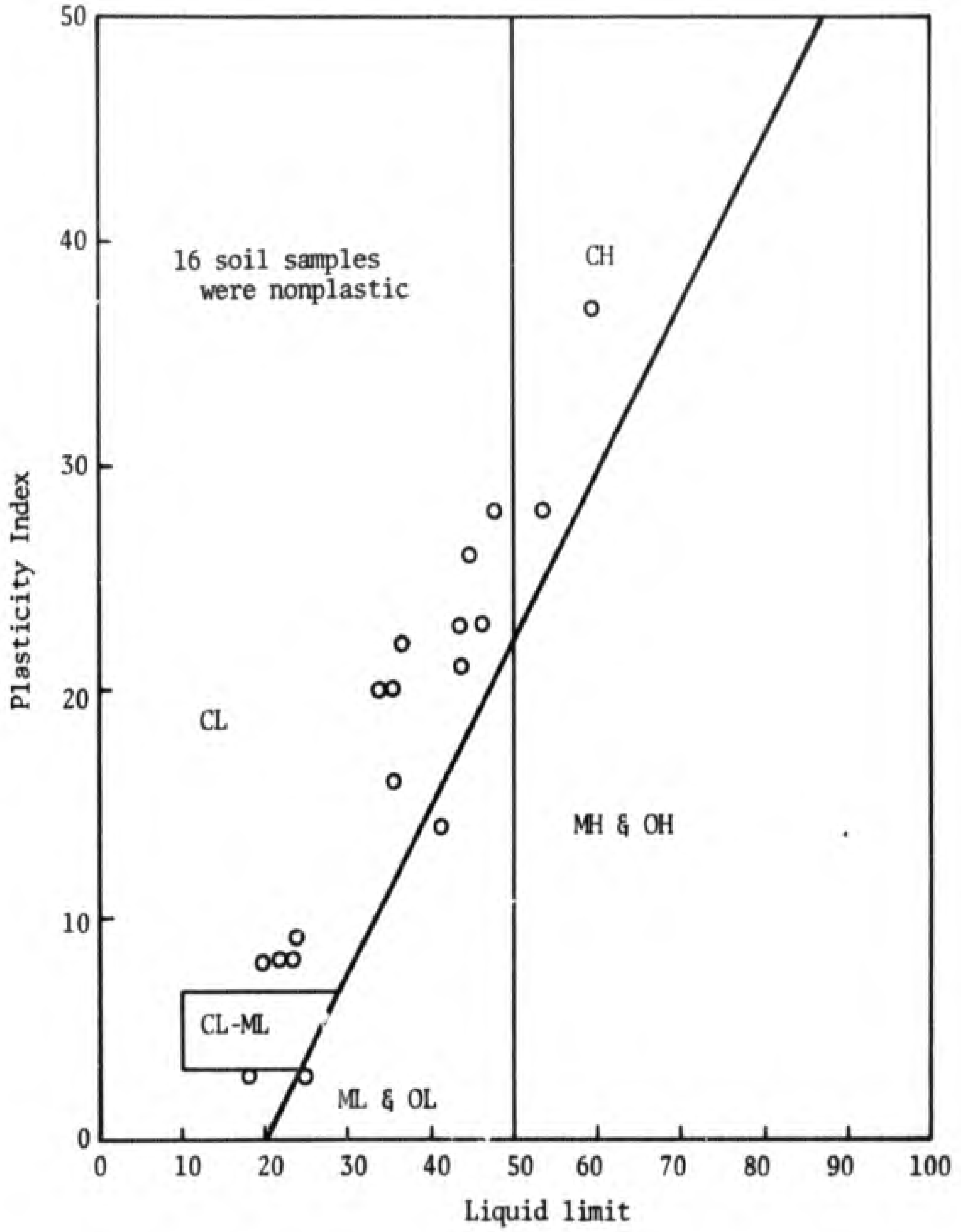

Figure 1. Plasticity chart for SEA soils using the Unified Soil Classification, 10 sites, 34 samples

The moisture-density relationships obtained with the Harvard miniature compaction apparatus were comparable to those of the ASTM "Moisture-Density Relations of Soils Using 5.5-pound Rammer and 12-inch Drop (D698-64T)." The correlation procedure has been described by Wilson (ref. 4).

A moisture-density plot was made for each soil sample, and from each plot the optimum moisture-density relations were determined. These data are given in the appendix. The water adsorptive characteristics of the soil stabilization additives were determined from their moisture-density curves by determining the moisture content at maximum density (e.g., 25 grams of water per 100 grams of portland cement). The water content of the soil-additive mixtures was adjusted to attain optimum moisture content, and the soil-cement mixtures were then compacted to maximum density.

The soil additives were chosen for investigation to satisfy certain criteria. These included availability (both from the United States and Thailand), satisfactory soil-cement strengths, economy, resistance to erosion, and general reliability. All the soil samples were tested using portland cement, Type I (PC). The only other additives used were hydrated lime, hematite, calcite, Lumnite* (aluminous cement), and various combinations of these additives. Hydrated lime and portland cement, Type I, from Thailand were also used in order to compare them to lime and portland cement from the United States. The testing of additional additives was felt unnecessary after it had been determined that the grain-size distribution of SEA soils was a major factor in the development of their soil-cement strengths. This factor is discussed in detail in section IV.

Duplicate soil-cement cylinders were compacted with two different amounts of additive and at two curing times. The soil-cement cylinders were stored in a high-humidity environment for 7 and 28 days. At the end of these curing times the soil-cement cylinders were submerged in water for 1 hour, removed, and tested for unconfined compressive strength. Six of the soil samples consisted of uniformly graded sands. Extra compaction sleeves were prepared and the sand-cement mixtures were compacted and allowed to cure in these open-ended sleeves. The soil-cement cylinders were then easily extruded and were treated in the same manner as the other specimens.

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*Lumnite, registered trademark, used by permission of The Reardon Co., St. Louis, Mo.

The soil-cement cylinders were tested at a strain rate of about 0.05 inch per minute (in./min), with only the maximum strain and strength being recorded. The type of failure and the moisture content at failure were also noted for test control. The maximum strength of the soil-cement cylinders was reduced to maximum unit stress and expressed in pounds per square inch (psi). The strength of each soil-additive mixture was plotted with respect to curing time when both 7- and 28-day data were available. When insufficient time was available for further 28-day curing periods, some additional soil-cement mixtures were allowed to cure for 7 and 14 days. These data are presented in the appendix by site.

The minimum criteria for successfully stabilized soil-cement mixtures vary but are generally considered to require a 7-day compressive strength greater than 250 psi for rural roadways and 400 psi for main roads (ref. 5). The state of California requires a 7-day compressive strength of 750 psi for cemented aggregate base material (ref. 5). The criteria should take into account the precipitation, erosion, ground water, and traffic conditions at each site.

4. Chemical Analyses.

Four types of chemical tests were conducted on all the soil samples. They included tests for determining water solubility, organic content, hydrogen activity determination (pH), and equivalent ferric iron content (expressed as Fe_2O_3). Preliminary investigation of the X-ray diffraction traces indicated the presence of significant amounts of calcite in three soil samples and gypsum in one; as a result, three equivalent carbonate tests were conducted (expressed as $CaCO_3$), and one equivalent gypsum test was conducted (expressed as $CaSO_4 \cdot 2H_2O$).

The water-solubility test consisted of leaching about 250 milliliters of boiling water through 10 grams of soil that has been broken down to material finer than 2 mm in size, the leachate being retained for further analysis. This test is a rough index of the more soluble salts in a soil.

The organic contents were determined according to the dichromate method given by Akroyd (ref. 6). This method is comparable to procedure #24 given in the *Agriculture Handbook No. 60* (ref. 7). The equivalent carbonate tests were conducted according to procedure #23b, alkaline-earth carbonates by gravimetric loss of carbon dioxide, in the same *Handbook*. This method generally gives an accuracy to within 1 percent by weight.

The pH of the soil samples was determined by the method proposed by Jackson (ref. 8), the "sticky point" method. The sticky point is reached when the soil is just wet enough to stick firmly to a spatula pressed to a soil mass and pulled directly away from it. This method was used in an effort to determine the pH of the "bound" water in the soil-water system. In general, the more dilute the soil suspension, the higher the soil pH value found, because of the effect of the "free" water pH.

A fast, simple method for determining the percent of ferric oxide in soil samples was used. "Iron oxide will go into solution when hot hydrochloric acid is used to leach the soil, and the iron leached from the soil may be determined iodometrically" (ref. 9). A rough estimate of the iron in a soil sample may also be made from the X-ray fluorescence background that occurs when the sample is subjected to X-ray radiation from a copper target.

The equivalent gypsum content of a soil was determined by gravimetric procedures, taking advantage of the narrow dehydration range of the mineral. The soil may be heated to 50°C, weighed, reheated to 105°C, and reweighed. The weight loss, as shown by Deer et al. (ref. 10), is due almost entirely to the dehydration of gypsum. This method appears to give an accuracy to within 1 percent by weight.

The results of these chemical analyses are also given in the appendix.

5. Mineralogical Analyses.

The mineral constituents of the soils were determined by X-ray diffraction analyses, using the spectrometric powder technique. The soils were reduced to material passing a No. 140 sieve, and X-ray diffraction traces were made from the randomly oriented powder samples according to the procedure given by Klug and Alexander (ref. 11).

The X-ray apparatus has a horizonal goniometer with a vertical specimen rack. For this reason the powder samples were pressed into the sample holder so that they would remain in place; thus, random orientation was not achieved with all soil minerals because of the cleavage habits of such minerals as the feldspars. This sample mounting procedure provided the advantage that a reliable quantitative analysis procedure could be developed.

X-ray diffraction patterns were made of each soil sample; and when more than 25 percent of a sample consisted of material coarser than 2 mm, a pattern was made of both the coarse and fine material. Mineral analyses were made using these patterns, along with the results of the chemical tests. The operating procedure for producing the diffraction patterns, using the General Electric XRD-5 unit, was as follows:

Copper Target--Nickel Filter

Tube power...............35 KV/23 ma.
Slits....................1° source and 0.1° reception
Count rate...............500 CPS and TC = 2
Goniometer rate..........2θ°/min
Chart rate...............E, 0.4 in./min

Chromium Target--Zirconium Oxide Filter

Tube power...............45 KV/16 ma.
Slits....................1° source and 0.1° reception
Count rate...............500 CPS and TC = 2
Goniometer rate..........4θ°/min
Chart rate...............E, 0.4 in./min

The chromium target was used to make X-ray diffraction patterns of soil samples with a high iron content because of X-ray fluorescence induced by use of a copper target ($\Delta Z = 3$).

The X-ray powder diffraction data used for the analyses of the soil samples were obtained mainly from the ASTM powder diffraction file. Other sources of information included data published by the British Mineralogical Society (ref. 12) and by Grim (ref. 13).

The procedures used for quantitative analyses were developed by Klug and Alexander (ref. 11) and recently elaborated by Moore (ref. 14).

SECTION II

EFFECT OF SOIL STABILIZATION ADDITIVES

1. General.

Thirty-four soil samples from ten sites were tested with 5- and 10-percent portland cement additive (PC) to determine its effectiveness as a soil stabilization agent and to compare the soil-cement mixtures. After the results of the portland cement additive were observed for the 7-day curing period and the predominant soil minerals were identified, other soil additives described on the following pages were tried.

There have been many studies of the characteristics of lateritic soils; however, the results of these studies are not so well known north of the tropics. Lateritic soils, in particular, have been investigated and discussed for over 150 years. The Natural Resources Research IV review by Maignien (ref. 2) probably contains the most complete summary of the nature and formation of lateritic soils; and volume III, chapter XI, of *Soils Engineering,* published by the United States Army, probably contains the most complete summary of the engineering characteristics of tropical soils (ref. 15). Recently an investigation was made of the comparison of engineering properties of some tropical and temperate soils, including soils from Thailand (ref. 16). Investigations of the engineering characteristics of lateritic soils began in the United States during World War II, one of the first studies being conducted in 1945 by Fruhauf (ref. 17). More recently much attention has been given to the problem of stabilizing tropical soils for use in road construction. Indurated laterites have been used as construction materials in the tropics for centuries and have been one of the main sources of aggregate for road construction. More recently in many cases stabilization of the *in-situ* material has proved to be faster and more economical. In Rhodesia, for example, hydrated lime and portland cement are now being used as soil stabilization agents (ref. 18).

Systematic studies of soil stabilization are being conducted at the SEATO Graduate School of Engineering in Thailand. Some of the completed studies include the effect of sulfates on lateritic soil-cements (ref. 19), asphaltic stabilization of lateritic soils (ref. 20), and the cement treatment of lateritic soils (ref. 21). The investigation of the engineering properties of lateritic soils will continue to become more important because it has been estimated (ref. 22) that these soils comprise the most common soil type on earth.

The choice of different additives to soil-cements was determined according to the mineral constituents in the soil samples and the grain-size distribution of the soils. The soil mineralogy is discussed in the following section. The soil samples were classified according to the results of mechanical analyses and tested according to soil type by using the following soil-cement mixtures (table 1).

Additional soil samples were tested using various portions of the material coarser than 2 mm. The coarse-size fractions of all the soils were pulverized for chemical tests. Two soil samples were reconstituted using the broken-down coarse-size material tested with portland cement additive, and the coarse-size fractions of three different soil samples were tested with portland cement additive.

2. Portland Cement Additive.

Type I portland cement was used, in amounts of 5 and 10 percent by oven-dry weight, as a soil stabilant to compare the different soil-cement mixtures and to determine the soil-cement strengths of tropical soils in comparison with other soils that have been tested. It was found that about half of the soil-cement mixtures could be given a 28-day unconfined compressive strength greater than 250 psi with a 5-percent portland cement admixture. A 10-percent portland cement admixture proved to give strengths greater than 250 psi for all but four of the soil-cement mixtures for the same curing time. These four mixtures consisted of two soils from Cam Ranh Bay containing uniformly

TABLE 1

SOIL-CEMENT MIXTURES

Additive	Number of soil samples
Portland cement	33
Hydrated lime	7
Aluminous cement (Lumnite)	4
Thailand portland cement	5
Thailand lime	3
Hematite and portland cement	3
Calcite and portland cement	1
Kaolinite and portland cement	2
Hydrated lime and portland cement	1
Sand and portland cement	2

graded sand and two soils from Nakhon Phanom containing lateritic nodules with little sand-size material. The results of these tests are given in the appendix. The "Jinglestone" aggregate from U Tapao is comparable to the soil sample from Red Horse Hill and should give similar aggregate-cement strengths. The reasons for the soil-cement strength variations are discussed in section IV.

It should be noted that eight of the soil-cement samples showed no further strength increases after 7 days curing time, and four of these showed some strength decrease. In areas of high rainfall the resultant soil leaching may be deleterious to soil-cement that is not covered with a waterproofing agent.

There appeared to be few reactive agents in the tested soil samples, the agents having been leached out by tropical weathering in most cases. The organic content of the soil samples was quite small, only three soil samples containing more than 1 percent; and the soils were also inactive, none greater than 0.75 (PI/[-2 μ] clay content). Sample 1 from Don Muang contained about 3-percent gypsum.

3. Portland Cement-Hematite Additives.

Iron oxide is very common in tropical soils, giving rise to the red, orange, and yellow color in the soils. When present in small amounts, iron oxide is usually hydrated and appears as goethite; and when it is a predominant portion of the soil, it may occur partly as goethite and partly as hematite (ref. 2).

Small amounts of hematite were added to soil-cement mixtures, using portland cement, to determine the effect of hematite on calcareous cement reactions in soils. Hematite, in the amounts of 2 and 5 percent by weight of oven-dry soil, was added to three samples consisting of sand from Bien Hoa and Cam Ranh Bay, along with 5- and 10-percent portland cement additive. The hematite does not appear to affect the 7-day strength of the 5-percent PC mixtures or the 7- and 28-day strength of the 10-percent PC mixtures, but the 2- and 5-percent hematite additive both appear to retard any additional strength gain in the 5-percent PC mixture after 7 days curing time. Uniform sand-cement mixtures were very difficult to form, and no further deductions were gained from these data.

4. Portland Cement-Calcite Additives.

Carbonate minerals were present in seashells in sample 2 from Cam Ranh Bay and consisted of both calcite and dolomite. Calcite in the amount of 5 percent was added to sample 1, a pure siliceous sand, along with 5- and 10-percent portland cement additive. The calcite was destructive to the 7- and 28-day strength of the 5-percent PC mixtures and also destructive to the 28-day strength of the 10-percent PC mixture. Ordinarily a soil contains some clays for the portland cement-water system to react on, but this soil system contained only quartz and calcite. The hydrated lime liberated from portland cement by the addition of water normally reacts first on water-soluble minerals, clays, and organic materials; but in this case it appears to have reacted mainly on the calcite, forming a weak hydraulic cement.

5. Portland Cement-Lime Additives.

A pre-treatment with lime is sometimes used to flocculate the clays and weakly cement the fines in a soil before treating the soil with portland cement additive. This method of treatment may be effective if the surplus residual hydrated lime is leached out before adding portland cement, but the method does not appear to be valid if there is residual lime available to disturb the natural chemical cementing reactions.

Soil sample 1 from Ubon was treated with an admixture of 4-percent lime and 5-percent portland cement. The 7- and 28-day compressive strength of the soil-cement was reduced to less than half the strength of the soil-cement mixture when only 5-percent portland cement additive was used.

The U.S. lime product used as an additive was found on analysis to contain a large amount of magnesium hydroxide, which is known to be deleterious to portland cement hydration reactions. Dolomitic dihydrate lime by itself generally shows poor strength-gaining properties (ref. 23).

6. Aluminous Cement Additive.

Of the three most common types of hydraulic cements used throughout the world, two types are readily available in the United States: calcium silicate cements (portland cements) and calcium aluminate cements (Lumnite). Slag cement and sintering cement are becoming more available but were not used in this investigation. Both cements may contain large amounts of iron, magnesium, or manganous oxide (ref. 24).

Aluminous cements are known to be resistant to attack by caustic alkalis and sulfate solutions but do not appear to make very durable soil-cements. Perhaps that is because the main hydraulic cements are quick-setting calcium aluminates and there may be transitory formations when silica is present. In hydrated portland cement calcium silicate hydrates are the main end-reaction products (ref. 24).

Four soil samples were tested with an admixture of Lumnite: one of sand, two of clayey soil, and one of laterite (appendix, pp. 54,76,87,109). An admixture of 5- and 10-percent of Lumnite was used in each soil sample with curing times of 7 and 28 days (as with the PC admixtures).

The sand-cement mixtures, sample 4 from Cam Ranh Bay (appendix, p. 52), gave a high, early strength after 7 days curing time but had very little strength after 28 days. The 10-percent admixture showed five times the strength of the PC admixture after 7 days but only one-tenth the strength of the PC admixture after 28 days, indicating a possible deterioration of the strength of the portland cement with time for this particular soil.

The soil-cement mixtures, sample 1 from Phan Rang (appendix, p. 87) and sample 3 from Tuy Hoa (appendix, p. 109), showed less than half the 7-day strength of soil-cement mixtures made with portland cement additive; and the soil-cement mixtures made from laterite, sample 4 from Nakhon Phanom (appendix, p. 76), showed less than one-quarter of the 7-day strength of soil-cement mixtures made with portland cement, with little change in strength after 28 days curing time.

7. Lime Additive.

Hydrated lime is used as a soil stabilization agent primarily when a soil contains significant amounts of clay minerals, the lime admixture resulting in ionic charge balance, flocculation, and formation of pozzolanic cements.

Seven soil samples that passed a No. 20 sieve and consisted of 17- to 52-percent clay-size material (most of it clay minerals) were chosen from six sites and tested. A dolomitic dihydrate lime was used and gave very poor soil-cement strengths, as might be expected. Lime additive in the amounts of 4 and 6 percent were used with the soil samples. The resultant compressive strengths of the soil-cement mixtures were so small that the difference between 4- and 6-percent admixtures was negligible. The Thailand lime admixtures gave soil-cement strengths about one-third greater than the U.S. lime admixtures, the 7-day compressive strengths varying between 5 and 40 psi with little or no gain in strength after 7 days curing time.

8. Thailand Cement Additives.

Two soil-cement additives, portland cement and hydrated lime, were available from Thailand. Both products appear to be of good quality and compare favorably with similar products manufactured in the United States. The lime appears to be a rather pure calcium hydroxide with very little magnesium hydroxide content, as determined by X-ray diffraction analysis.

Five soil samples from five sites were tested with Thailand portland cement in the same manner as with the portland cement manufactured in New Mexico. In every case except one, the soil-cement mixtures made with Thailand PC were comparable to that made with the U.S. product. The soil-cement mixture, soil sample 1 from Phan Rang, gave slightly lower strengths for the 5-percent PC admixture, but in any case the 10-percent PC admixture should give more than adequate soil-cement strength.

As previously mentioned, the Thailand lime product is superior to the dolomitic dihydrate lime as a soil stabilization agent.

9. Soil Grain-Size Additives.

The gradation of soil in soil-cement mixtures is a major factor in the production of soil-cement that has adequate compressive strength. Specifications for gradation of soils that may be successfully stabilized by the use of portland cement admixtures are given by the Portland Cement Association (ref. 25), the British Ministry of Transport (ref. 5), and many other organizations. These specifications vary according to the use that is to be made of the soil-cement but are in agreement that gap-graded soils, uniformly graded soils, and most soils with an excessive amount of fines do not make strong soil-cements. The most effective gradation for soil-cement mixtures would also appear to be somewhat comparable to the AASHO materials specifications for soil in roadway construction (ref. 26).

Kaolinite in amounts of 10 and 20 percent of the oven-dry weight of the soil was added to two samples of uniformly graded sands, sample 1 from Cam Ranh Bay and sample 1 from Tuy Hoa, along with 5- and 10-percent portland cement additive. The results of the tests are given in figures 2 and 3; and, as can be seen, from pages 48 and 104, the two sands had somewhat different grain-size distributions. The Cam Ranh Bay sand held about 20-percent kaolinite with an ensuing increased density and strength, whereas the Tuy Hoa sand held about 10-percent kaolinite at maximum density and strength. When more clay was added to the Tuy Hoa sand (20 percent), the sand matrix appeared to be spread open so that the soil-cement strength was determined by the cemented clay.

Sand was added to two clayey soil samples, samples 1 and 2 from Don Muang, which contained about 40- to 50-percent clay-size material in the portion passing

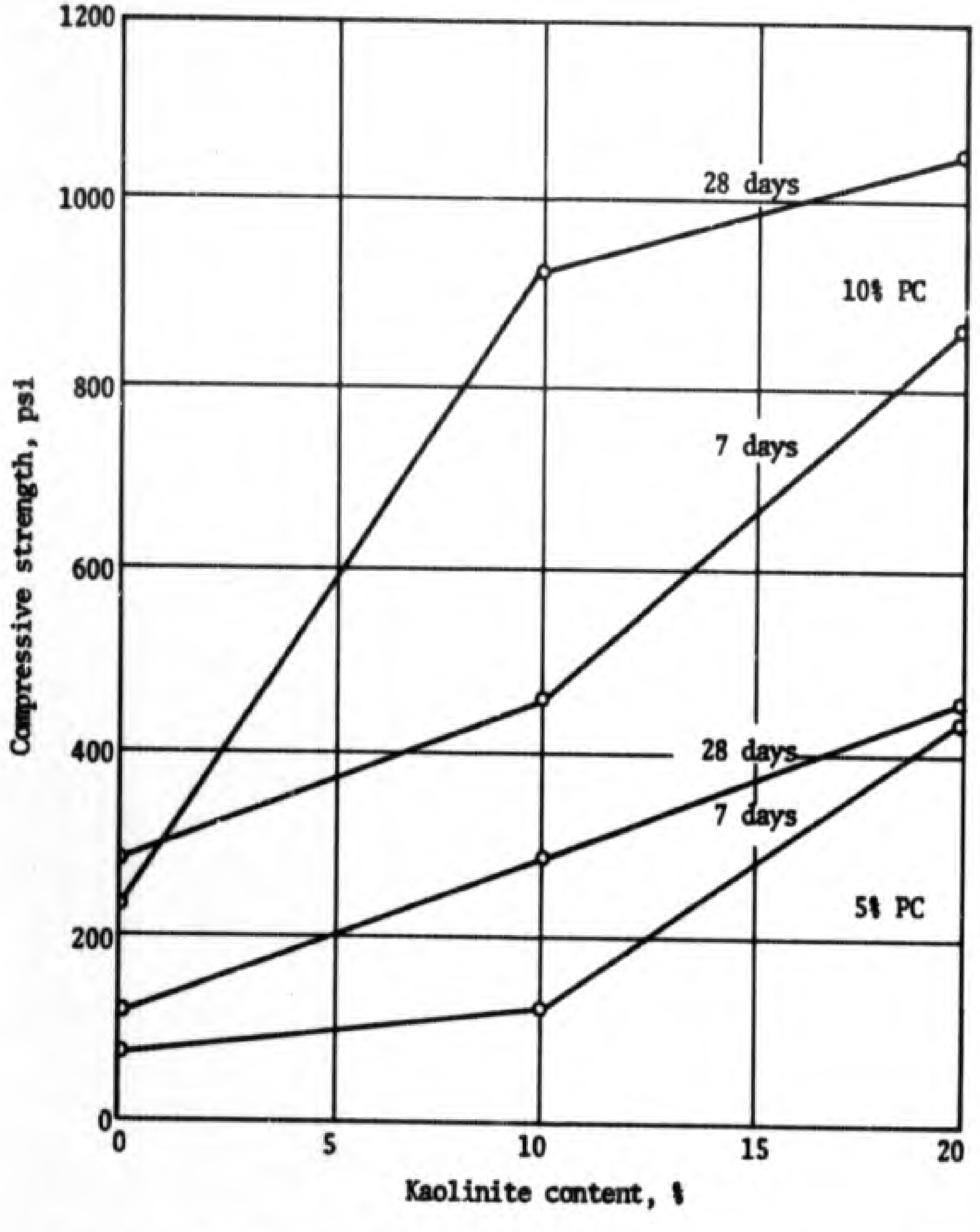


Figure 2. The effect of kaolinite additive on the compressive strength of soil-cement mixtures (portland cement), Cam Ranh Bay sample 1

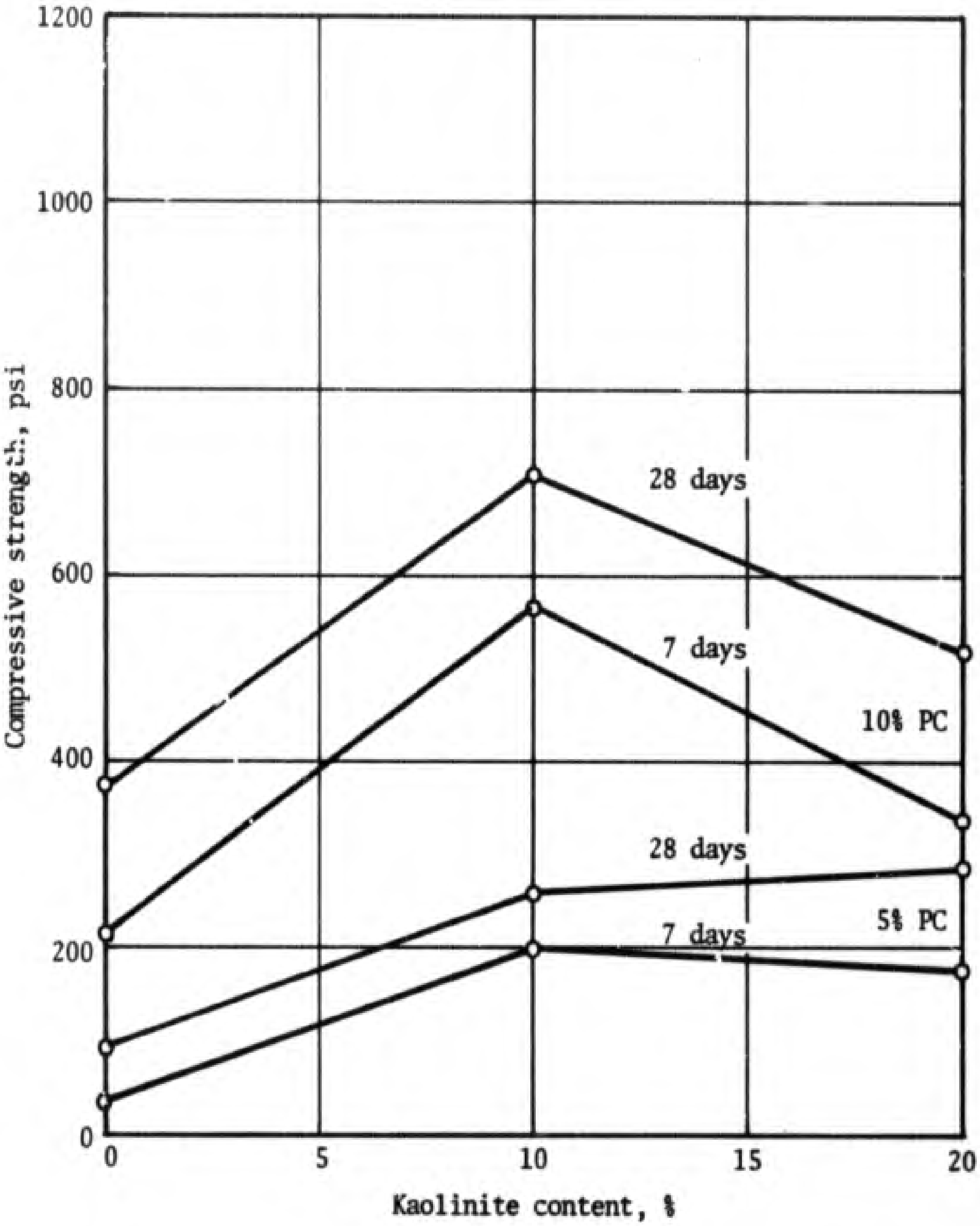


Figure 3. The effect of kaolinite additive on the compressive strength of soil-cement mixtures (portland cement), Tuy Hoa sample 1

a No. 20 sieve. The sand, sample 2 from Tuy Hoa, was added in the amount of 25 percent of the oven-dry weight of the clayey soils, along with 5- and 10-percent portland cement. The 7-day compressive strengths of the soil-cement mixtures were more than doubled and increased as much as fourfold. These are good examples of the effect of soil gradation on soil-cement strength.

10. Soil-Aggregate Stabilization.

Twelve of the soil samples contained more than 25 percent of material coarser than 2 mm, and nine of these consisted of lateritic soils. The coarse-size material of all the samples except the "Jinglestone" aggregate (sample 2) was pulverized for additional tests.

Portions of the pulverized soil aggregate material from two soil samples were remixed with the fines to reconstitute the composition of the original soil material. These reconstituted soils were then tested with 5- and 10-percent portland cement admixture to compare the soil-cement strength of the total soil sample with that of the material passing a No. 20 sieve. The total soil sample 3 from Bien Hoa showed a strength more than 25 percent greater than the fine soil material for both 7- and 28-day curing times. The total soil sample 2 from Nakhon Phanom showed a strength more than five times greater than the fine soil material. To verify what has long been known, laterite makes a very good construction material; however, it is possible that the whole laterite nodules would make a much weaker aggregate-cement because some of the nodules are friable.

The pulverized material of two soil samples was tested with 5- and 10-percent portland cement additive to compare the pulverized aggregate material with the soil fines where the coarse material comprised the predominant portion of the soils (more than 70 percent). The pulverized aggregate material (a lateritic soil), sample 1 from Don Muang, showed four times the strength of the fine portion of the same soil, and the aggregate material from sample 3 from U Tapao showed twice the strength of the fine portion of the soil for 5-percent PC additive and more than a 10-percent increase for 10-percent additive. The composition of the aggregate and fines of the sample from U Tapao are similar except for the larger clay content of the fines. Soil-cement made from the "Jinglestone" aggregate sample 2 would probably be similar to the soil-cement made from sample 3.

The indurated laterite comprising sample 4 from Nakhon Phanom was also pulverized and tested with 5- and 10-percent portland cement additive. It is apparent that sesquioxides of iron in soils do not interfere with portland cement hydration reactions and that while indurated laterite makes a good construction material, laterite-cement makes a better material.

The soil-cement strength data for all the soil-cement mixtures are tabulated in the appendix by site, and the soil cement mixtures that were tested after a curing time of 7 and 28 days are also given in the appendix as strength-time graphs.

SECTION III

SOIL MINERALOGY

1. Analysis Procedures.

X-ray identifications of soil minerals were made for all 34 soil samples; and when more than 25 percent of a soil sample consisted of material coarser than 2 mm, an additional mineral analysis of the coarse fraction was made. The quantitative determinations were based on relative X-ray diffraction intensities and were estimated by means of mineral calibration charts. The quantitative determinations were correlated with quantitative chemical analyses which were also made (see sec. I).

The float rock, sample 3 from Phan Rang, was identified as dolomitic limestone, but it was not considered as part of the soil mineral composition (as given in the appendix) because the soil appeared to be derived from igneous rock.

The soil samples were found to have a rather simple composition consisting mainly of quartz, perthite, kaolinite, illite, and geothite, or some combination of these minerals.

2. Silicates.

The predominant silicate minerals in the soil samples are quartz and feldspars. Quartz was found in all the soil samples, even in the indurated laterite, although the lateritic soils were found to contain lesser amounts, as was stated by Maignien (ref. 2). The feldspars in the soil samples were all perthitic feldspars consisting mainly of microcline with smaller amounts of plagioclase feldspar that has been tentatively identified as oligoclase.

The sands consisted mainly of quartz and perthite with some feldspar (as high as 25 percent). One sand, sample 1 from Cam Ranh Bay, was found to be very nearly pure quartz.

The quartz content of the soils, other than sands and lateritic soils, varied from about 25 to 50 percent of the oven-dry weight of the soils, except for the two samples of aggregate material from U Tapao; and the quartz content of the lateritic soils varied from 5 to 40 percent.

Only nine of the soil samples contained more than 5-percent perthite; sample 2 from Cam Ranh Bay contained nearly 30 percent.

3. Clay Minerals.

The predominant clay minerals in the soil samples were kaolinite and illite. The remainder of the clay minerals, listed in the appendix as "other clays," have been tentatively identified as mixed-layer clays and consist primarily of kaolinite-illite interlayered structures.

Some chlorite is believed to be present in the soils, especially in sample 4 from Phan Rang and sample 3 from Tuy Hoa. Where the detrital soil is not yet sufficiently altered by weathering, both chlorite and vermiculite may be found.

The kaolinite appeared to be partially hydrated in some of the soils, especially those from Nakhon Phanom and Phan Rang, and may exist partly as halloysite. The two minerals are listed together for those sites.

The illite content of the soils was estimated by comparing its 10.0Å (001) and 1.50Å (060) diffraction peak intensities with those of kaolinite and by noting the total clay-size content of the soil samples. Where the detrital soil was not badly weathered, the illite was reported as "mica-illite." The identification procedures suggested by Warshaw and Roy (ref. 27) were used to positively identify both illite and kaolinite.

4. Iron Sesquioxides.

Laterite is a general term used to describe naturally occurring mixtures consisting essentially of hydrated oxides of aluminum, iron, and titanium but often containing a considerable amount of dry minerals such as kaolinite or halloysite (ref. 12). The soil samples that were analyzed did not appear to contain significant amounts of gibbsite or any other aluminum oxide minerals.

All of the soil samples contained at least a small amount of ferric oxide, probably in the form of goethite. Often there was only sufficient ferric oxide present in the soils to color the soils reddish to yellowish shades. In no case was it possible to determine the ferric oxide content by soil color.

Nine of the soil samples could be classified as true lateritic soils, eight consisting largely of ferruginous nodules and one of indurated material. When there was sufficient ferric oxide to form ferruginous nodules, the ferric oxide was found to be present both as goethite and hematite. The estimated amounts of each were derived from the chemical analyses, given in table 2 and in the appendix. The remaining soil samples contained much smaller amounts of ferric oxide, ranging from 0.1- to 5.7-percent equivalent ferric oxide.

TABLE 2

PERCENT FERRIC OXIDE CONTENT OF LATERITES

Site and soil sample	Amount of soil smaller than 2 mm, %	Size of material	
		>2 mm	<2 mm
Bien Hoa 3	49.5	1.6	25.8
Tan Son Nhut 1	43.4	5.2	34.0
Don Muang 1	73.4	6.4	19.5
Nakhon Phanom 1	64.0	14.9	38.7
Nakhon Phanom 2	71.1	8.8	45.8
Nakhon Phanom 3	32.4	2.1	41.2
Nakhon Phanom 4	100.0	--	40.8
Ubon 3	41.9	6.8	30.3
Udorn 1	73.8	12.2	35.4

The amount of ferric oxide in the material finer than 2 mm is probably partially dependent on whether the soil was naturally formed or recently hauled in and mixed.

The formation of lateritic soils has been described by Maignien (ref. 2), but there is some question about the source of energy that forms the lateritic nodules, which consist mainly of concentric surfaces of kaolinite and goethite. The zeta potential of each soil mineral is dependent on the pH of the soil-water system (ref. 28). The isoelectric points for kaolinite and goethite are at pH 3.4 and 6.7, and all of the lateritic soil samples show pH readings that are between 3.5 and 6.5. It is possible that the nodules are formed by an electrokinetic method (electrophoresis), once the necessary minerals and climatic conditions exist.

5. Trace Minerals.

Small amounts of calcite and dolomite were found in the Phan Rang soil samples, less than 2 percent except for the previously mentioned dolomitic limestone float rock found in sample 3. About 10 percent of soil sample 2 from Cam Ranh Bay consisted of seashells, which were composed mainly of calcite and dolomite.

All of the lateritic soils contained small amounts of magnetite, which could be removed from the pulverized lateritic material with a magnet. Probably less than 2 percent of any lateritic soil was comprised of magnetite.

Only one soil, sample 2 from Nakhon Phanom, contained less than 5-percent gibbsite; and one soil, sample 2 from Don Muang, contained about 3-percent gypsum. Five soil samples contained small amounts of amphibole, and in three of these samples the amphiboles were identified as hornblende.

The leaching tests were made on the material finer than 2 mm from each soil sample. The soil was leached on No. 1 Whatman filter paper with boiling distilled water.

Because of the tropical, humid climate the soils contained little residual water-soluble material and very little organic matter. Only four soil samples contained more than 1-percent water-soluble material, which was not considered sufficient for further analyses. The organic content of the soil samples was less than 1 percent, except for three surface samples.

The results of the mineralogical analyses are given in the appendix by site.

SECTION IV

CORRELATION OF SOIL-CEMENT CONSTITUENTS

1. Grain-Size Distribution.

The soil-cement mixtures made with portland cement additive indicate that the compressive strength of the soil-cements is mainly dependent on the grain-size distribution, or grading, of the soil. Although the strength of the soil-cement also appears to be dependent on the ferric oxide content of the soils, this is only because the ferric oxide is largely incidental to the clay content of the soils. The high-compressive strength of the remolded laterite made from soil sample 4 from Nakhom Phanom proves this (appendix, p. 81). Although siliceous sand appeared to be a necessary component for high-early-strength soil-cement, the reconstructed lateritic soils which were tested also gave adequate soil-cement strengths (sec. II.10).

Nearly every type of soil, except organic, was represented by the soil samples. The Plasticity Index of the soils varied from N.P. to 37 percent and it was determined that the soil fines contained relatively inactive clays, as verified by X-ray diffraction analyses. The activity of the soils was determined for the fraction of the soils finer than 2 mm in size and was found to vary from zero for the sands to 0.74 for the lateritic soils.

2. Soil-Cement Strength.

The 7-day strength of the soil-cements appeared to be closely related to the soil gradation. The strongest soil-cements were found to have grain-size distribution curves that lay within rather narrow bounds, as shown by the envelope curves in figure 4. These soil-cements, with 7-day compressive strengths varying from 900 to 1,300 psi, did not include any lateritic soils. The strongest soil-cements were set apart from the rest of the soil-cement mixtures in that there were no mixtures with 7-day strengths from 700 to 900 psi.

The soil-cements with 7-day compressive strengths ranging from 500 to 700 psi lay within the bounds shown in figure 5. The mixtures with 500- to 600-psi compressive strength having soil-gradation curves that lay in the outer portions of the envelope curves and the mixtures with 600- to 700-psi compressive strength having soil-gradation curves that lay in the inner portion of the envelope curves are also shown in figure 5 as solid and dashed lines, respectively.

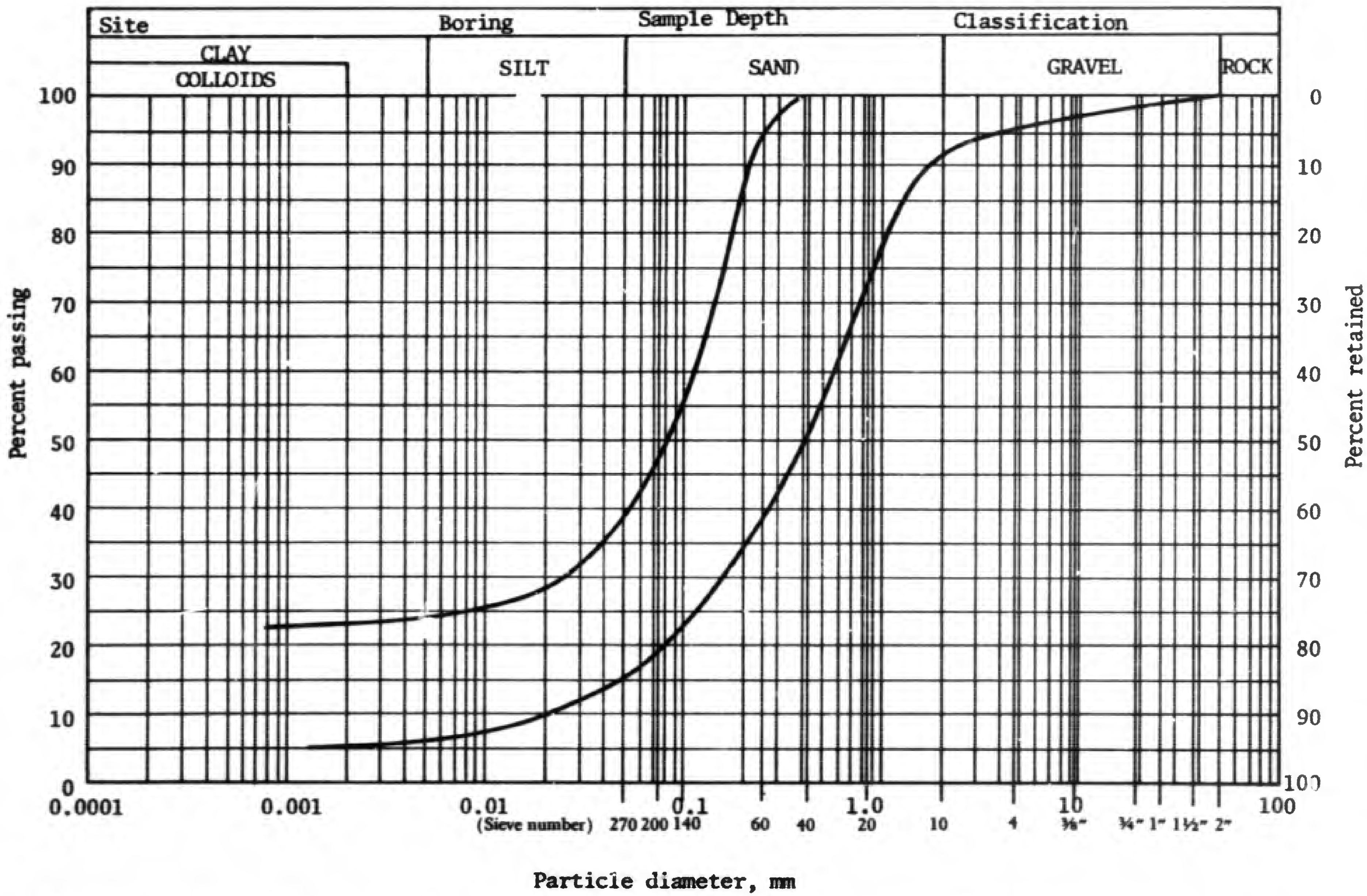


Figure 4. Grain-size distribution limits for soil samples giving 7-day compressive strengths of 900 to 1,300 psi in soil-cements with 10-percent portland cement

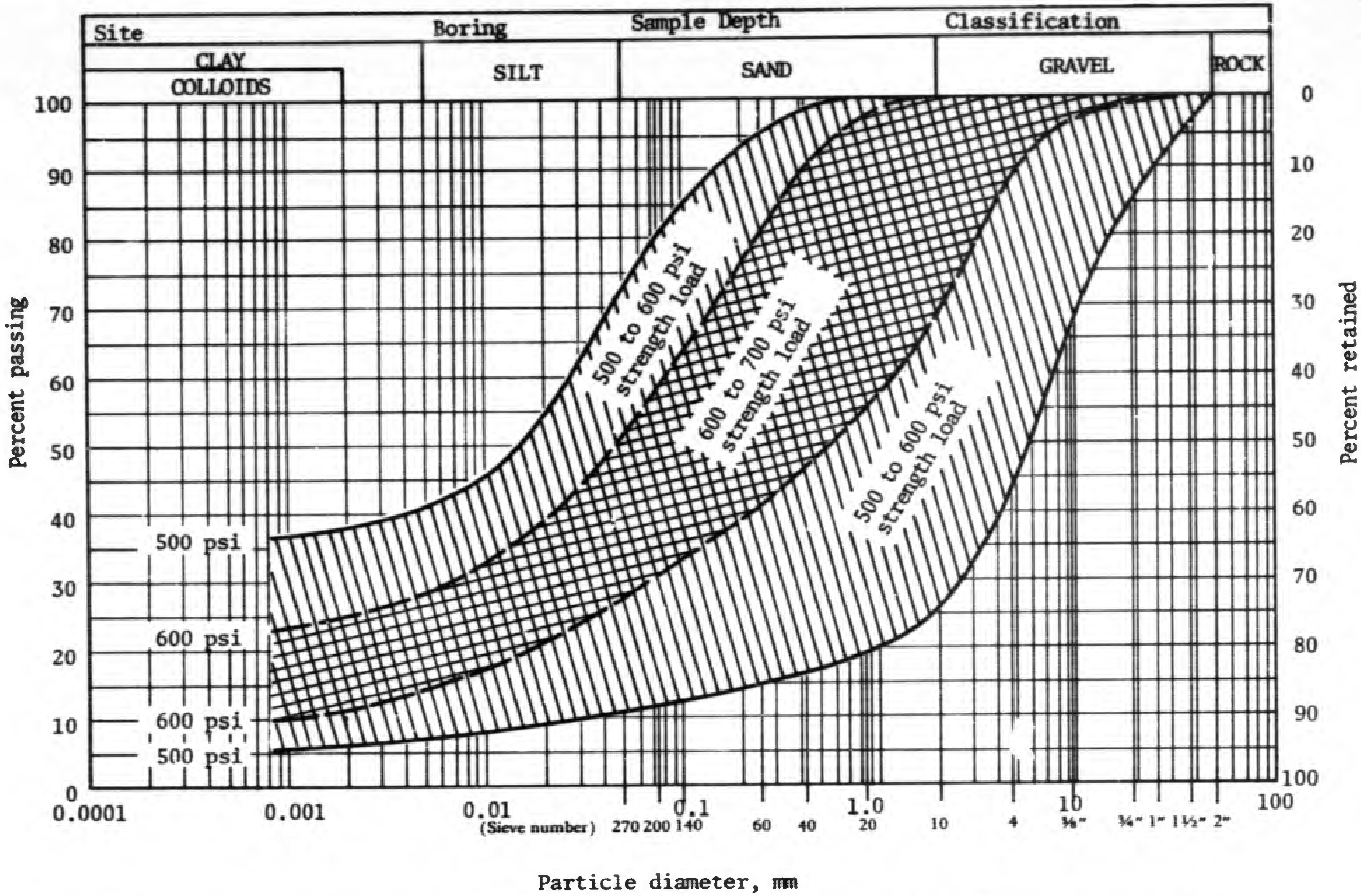


Figure 5. Grain-size distribution limits for soil samples giving 7-day compressive strengths of 500 to 700 psi in soil-cements with 10-percent portland cement

Any soil with a gradation curve that crosses any of the envelope curves shown in figure 5, except for the special cases previously discussed, had a soil-cement strength considerably less than those soils with gradation curves that tended to parallel the envelope curves. The soils with gradation curves that lay within the upper bounds tended to contain too much clay-size material, and the soils with gradation curves that lay within the lower bounds tended to contain too much coarse-size material.

It is possible to change soil gradations to meet stipulated soil-cement strength requirements, at least to gain a 7-day compressive strength of 500 psi and possibly more. As examples, four soil samples were mixed with different grain-size portions and two were reconstituted after the coarse-size fractions were pulverized. In each case stronger soil-cement mixtures resulted.

Some of the sandy soils contained no fines and thus exhibited low soil-cement strengths. Clay in the form of Florida kaolinite was added to two soil-cements as shown in figures 2 and 3. As was stated, the soil-cement strength increased with added clay until the soil voids were filled. Clayey soils may be used in the same manner to strengthen these soil-cements. When there is more than enough clay in a soil to fill the larger voids, the cement requirements increase with increased clay content (ref. 29).

Some of the clayey soils contained very little sand-size material and also exhibited low soil-cement strengths. A portion of the two soil samples from Don Muang were mixed with an admixture of 25-percent sand (100-gram soil plus 25-gram sand) along with 10-percent portland cement, the sand used being from Tuy Hoa sample 2. The resultant gradation curve for the soil mixture is shown in figure 6, along with the grain-size distribution curves for the two original soil samples (dashed lines). It may be seen that the gradation curve for the soil mixture lies within the upper bounds of the envelope curves in figure 5 but that it cuts across the 600-psi limiting envelope. A soil-cement strength somewhat greater than 500 psi might be predicted for the mixture; and, in fact, a 7-day compressive strength of 539 psi was attained with a 10-percent portland cement admixture.

The soil mineral constituents were in most cases inert in that they did not appear to affect the soil-cement reactions. An exception to this were the sea-shells in sample 2 from Cam Ranh Bay and possibly the gypsum in sample 2 from Don Muang. As was stated, the minor constituents of sands probably react with the portland cement because of a lack of clay minerals in the soil.

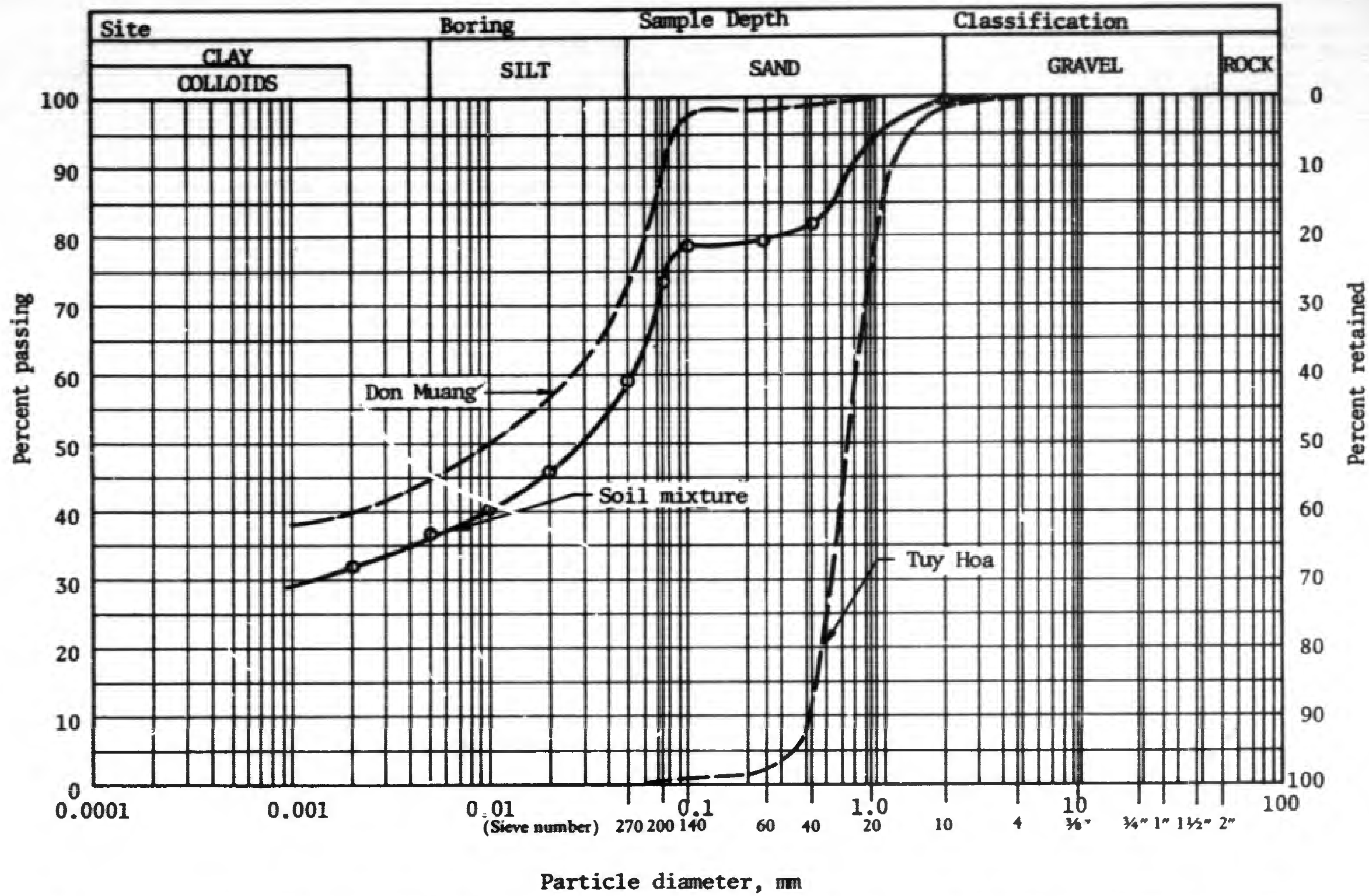


Figure 6. Grain-size distribution curve for soil mixture consisting of 80 percent of sample 2 from Don Muang and 20 percent of sample 2 from Tuy Hoa

Figure 7 shows the maximum soil-cement compressive strengths that may be realized when the most beneficial soil-gradation conditions are obtained. It is of course possible that additional soil samples from the same area having ideal soil gradations might show somewhat higher soil-cement strengths.

Although soils that are very well graded may be expected to give higher soil-cement strengths, this was not found to be so with the soils that were tested. The clay portion of the soils consists of platelets rather than well-rounded anhedral particles so that the soil gradation giving the densest structure will not hold as much clay as might otherwise be expected. Well-graded soils with grain-size distribution curves that cut across the envelope curves shown in figure 5 always showed lower strengths than those that paralleled the envelope curves, especially when an excess of clay was present.

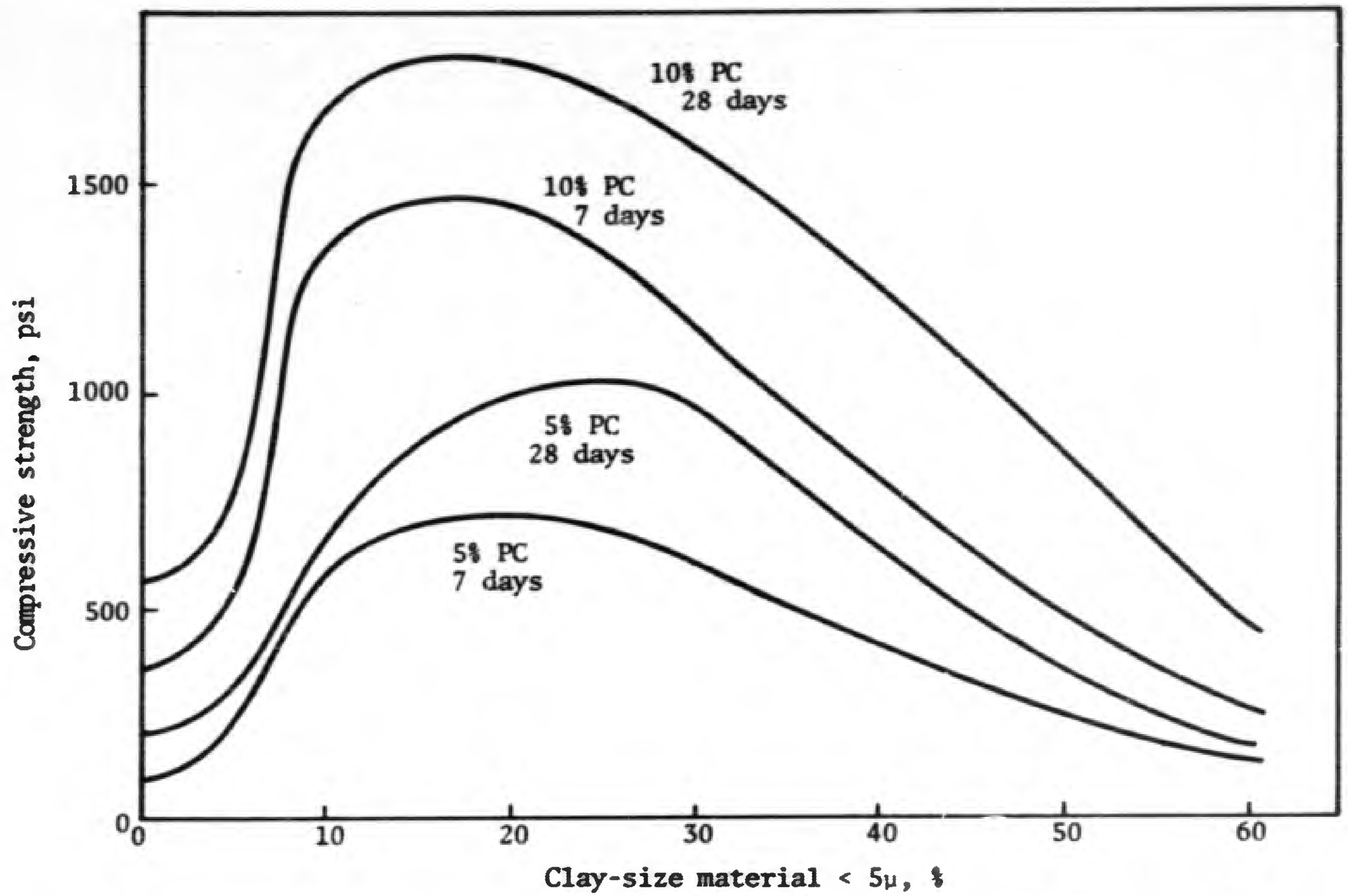


Figure 7. Effect of clay-size content on maximum compressive strength of soil-cement made from SEA soils with U.S. portland cement cured for 7 and 28 days

SECTION V

SUMMARY AND RECOMMENDATIONS

1. Summary.

The soil samples from Southeast Asia that were tested represented a wide variety of common soil types but did not include any with large amounts of organic material or swelling clays. The two most common soil types received were sandy soils and lateritic soils. Most of the samples were classified as non-plastic or CL in the Unified Soil Classification.

The soil samples were composed mainly of quartz, perthite, kaolinite, illite, and goethite, or some combination of these minerals. The sands consisted mainly of quartz, with some feldspar contents as high as 25 percent. The lateritic soils consisted mainly of kaolinite and goethite. The remaining soils consisted mainly of quartz, kaolinite, and illite. Some of the soil samples also contained small amounts of hematite, calcite, and other minerals.

Portland cement additive was found to be the most effective soil stabilization agent that gave adequate (250 to 300 psi) 28-day compressive strength to the soil-cement mixtures when using ASTM standard compactive effort. It was found that about half of the soil-cement mixtures could be given an adequate strength with a 5-percent admixture and that a 10-percent admixture was satisfactory for all but four of the soil samples: two from Cam Ranh Bay containing uniformly graded sand, and two from Nakhon Phanom containing lateritic nodules with little sand-size material.

Calcite and hematite proved to be destructive to the soil-cements made with portland cement only when no clay minerals determined by mineralogical analyses were present to react with the cement. Lime proved to be of little value in forming soil-cements of adequate strength and rather destructive when used with portland cement. Aluminous cement additive was effective with some soils of low quartz content, but it was not very reliable.

The Thailand portland cement and lime products were found to be of good quality, the lime in particular being quite pure calcium hydroxide and superior to the U.S. dolomitic dihydrate lime product locally acquired. Both the portland cement and lime gave comparably good results when used as soil-cement additives. Lime is found to be useful for preliminary treatment in controlling soil moisture and in reducing soil plasticity.

The compressive strength of the soil-cements was found to be dependent mainly on gradation, or grain-size distribution, of the soils and was not affected adversely by the sesquioxides that largely comprise the lateritic soils. It was found that the compressive strength of the soil-cement mixtures, including the four mentioned above, could be increased simply by improving the soil-gradation characteristics of the soil samples.

2. <u>Recommendations</u>.

It is recommended that additional tests be made with Southeast Asia soils to more accurately delineate the most beneficial soil gradations for adequate soil-cement compressive strengths. The effect of varied amounts of compactive energy on these soil-cement mixtures should also be investigated.

APPENDIX

TEST DATA SUMMARY BY SITE

BIEN HOA

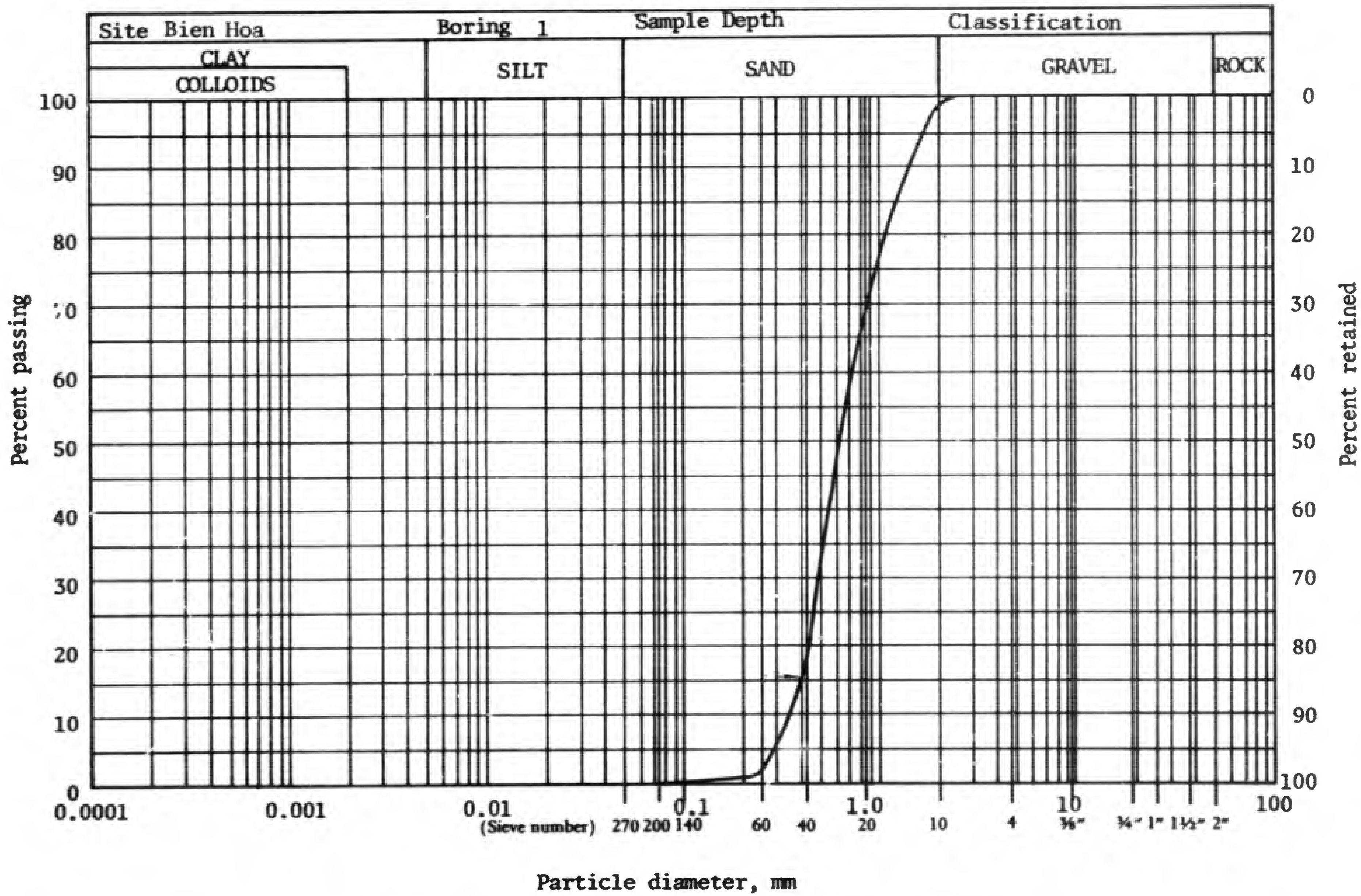


Figure 8. Grain-size distribution curve, Bien Hoa sample 1

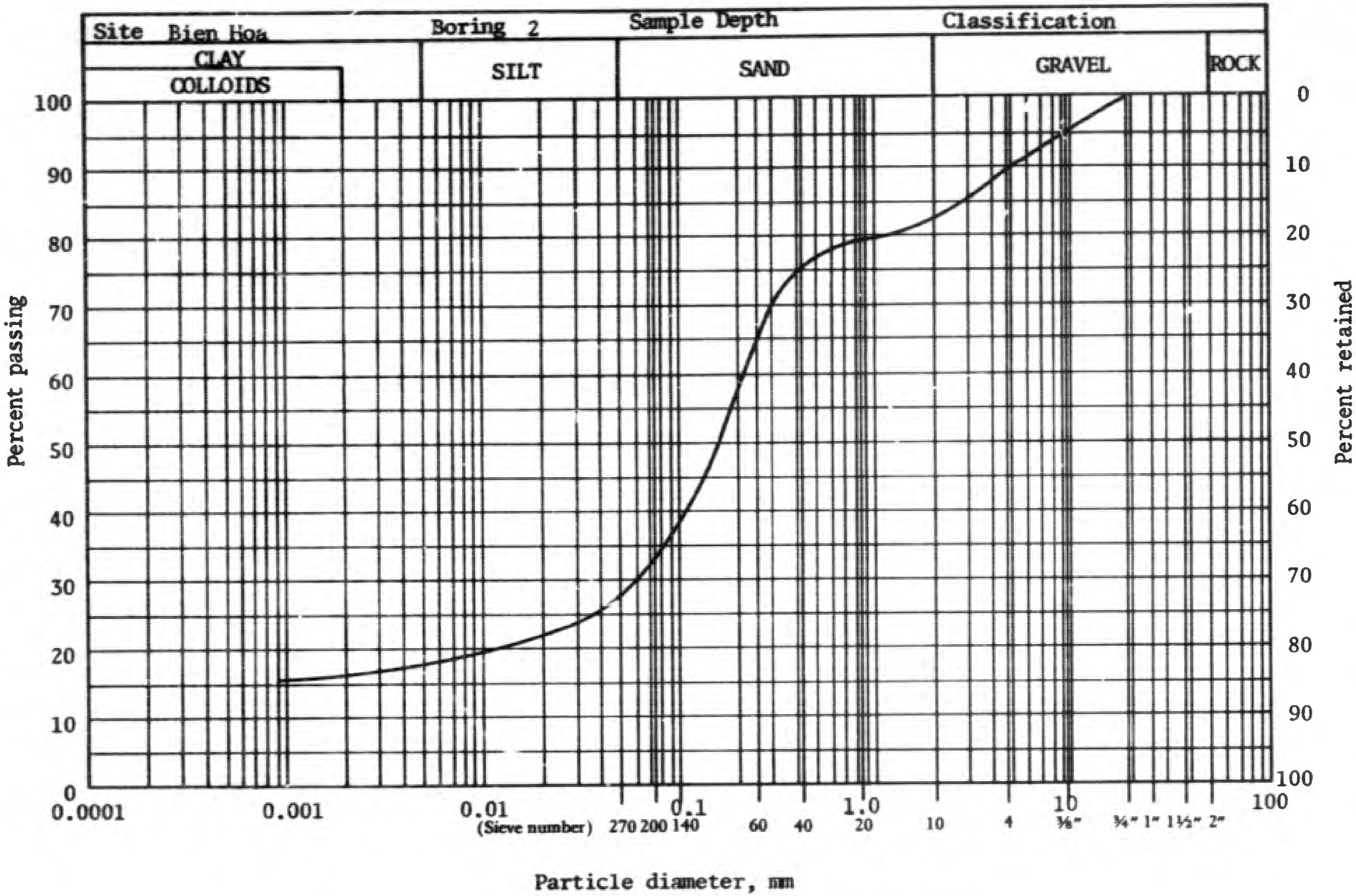


Figure 9. Grain-size distribution curve, Bien Hoa sample 2

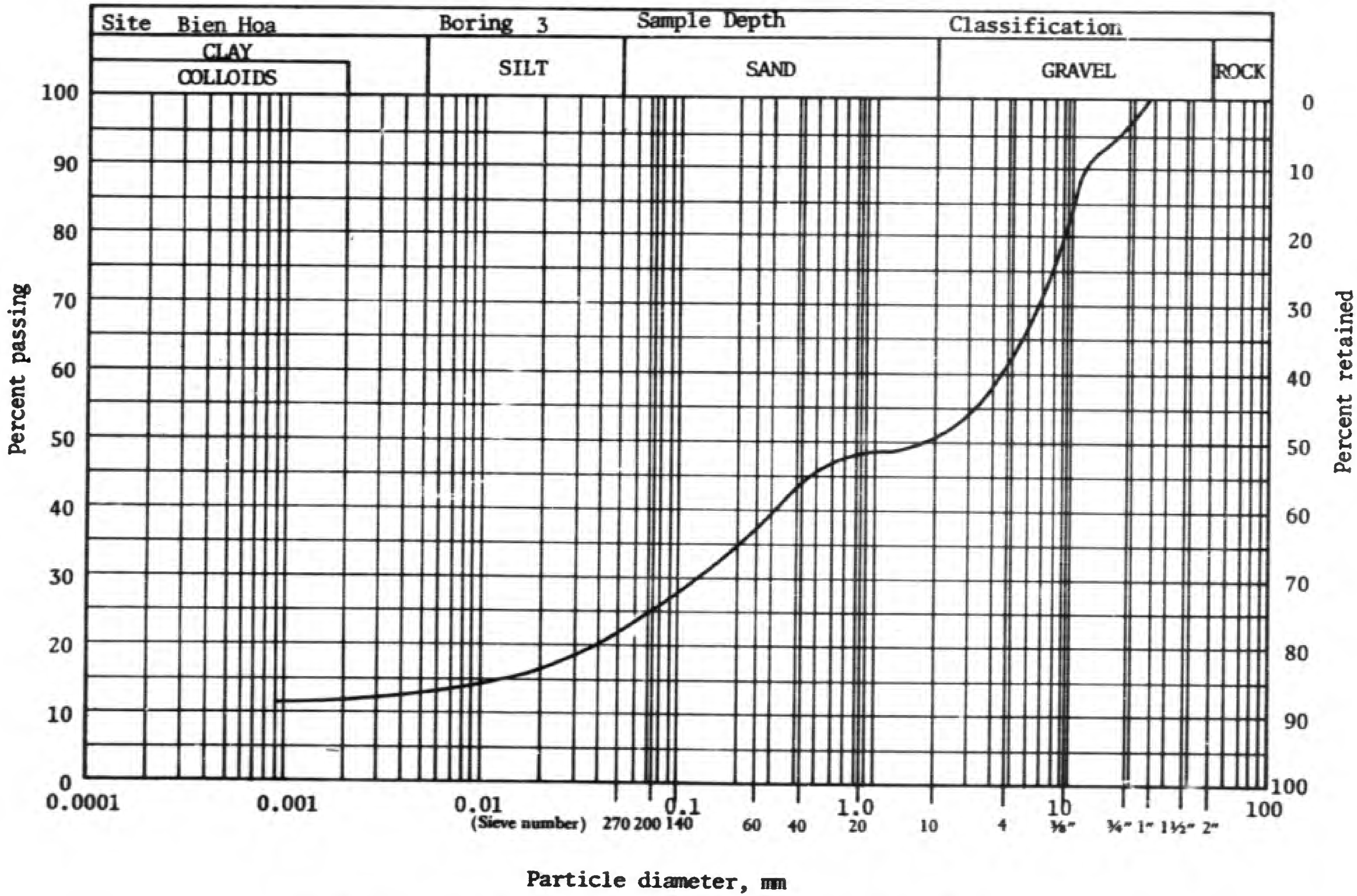


Figure 10. Grain-size distribution curve, Bien Hoa sample 3

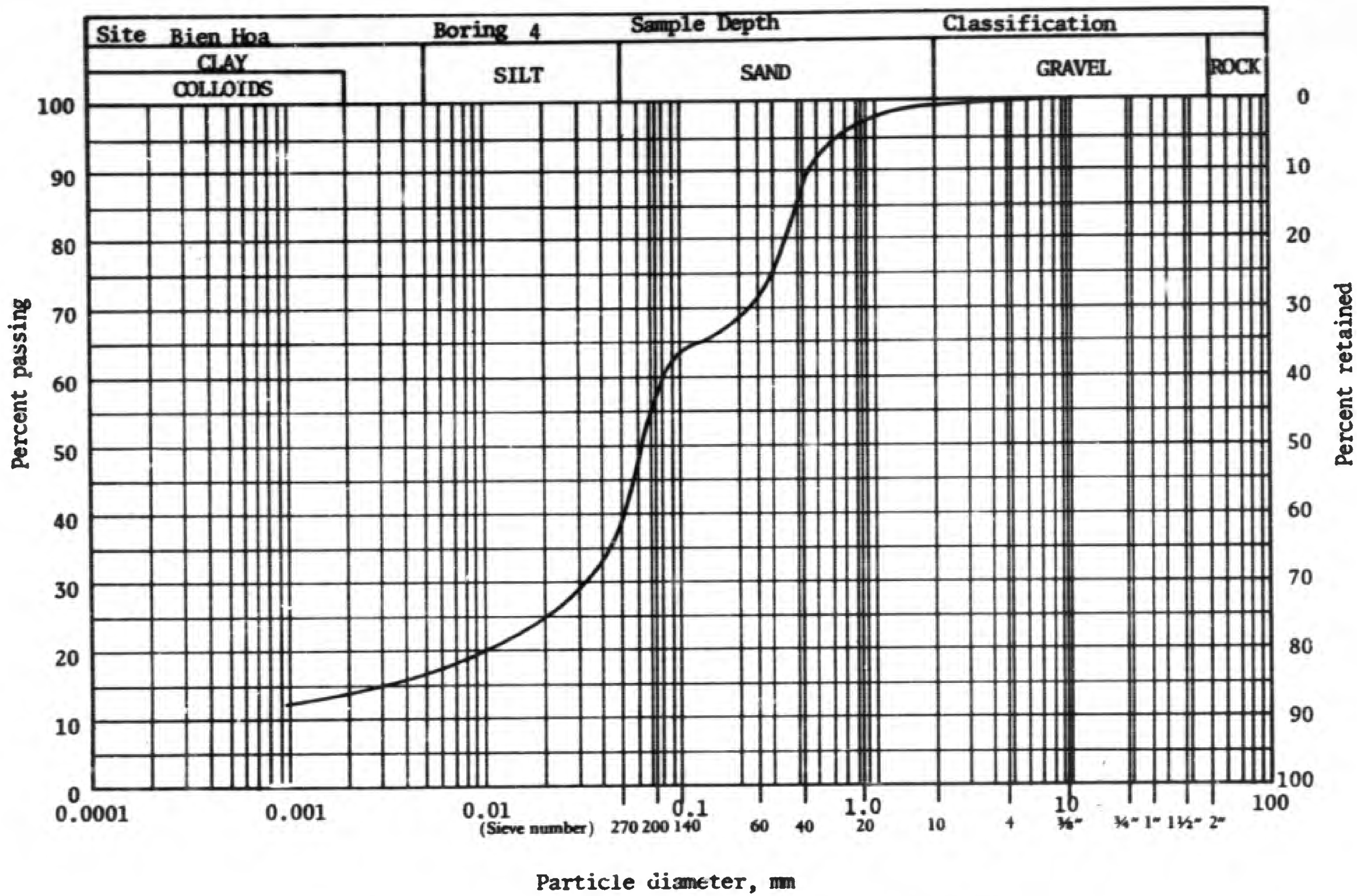


Figure 11. Grain-size distribution curve, Bien Hoa sample 4

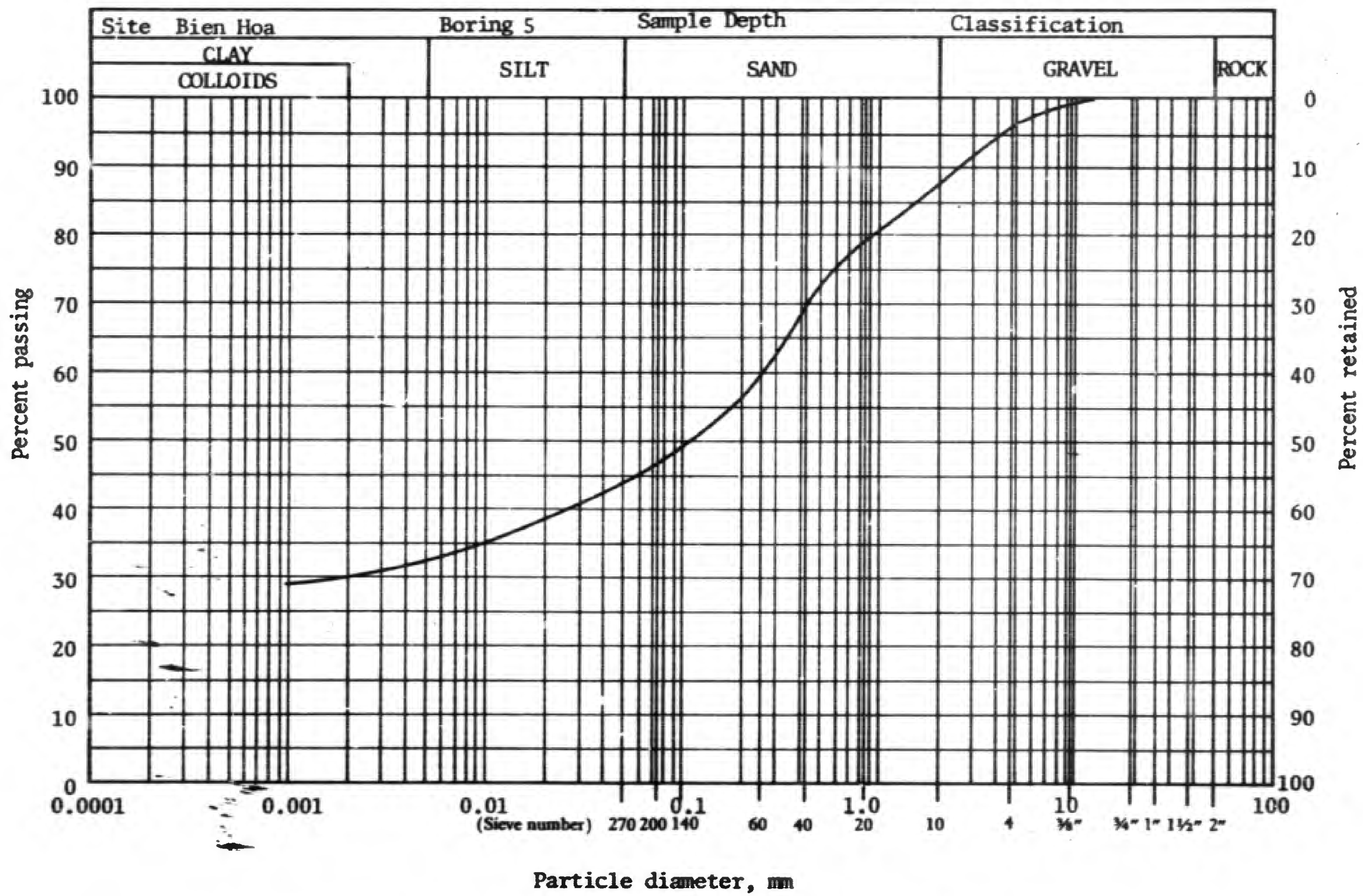


Figure 12. Grain-size distribution curve, Bien Hoa sample 5

TABLE 3

PROPERTIES OF SOILS FROM BIEN HOA

Soil Sample:	1	2	3	4	5
Textural Composition: %					
Sand (2.0-0.05 mm)	100	54	29	61	43
Silt (50-5 μ)	--	10	9	21	12
Clay (<5 μ)	--	18	13	17	32
Classifications:					
Unified	SP	SC	GC	SM	SC
AASHO	A-1-b[0]	A-2-4[0]	A-2-4[0]	A-4[4]	A-6[4]
Physical Properties:					
Liquid limit, %	--	18	24	11	36
Plastic limit, %	--	15	15	--	20
Plasticity Index, %	N.P.	3	9	N.P.	16
Activity[1,2]	--	0.15	0.38	--	0.46
Specific gravity[1]	2.62	2.59	2.63	2.59	2.68
ASTM standard compaction:[3]					
Dry density, lb/cu ft	96.0	122.0	121.5	125.0	110.0
Optimum moisture content, %	10.0	11.5	12.5	9.5	17.5
Chemical Properties:[1]					
Equivalent Fe_2O_3, %	0.5	1.2	1.6	0.4	5.7
Total soluble salt, %	0.5	0.4	0.5	0.6	0.4
Organic matter, %	--	0.7	0.3	0.3	0.1
pH	6.95	6.40	5.20	6.10	6.50

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 4

SOIL MINERALOGY, BIEN HOA

Mineral, %	Sample: 1	2	3	4	5
Fraction Passing No. 10 Sieve, %	98.8	82.1	50.5	99.4	86.9
Quartz	70	70	70	75	35
Feldspar (perthite)	25	--	2	--	--
Kaolinite	--	20	20	15	35
Illite	--	2	3	--	--
Goethite	0.6	1.4	1.8	0.5	6.3
Other minerals:	--	--		--	--
Other clays			3		
Fraction Retained on No. 10 Sieve					
Quartz	--	--	30	--	--
Feldspar (perthite)	--	--	5	--	--
Kaolinite	--	--	10	--	--
Illite	--	--	10	--	--
Goethite	--	--	25.3	--	--
Other minerals:	--	--		--	--
Other clays			5		
			Percent		
Moisture content of samples when received	1.6	8.4	7.4	6.7	13.2
Air-dry moisture content of material finer than 2 mm	0.2	0.6	0.8	0.3	4.3
Air-dry moisture content of material coarser than 2 mm	--	--	0.8	--	--

TABLE 5

STABILIZATION OF SOILS FROM BIEN HOA[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.010	0.021	29	77
	10.0% PC	0.015	0.014	243	292
	5.0% PC + 2.0% Fe_2O_3	0.018	0.019	68	49
	5.0% PC + 5.0% Fe_2O_3	0.014	0.010	22	47
	10.0% PC + 5.0% Fe_2O_3	0.020	0.016	175	310
2	5.0% PC	0.017	0.014	121	110
	10.0% PC	0.016	0.027	294	381
	5.0% Thailand PC	0.015	0.014	133	181
3	5.0% PC	0.016	0.016	255	337
	10.0% PC	0.024	0.024	537	678
	5.0% PC[2]	0.020	0.020	332	483
4	5.0% PC	0.020	0.024	326	216
	10.0% PC	0.029	0.070	629	808
	4.0% lime	0.015	0.012	13	21
5	5.0% PC	0.017	0.020	331	430
	10.0% PC	0.022	0.031	502	700
	4.0% lime	0.009	0.023	14	9

[1]Determined for the fraction passing No. 20 sieve.

[2]Material retained on No. 20 sieve pulverized and original soil reconstituted.

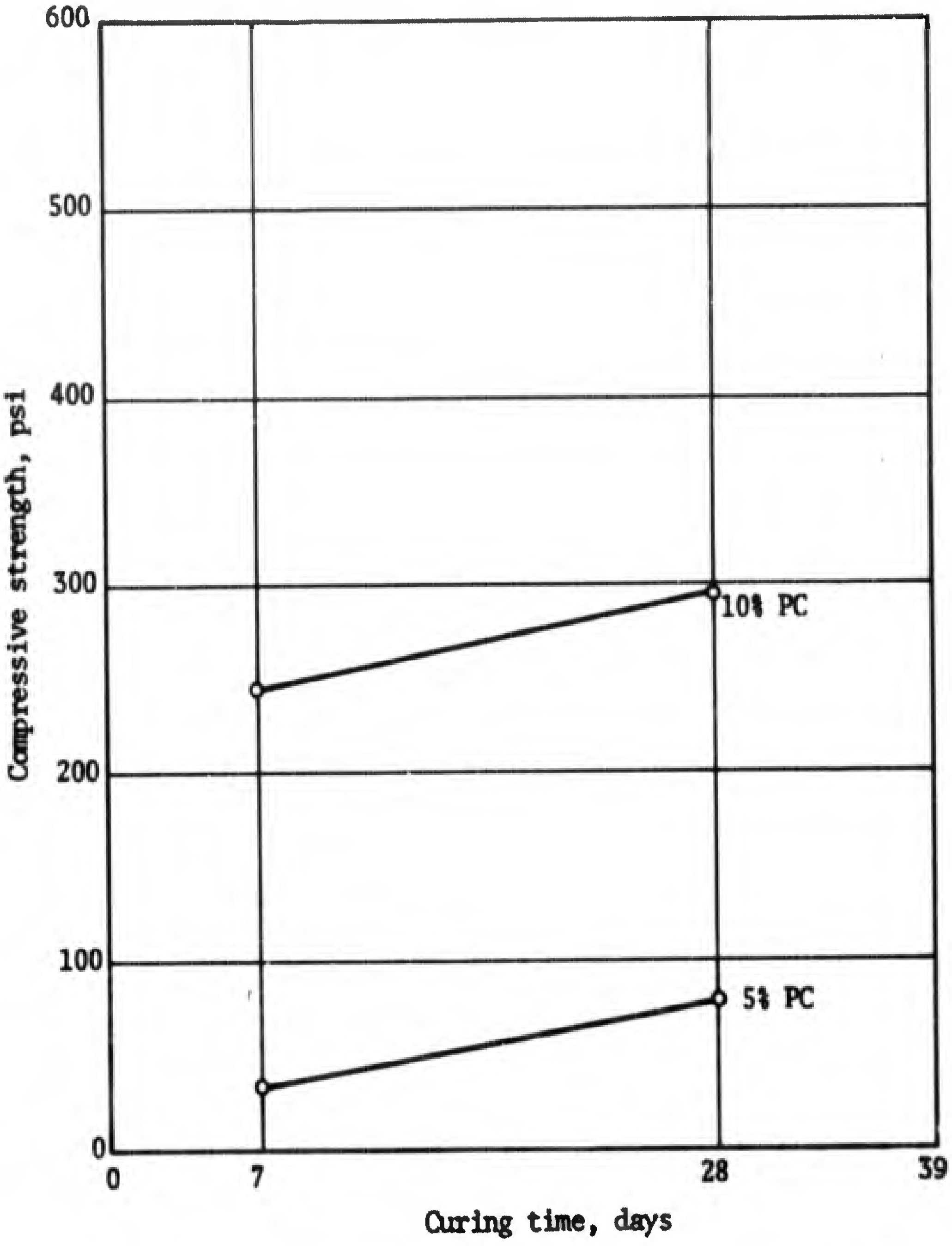


Figure 13. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Bien Hoa sample 1

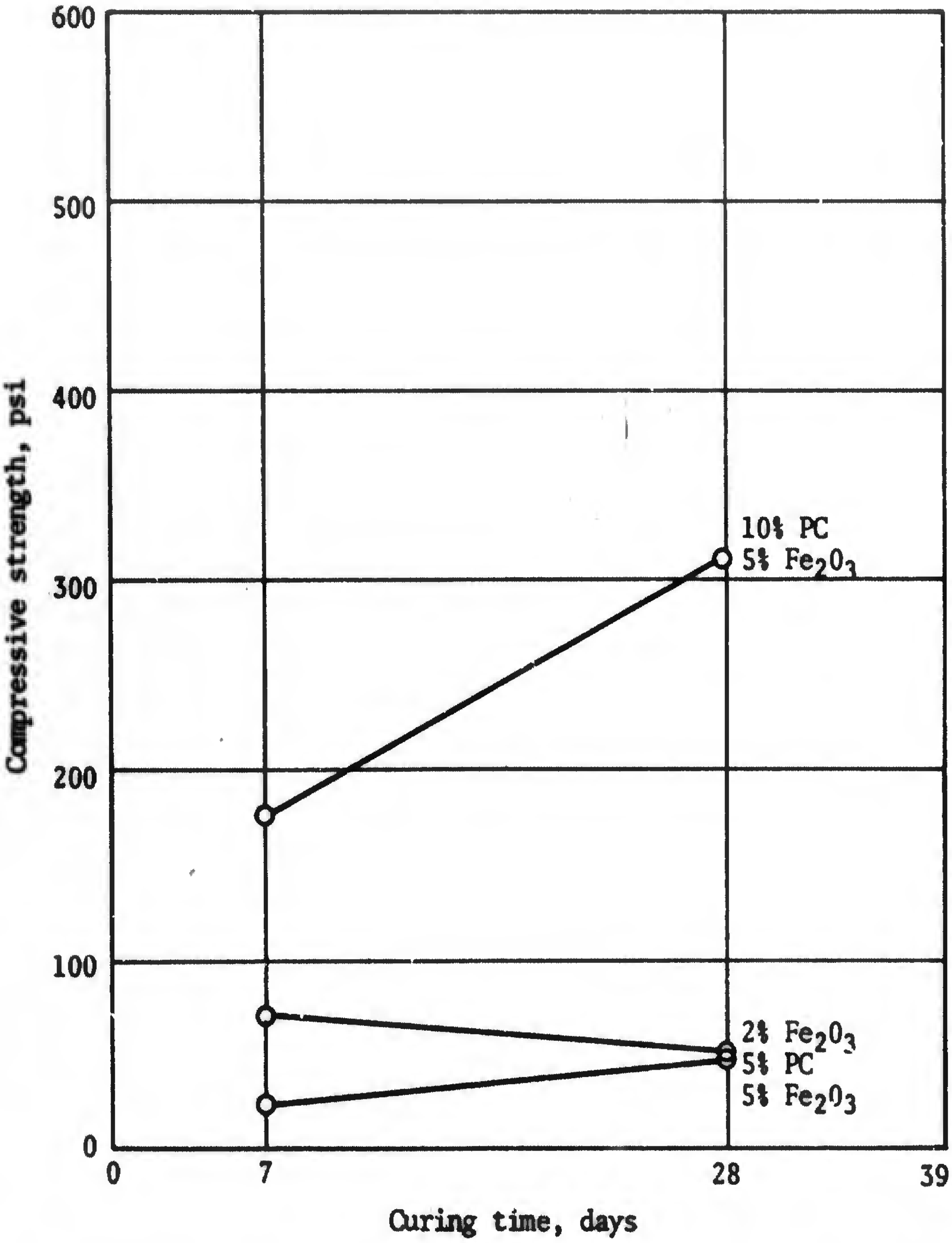


Figure 14. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement-hematite), Bien Hoa sample 1

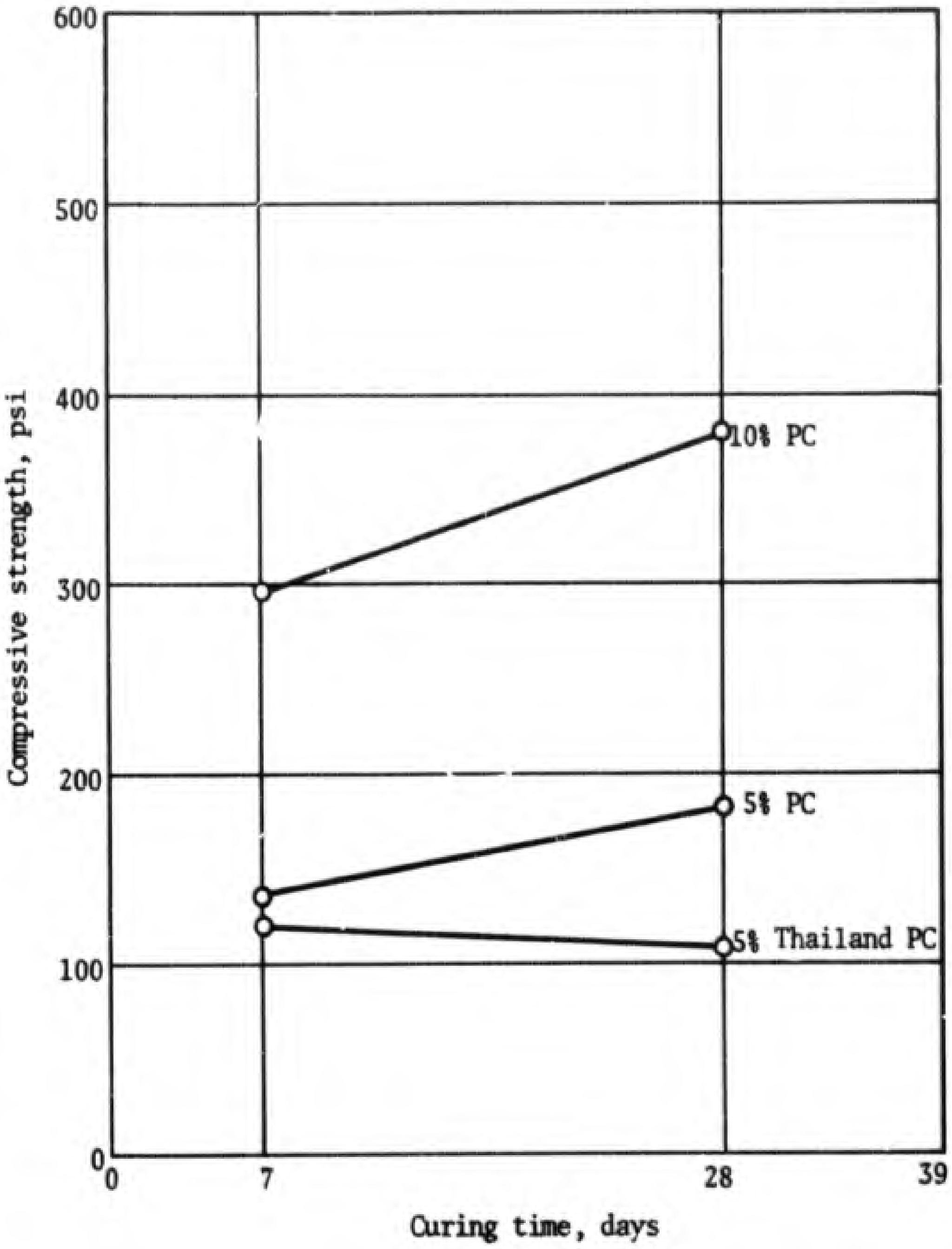


Figure 15. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Bien Hoa sample 2

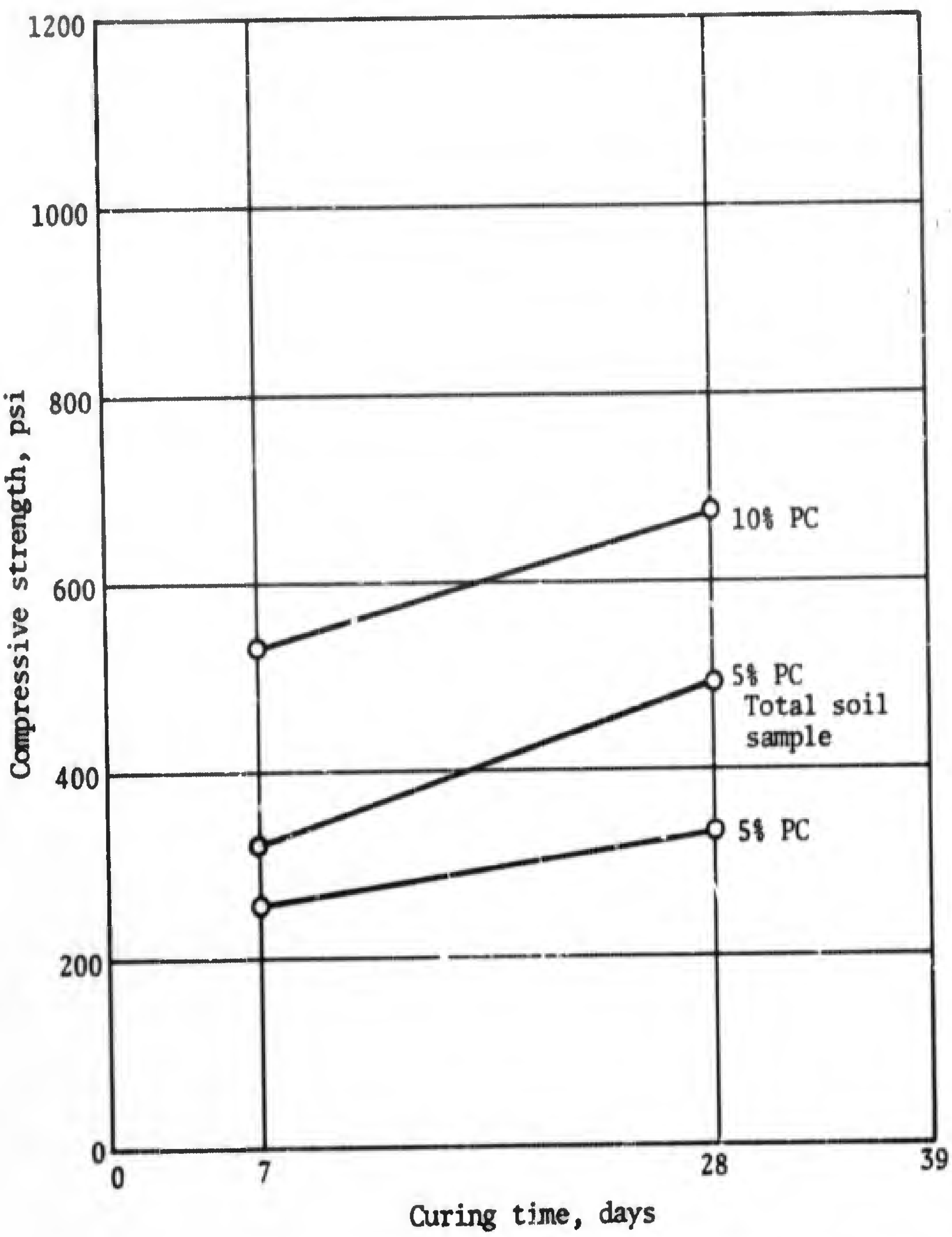


Figure 16. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Bien Hoa sample 3

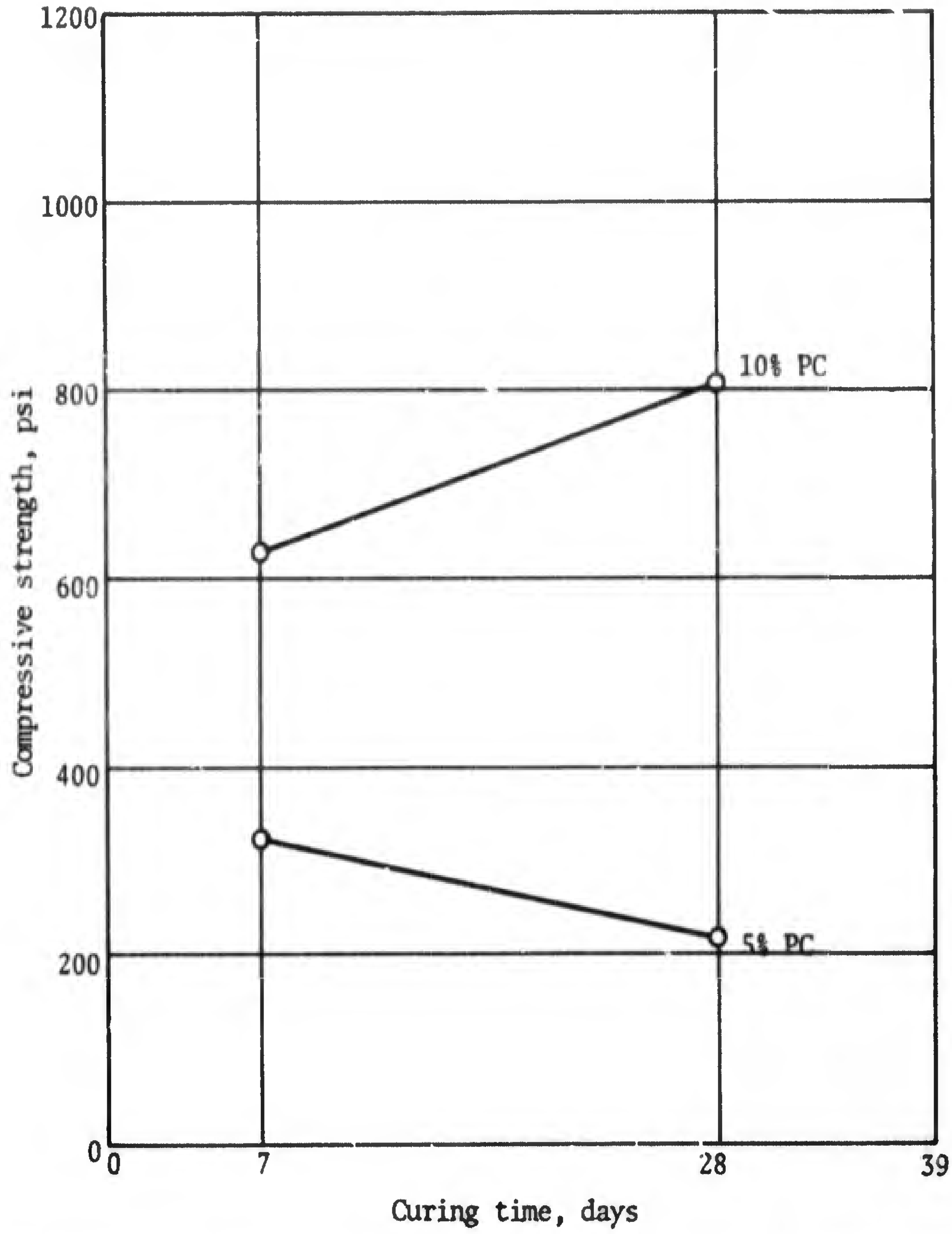


Figure 17. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Bien Hoa sample 4

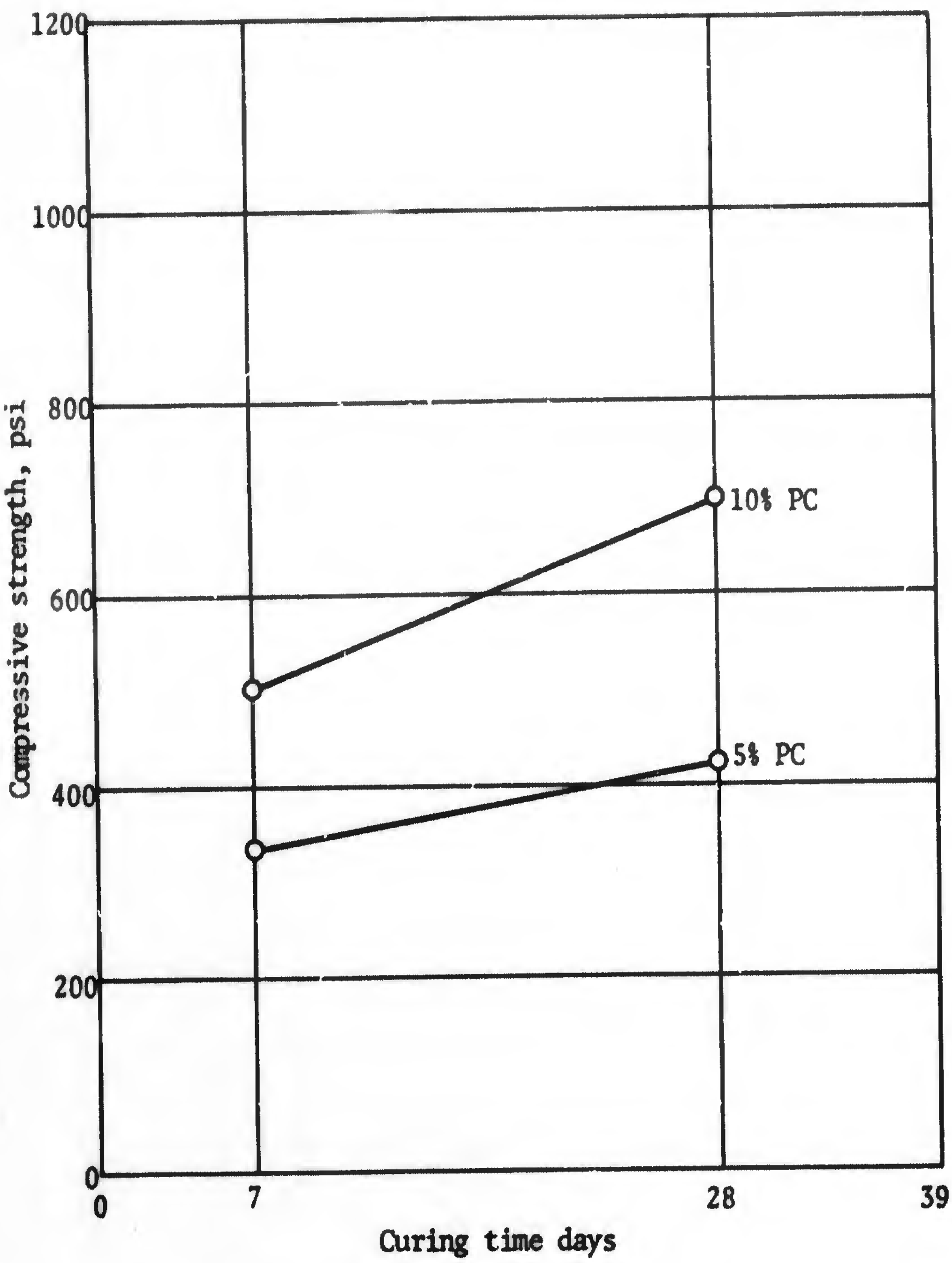


Figure 18. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Bien Hoa sample 5

CAM RANH BAY

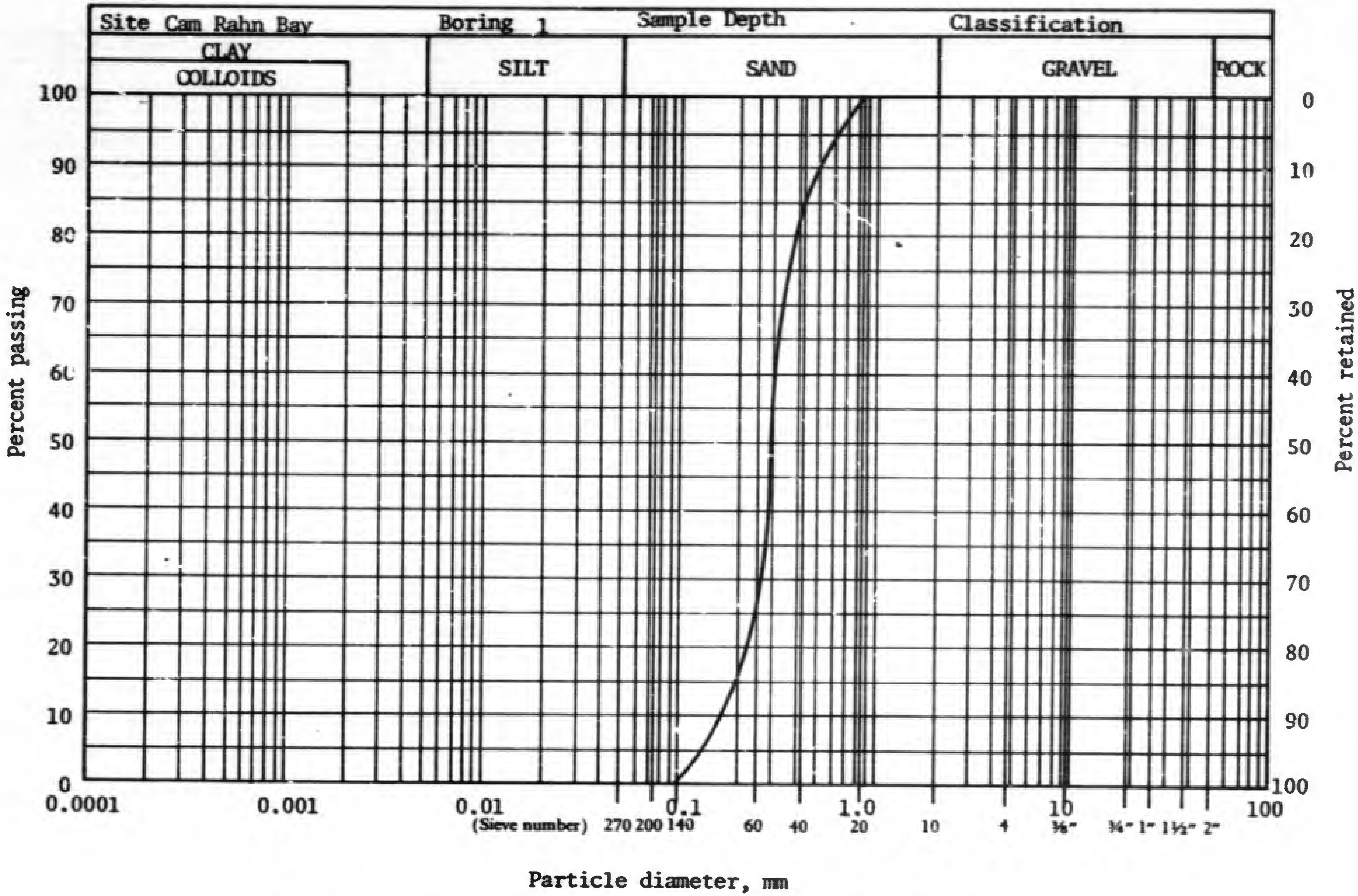


Figure 19. Grain-size distribution curve, Cam Ranh Bay sample 1

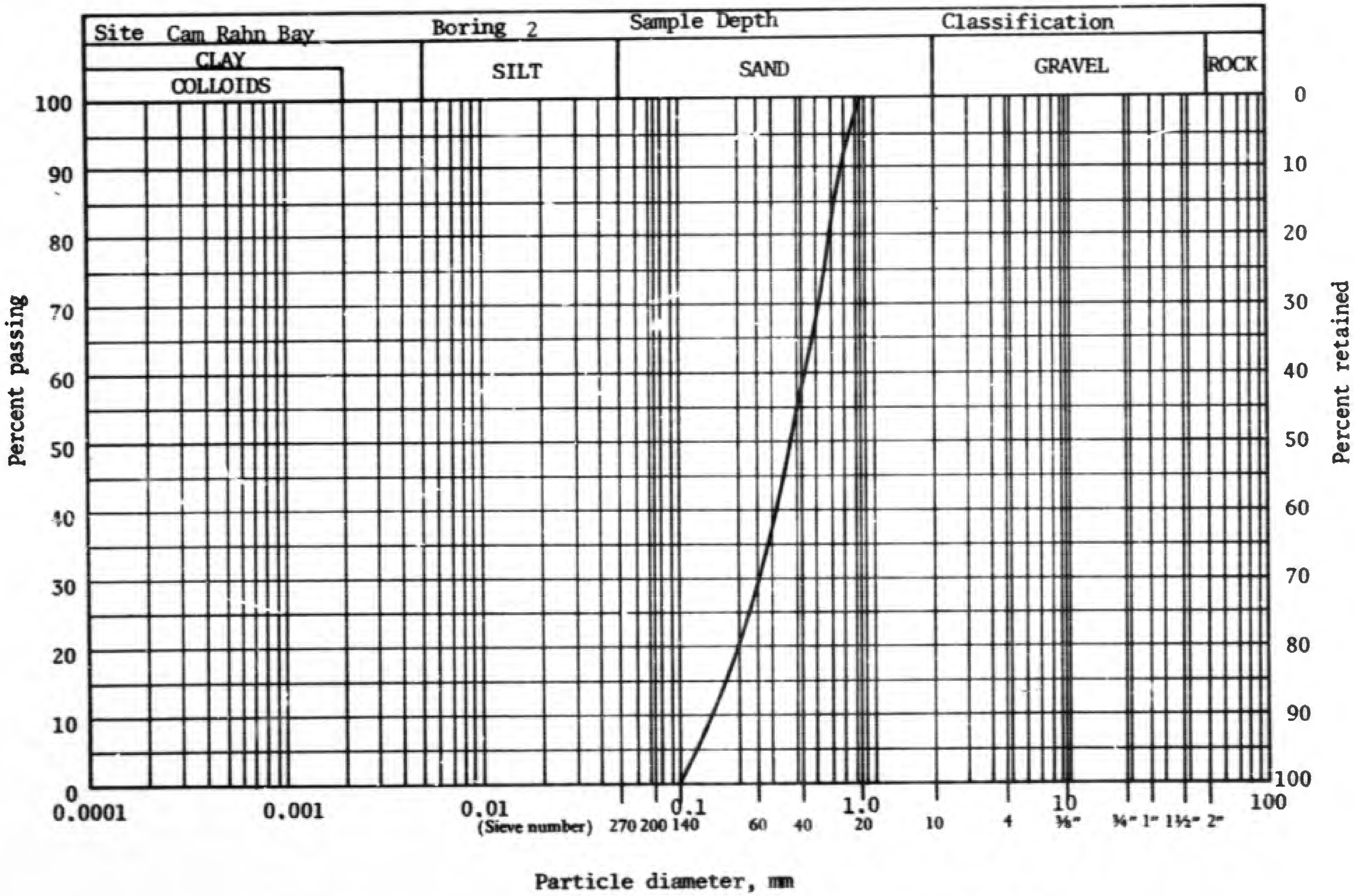


Figure 20. Grain-size distribution curve, Cam Ranh Bay sample 2

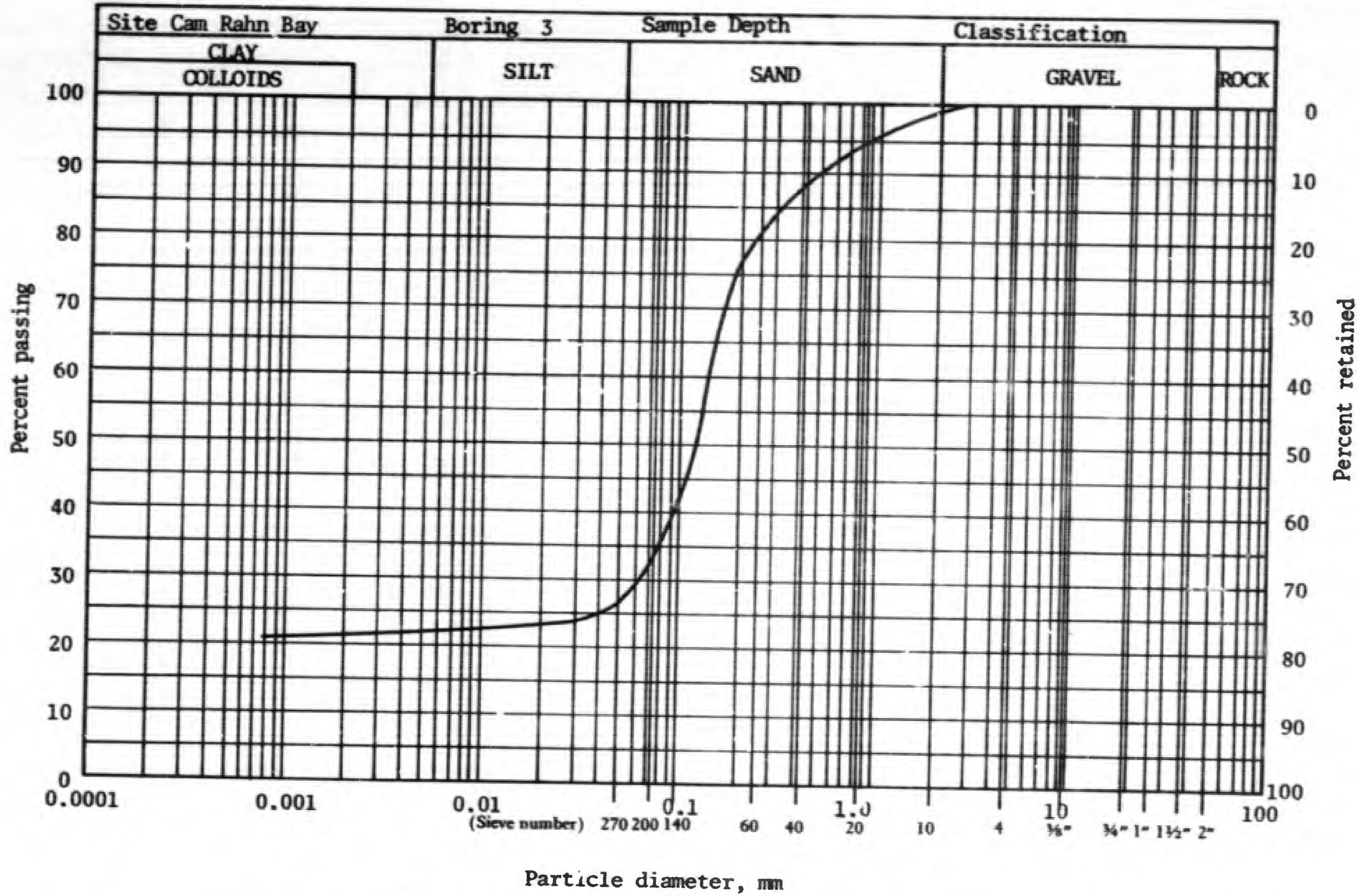


Figure 21. Grain-size distribution curve, Cam Ranh Bay sample 3

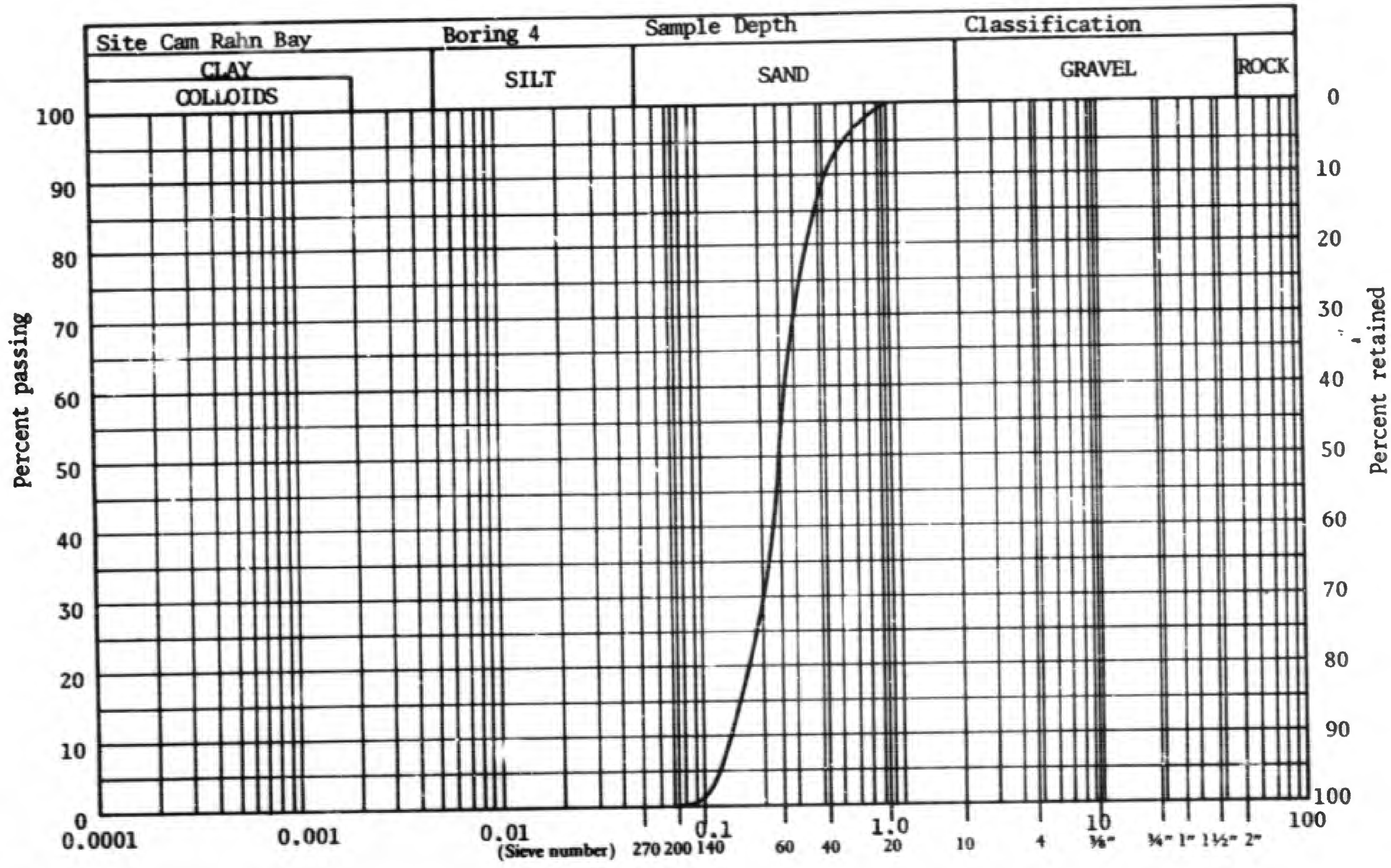


Figure 22. Grain-size distribution curve, Cam Ranh Bay sample 4

TABLE 6

PROPERTIES OF SOILS FROM CAM RANH BAY

Soil Sample:	1	2	3	4
Textural Composition: %				
Sand (2.0-0.05 mm)	100	100	72	100
Silt (50-5 μ)	--	--	4	--
Clay (<5 μ)	--	--	22	--
Classifications:				
Unified	SP	SP	SM	SP
AASHO	A-3[0]	A-3[0]	A-2-4[0]	A-3[0]
Physical Properties:				
Liquid limit, %	--	--	14	--
Plastic limit, %	--	--	--	--
Plasticity Index, %	N.P.	N.P.	N.P.	N.P.
Activity[1,2]	--	--	--	--
Specific gravity[1]	2.62	2.60	2.62	2.63
ASTM standard compaction:[3]				
Dry density, lb/cu ft	104.0	99.0	125.0	99.5
Optimum moisture content, %	15.0	10.0	10.0	10.0
Chemical Properties:[1]				
Equivalent Fe_2O_3, %	0.6	0.2	0.8	0.1
Total soluble salt, %	0.8	0.7	1.0	0.9
Organic matter, %	--	--	0.1	0.4
pH	6.93	7.00	7.00	7.10

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 7

SOIL MINERALOGY, CAM RANH BAY

Mineral, %	Sample: 1	2	3	4
Fraction Passing No. 10 Sieve, %	100.0	100.0	98.7	100.0
Quartz	98	55	65	85
Feldspar (perthite)	--	30	2	10
Kaolinite	--	--	20	--
Illite-mica	--	3	2	--
Goethite	0.6	0.2	0.9	0.1
Other minerals:	--		--	--
Calcite		6.5		
Dolomite		3.3		
		Percent		
Moisture content of samples when received	3.4	2.0	3.2	3.3
Air-dry moisture content of material finer than 2 mm	0.1	0.1	0.4	0.2

Note: The carbonate minerals in sample 2 occur in seashells.

TABLE 8

STABILIZATION OF SOILS FROM CAM RANH BAY[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.011	0.015	76	119
	10.0% PC	0.013	0.017	285	235
	5.0% PC + 2.0% Fe_2O_3	0.016	0.018	80	68
	5.0% PC + 5.0% $CaCO_3$	0.016	0.007	4	18
	10.0% PC + 5.0% $CaCO_3$	0.016	0.009	396	58
	5.0% PC + 10.0% clay[2]	0.011	0.013	125	287
	5.0% PC + 20.0% clay[2]	0.016	0.018	419	462
	10.0% PC + 10.0% clay[2]	0.020	0.027	459	928
	10.0% PC + 20.0% clay[2]	0.027	0.027	863	1053
2	5.0% PC	0.010	0.012	38	105
	10.0% PC	0.020	0.017	327	476
	5.0% PC + 2.0% Fe_2O_3	0.020	0.017	29	59
	5.0% PC + 5.0% Fe_2O_3	0.013	0.017	60	63
	10.0% PC + 5.0% Fe_2O_3	0.022	0.024	312	396
3	5.0% PC	0.023	0.024	407	588
	10.0% PC	0.036	0.042	966	1157
	4.0% lime	0.014	0.013	13	14
4	5.0% PC	0.010	0.015	27	48
	10.0% PC	0.011	0.024	73	253
	5.0% Lumnite	0.012	0.009	61	8
	10.0% Lumnite	0.020	0.008	381	24

[1]Determined for the fraction passing No. 20 sieve.

[2]Florida kaolinite was used.

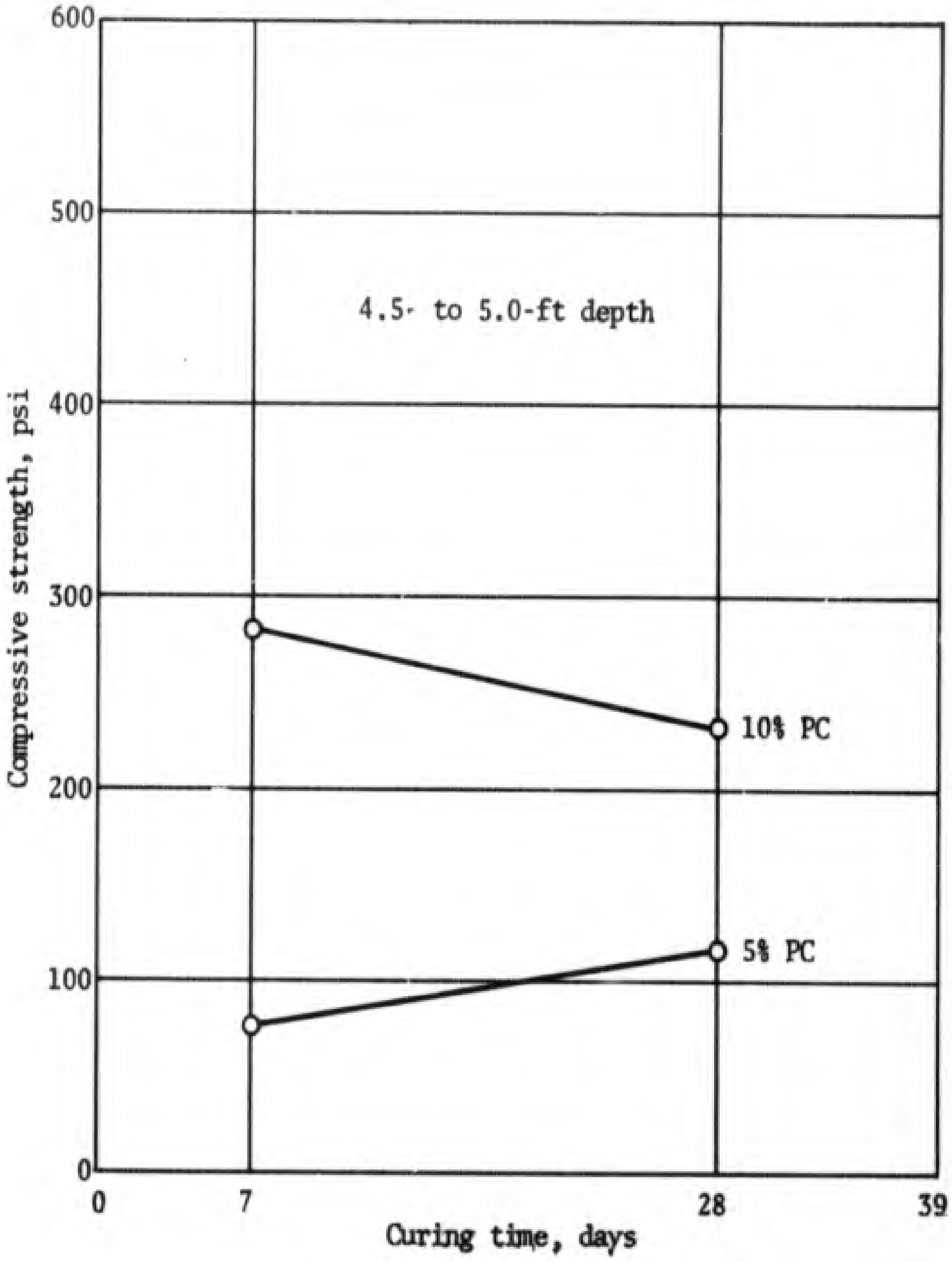


Figure 23. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Cam Ranh Bay sample 1

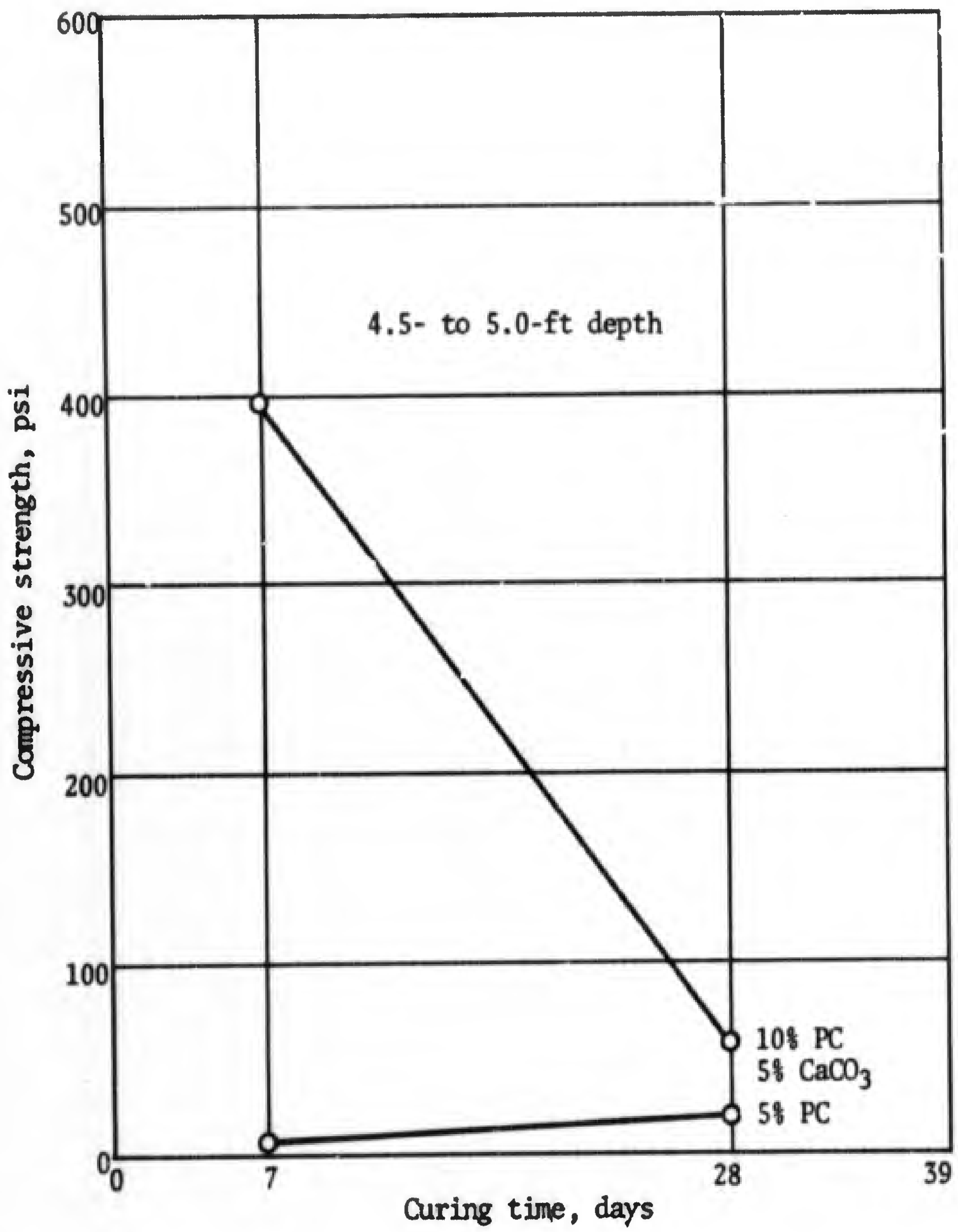


Figure 24. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement-calcite), Cam Ranh Bay sample 1

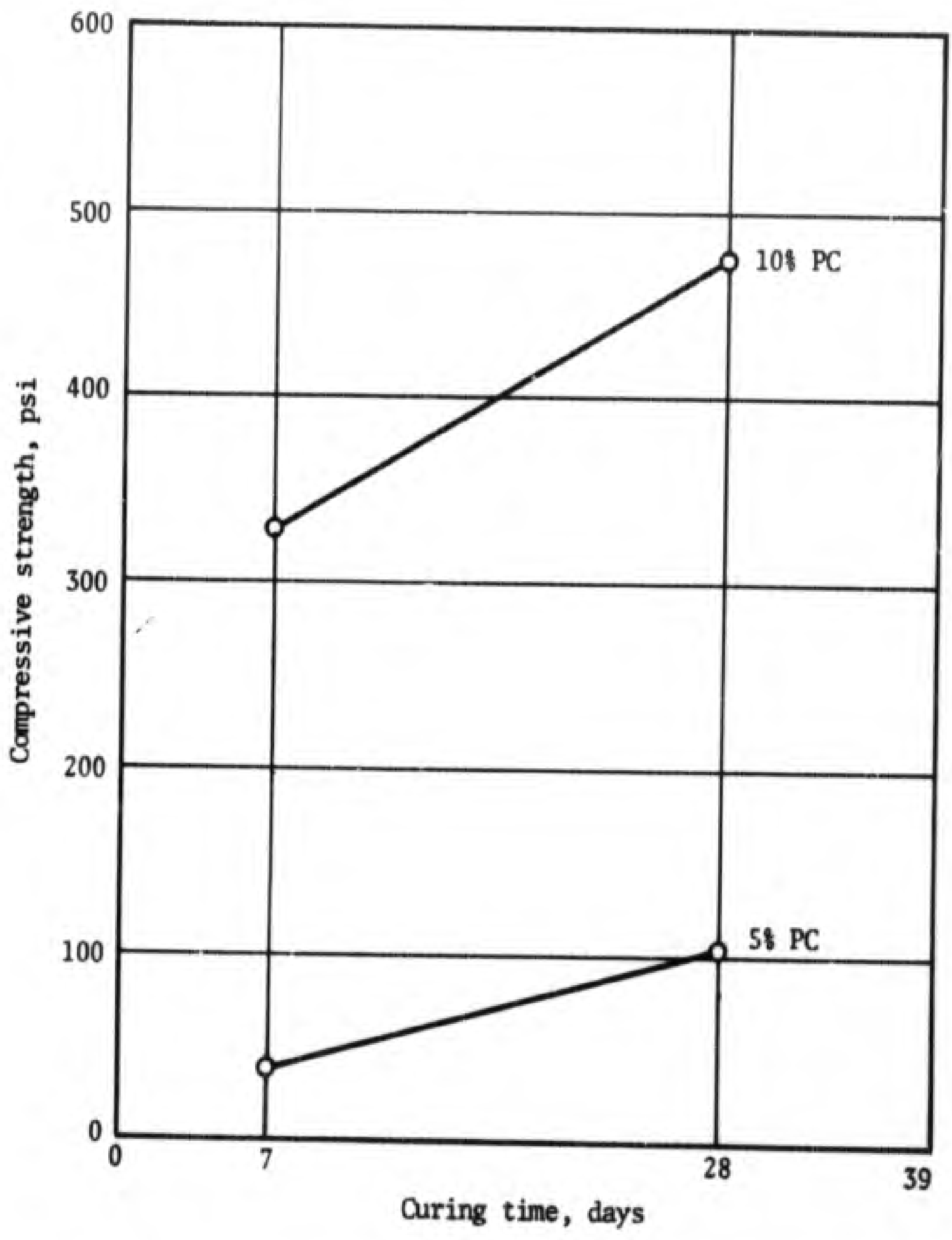


Figure 25. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Cam Ranh Bay sample 2

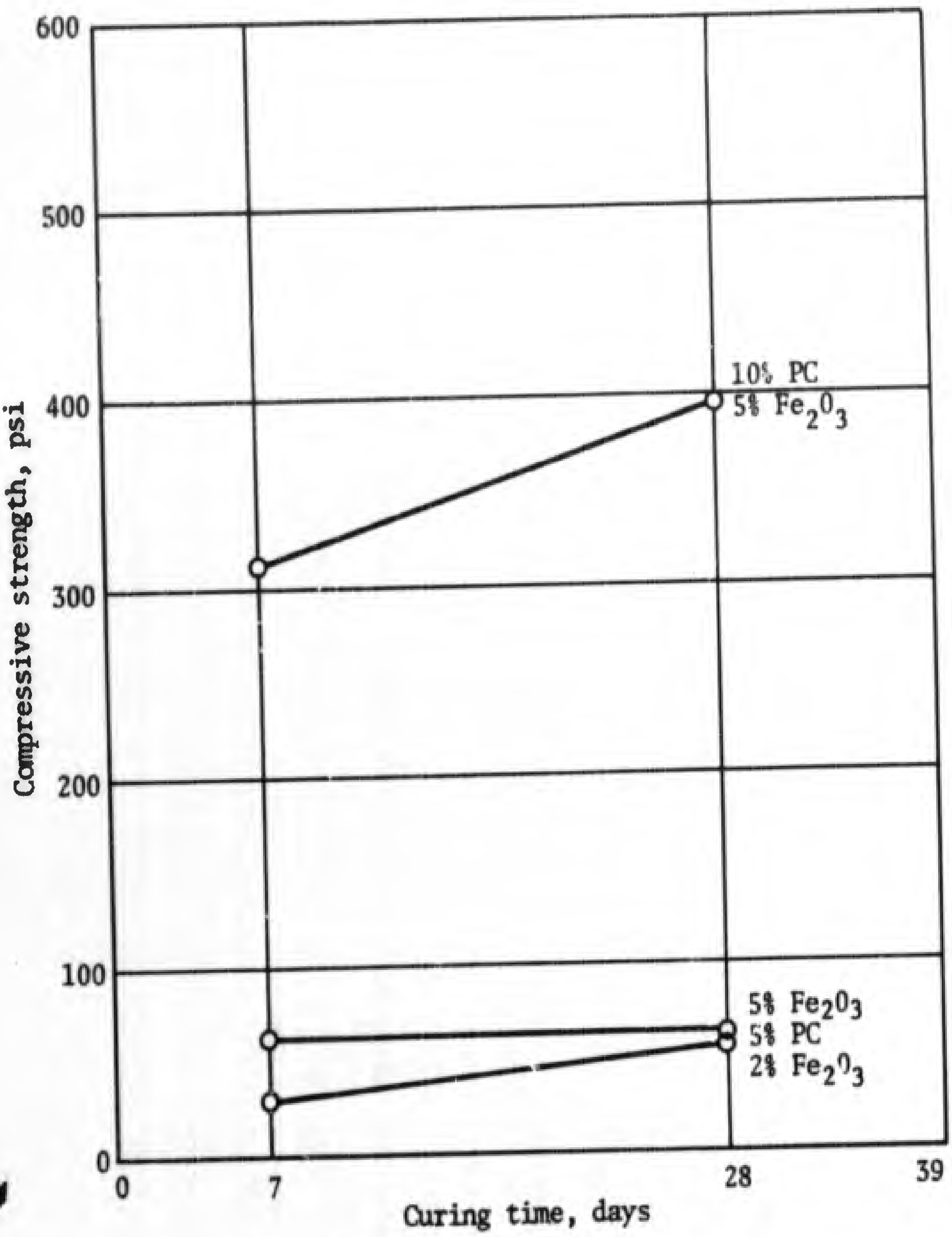


Figure 26. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement-hematite), Cam Ranh Bay sample 2

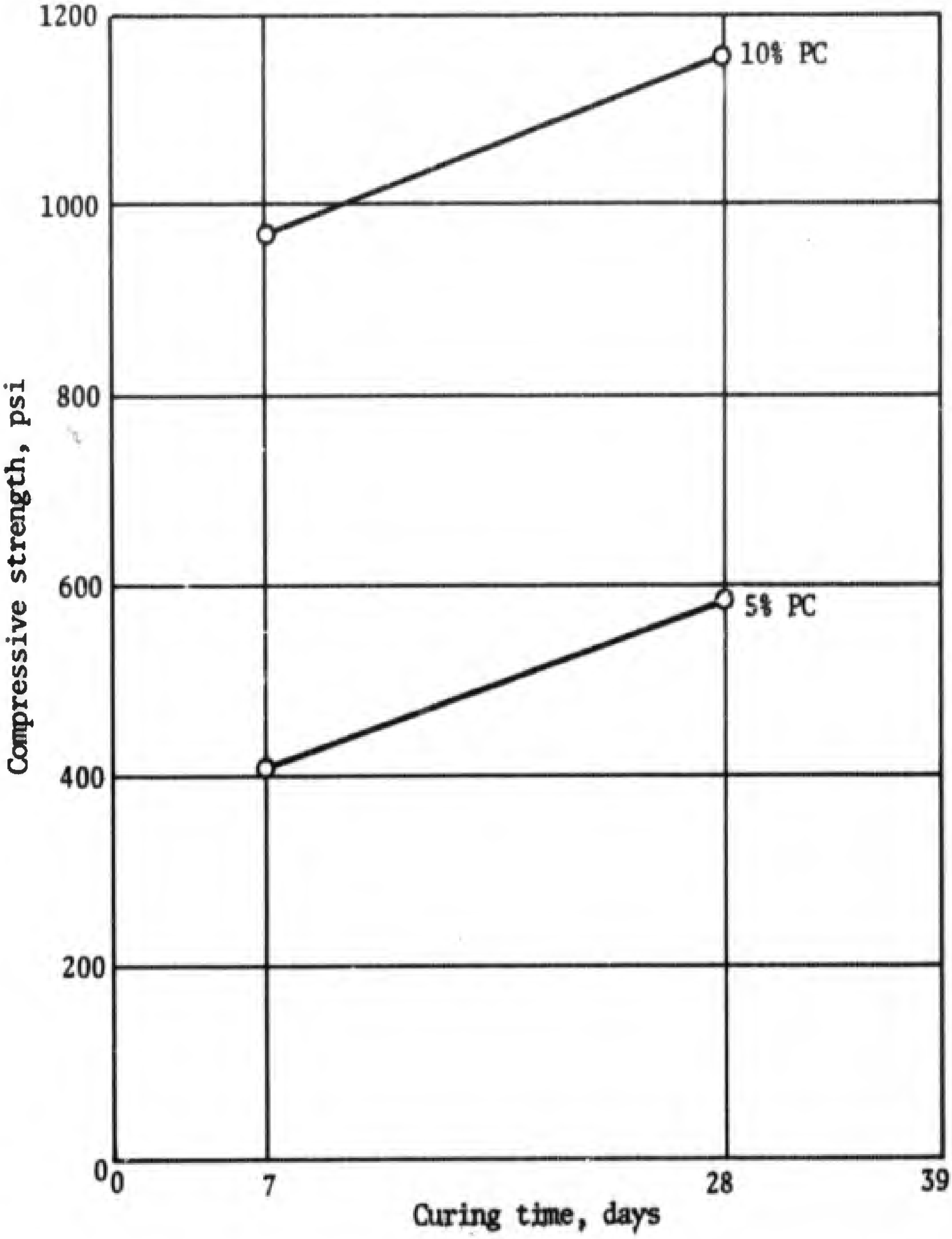


Figure 27. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Cam Ranh Bay sample 3

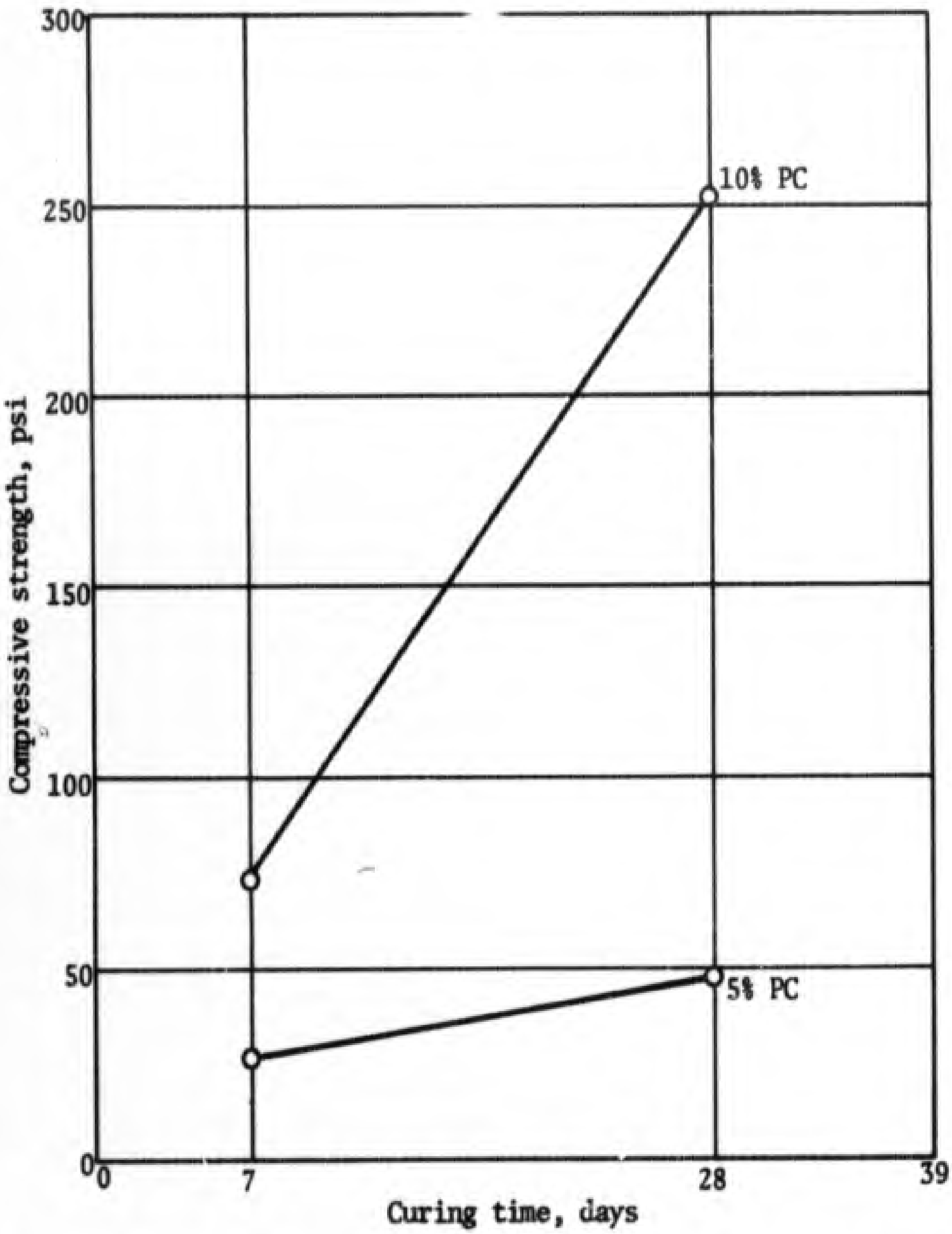


Figure 28. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Cam Ranh Bay sample 4

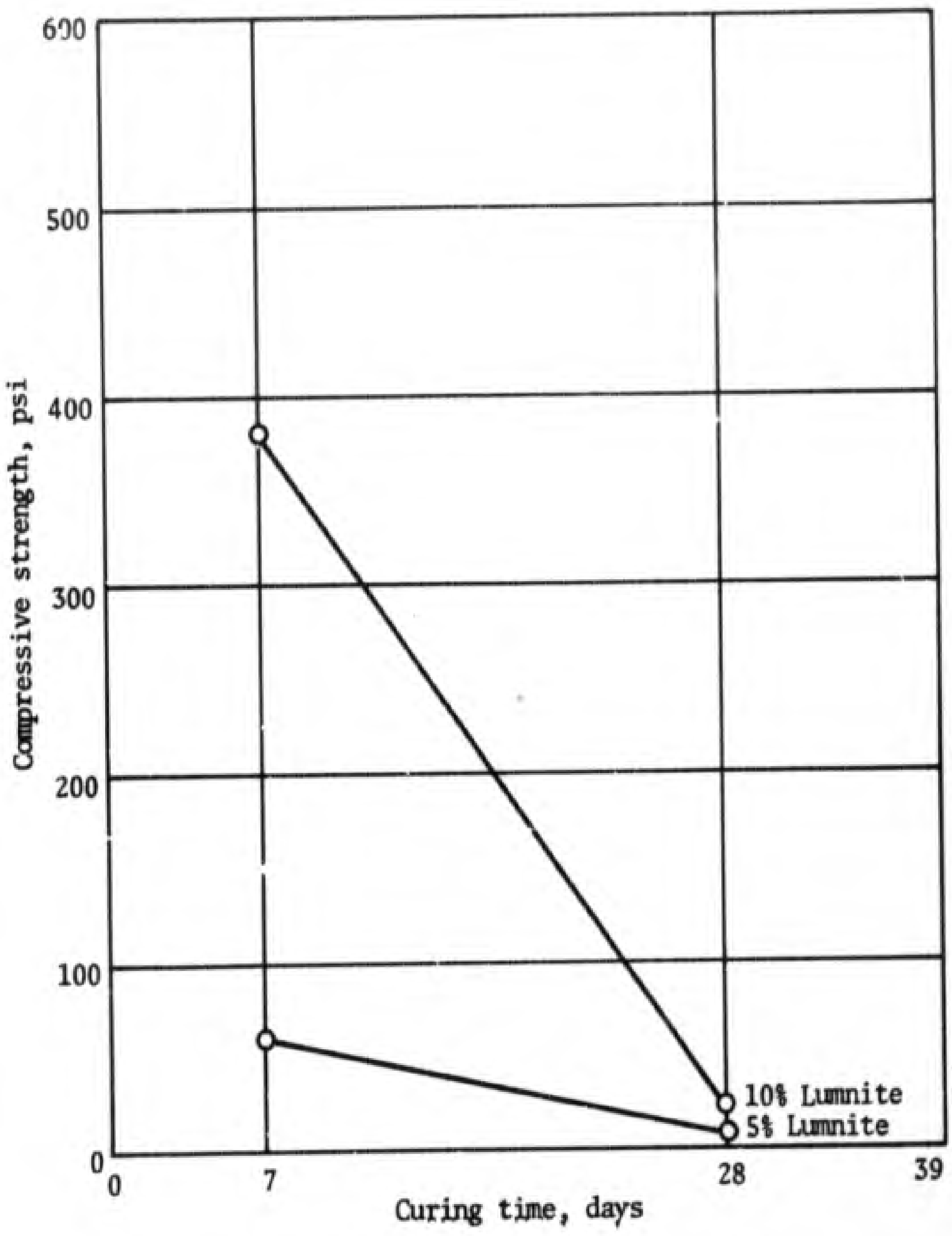


Figure 29. Compressive-strength changes with time in compacted soil-cement mixtures (aluminous cement), Cam Ranh Bay sample 4

DON MUANG

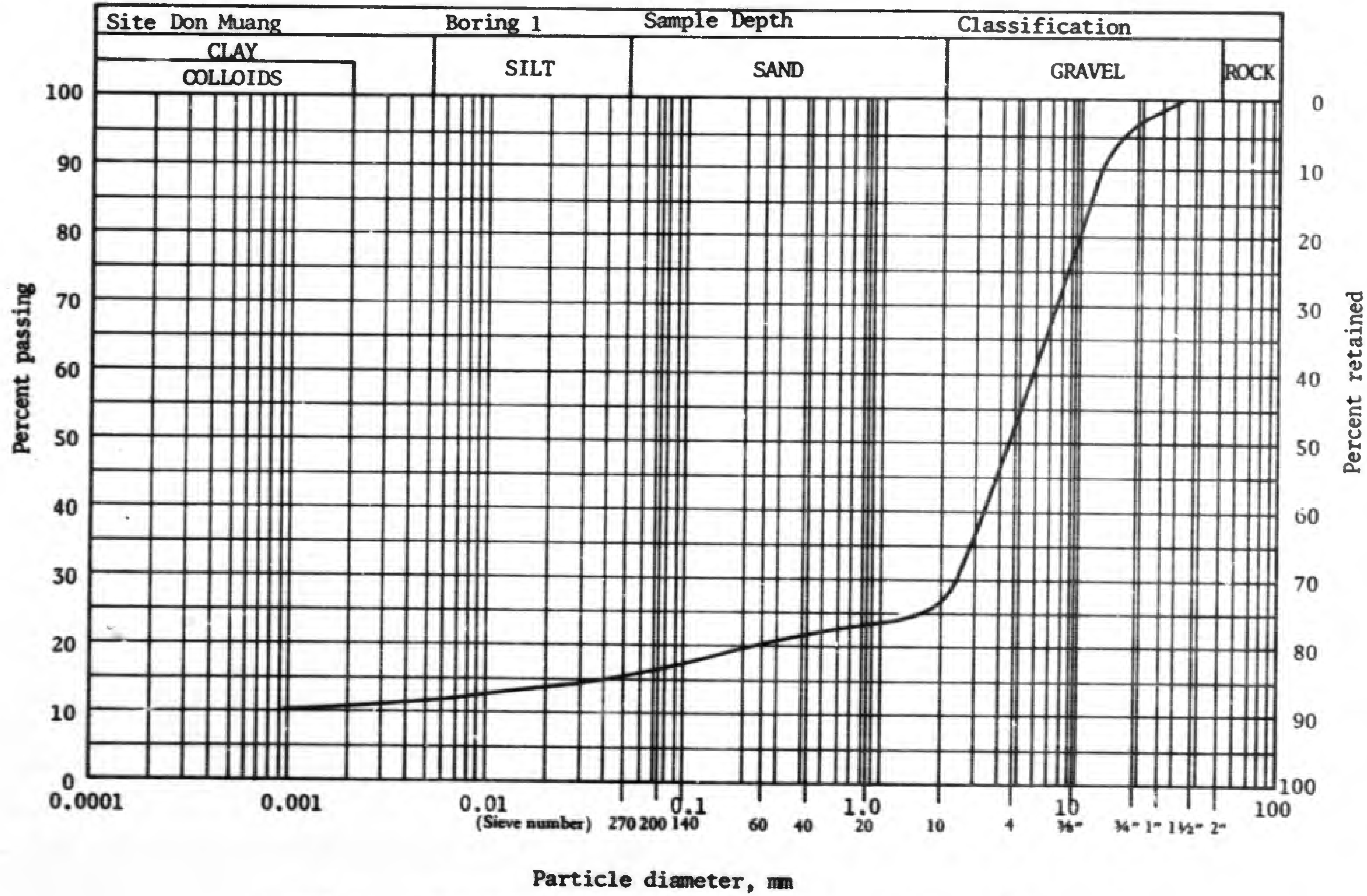


Figure 30. Grain-size distribution curve, Don Muang sample 1

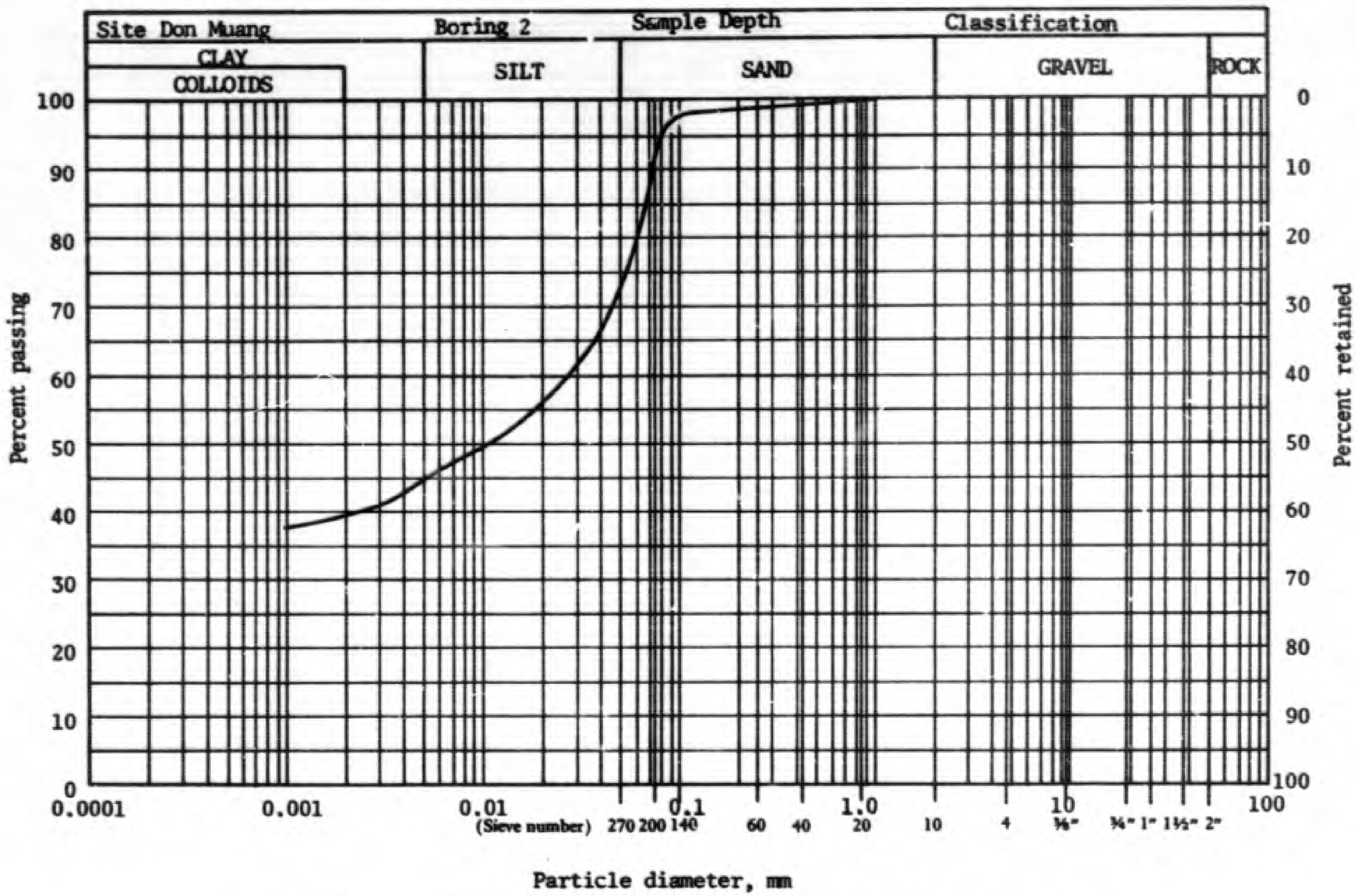


Figure 31. Grain-size distribution curve, Don Muang sample 2

TABLE 9

PROPERTIES OF SOILS FROM DON MUANG

Soil	Sample: 1	2
Textural Composition: %		
Sand (2.0-0.05 mm)	12	27
Silt (50-5 μ)	3	28
Clay (<5 μ)	12	45
Classifications:		
Unified	GC	CL
AASHO	A-2-6[0]	A-6[12]
Physical Properties:		
Liquid limit, %	37	36
Plastic limit, %	15	16
Plasticity Index, %	22	20
Activity[1,2]	0.54	0.51
Specific gravity[1]	2.75	2.61
ASTM standard compaction:[3]		
Dry density, lb/cu ft	118.0	110.5
Optimum moisture content, %	15.5	15.5
Chemical Properties:[1]		
Equivalent Fe_2O_3, %	6.4	1.8
Total soluble salt, %	1.0	1.6
Organic matter, %	0.3	0.5
pH	6.13	4.85

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay fraction.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 10

SOIL MINERALOGY, DON MUANG

Mineral, %	Sample: 1	2
Fraction Passing No. 10 Sieve, %	26.6	100.0
Quartz	40	50
Feldspar (perthite)	5	5
Kaolinite	35	20
Illite	--	5
Goethite	7.1	2.0
Other minerals:		
Other clays	5	10
Gypsum		3.0
Fraction Retained on No. 10 Sieve		
Quartz	25	--
Feldspar (perthite)	--	--
Kaolinite	20	--
Illite-mica	20	--
Goethite	19.5	--
Other minerals:		--
Hornblende	5	
	Percent	
Moisture content of samples when received	7.2	22.2
Air-dry moisture content of material finer than 2 mm	2.6	4.3
Air-dry moisture content of material coarser than 2 mm	1.6	--

TABLE 11

STABILIZATION OF SOILS FROM DON MUANG[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.010	0.012	79	99
	10.0% PC	0.011	0.010	173	388
	5.0% PC + 25.0% #966[2]	0.019		387	
	10.0% PC + 25.0% #966[2]	0.033		804	
	5.0% PC[3]	0.022		453	
	10.0% PC[3]	0.028		763	
2	5.0% PC	0.011	0.012	5	74
	10.0% PC	0.015	0.012	247	297
	5.0% PC + 25.0% #966[2]	0.007		137	
	10.0% PC + 25.0% #966[2]	0.017		539	

[1]Determined for the fraction passing No. 20 sieve.

[2]Sample 2 from Tuy Hoa #966.

[3]Material retained on No. 10 sieve pulverized and used.

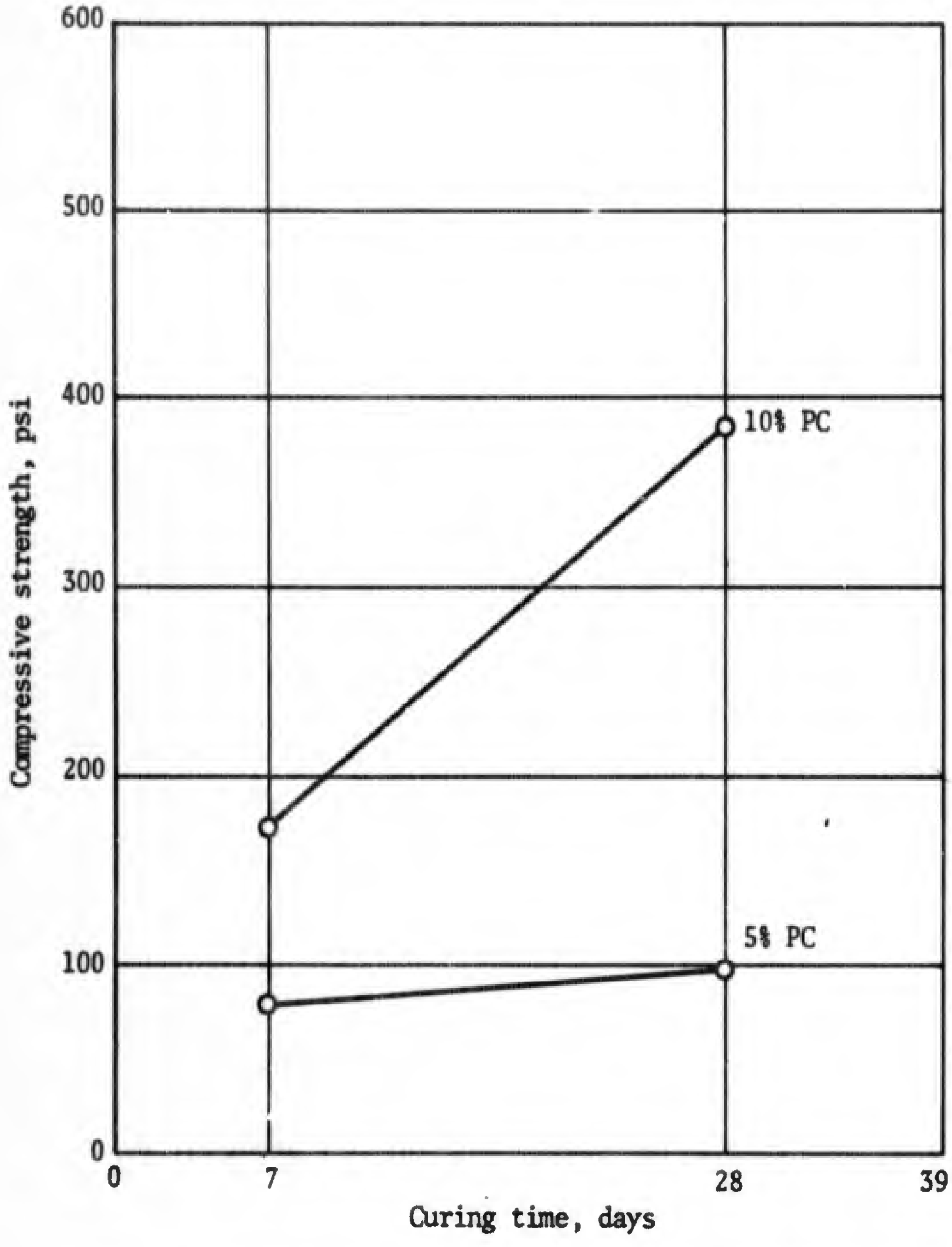


Figure 32. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Don Muang sample 1

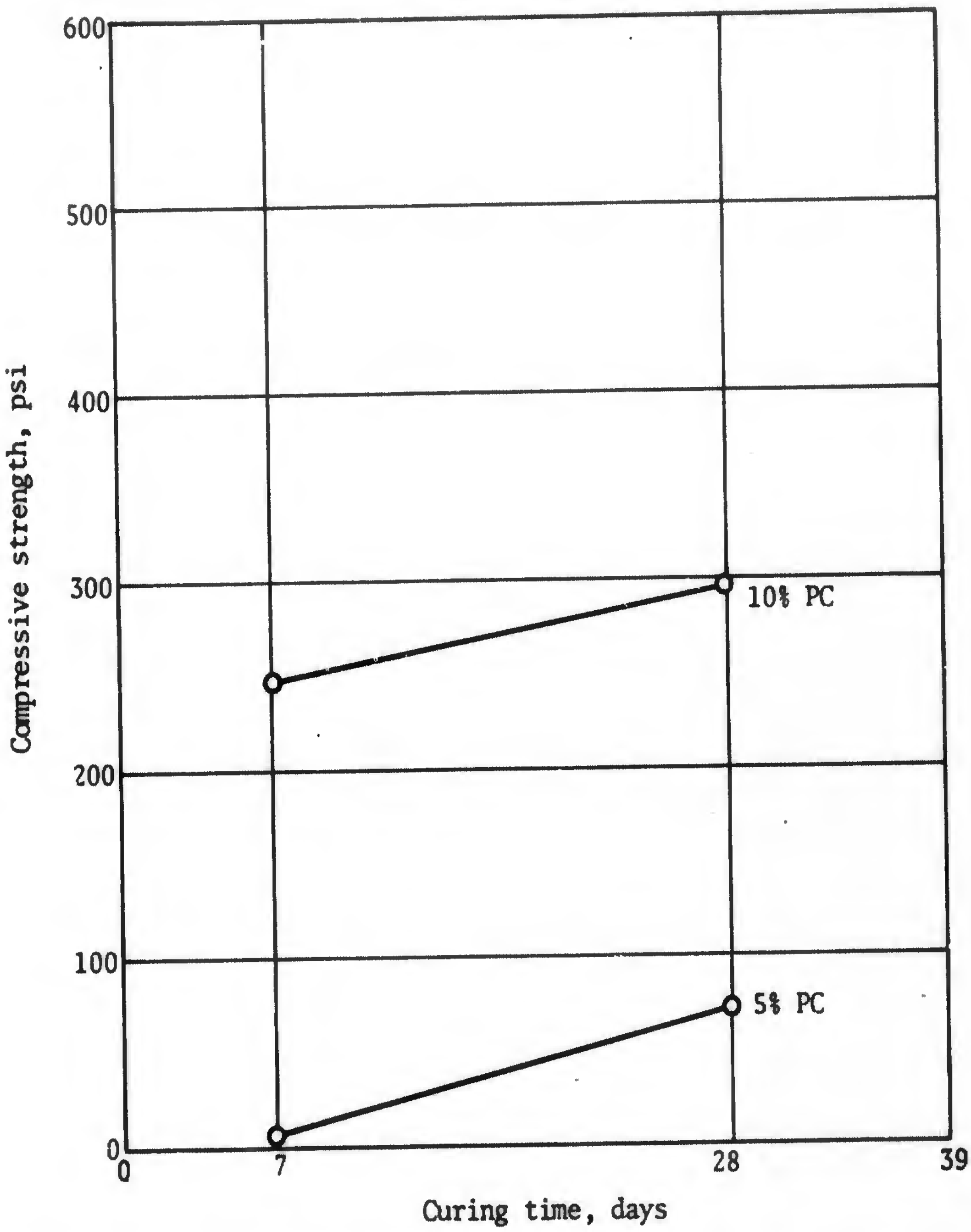


Figure 33. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Don Muang sample 2

NAKHON PHANOM

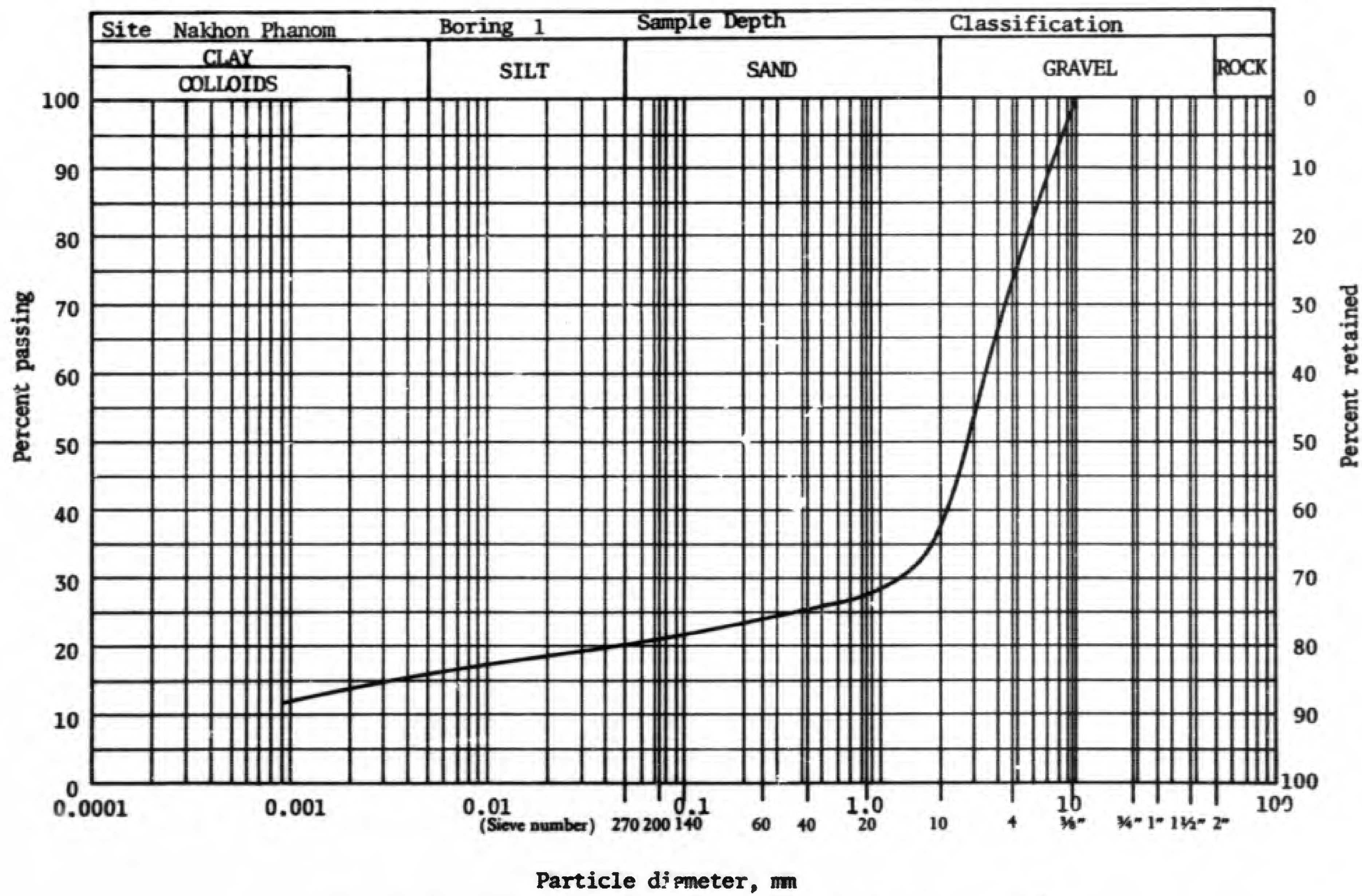


Figure 34. Grain-size distribution curve, Nakhon Phanom sample 1

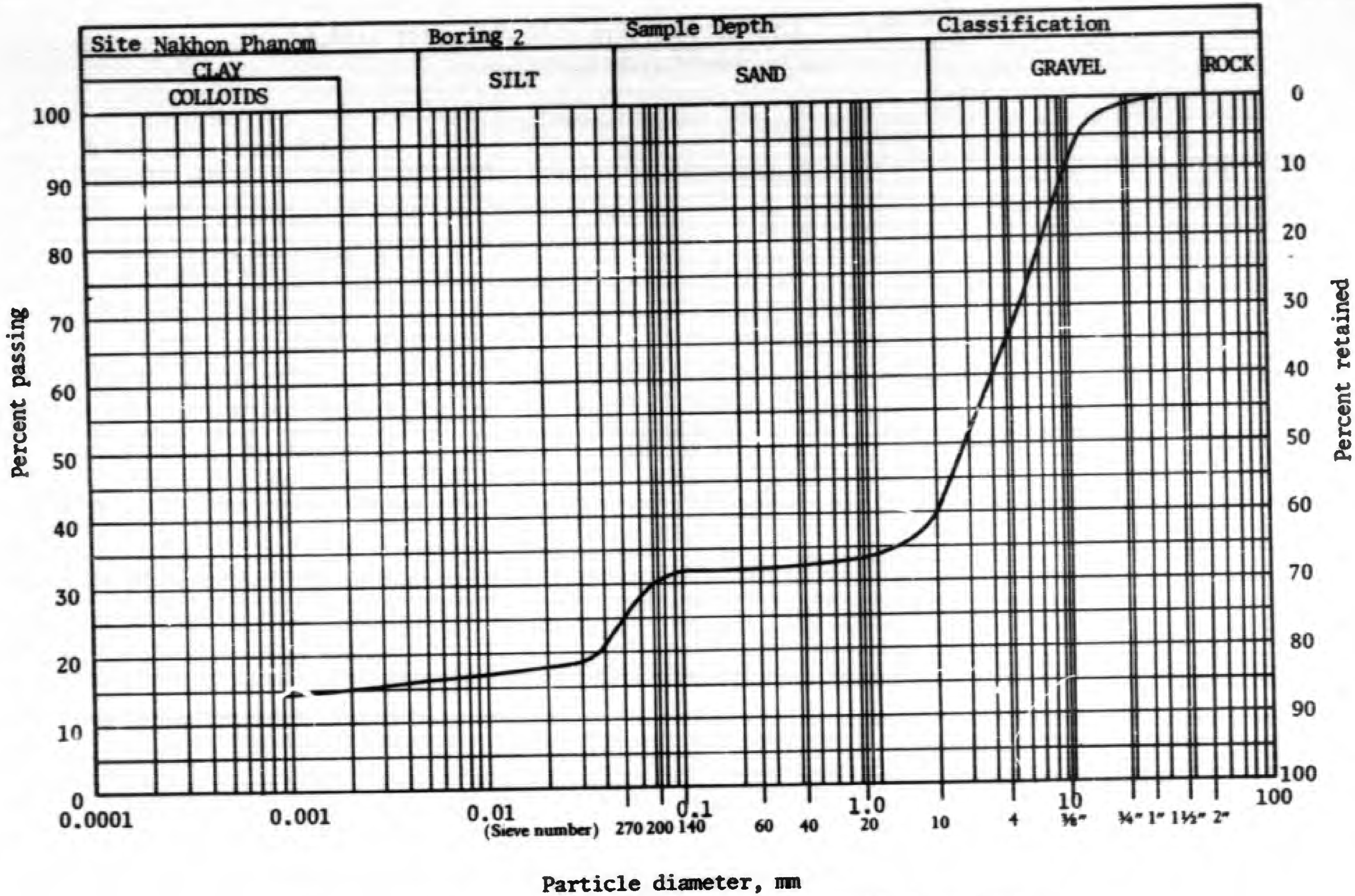


Figure 35. Grain-size distribution curve, Nakhon Phanom sample 2

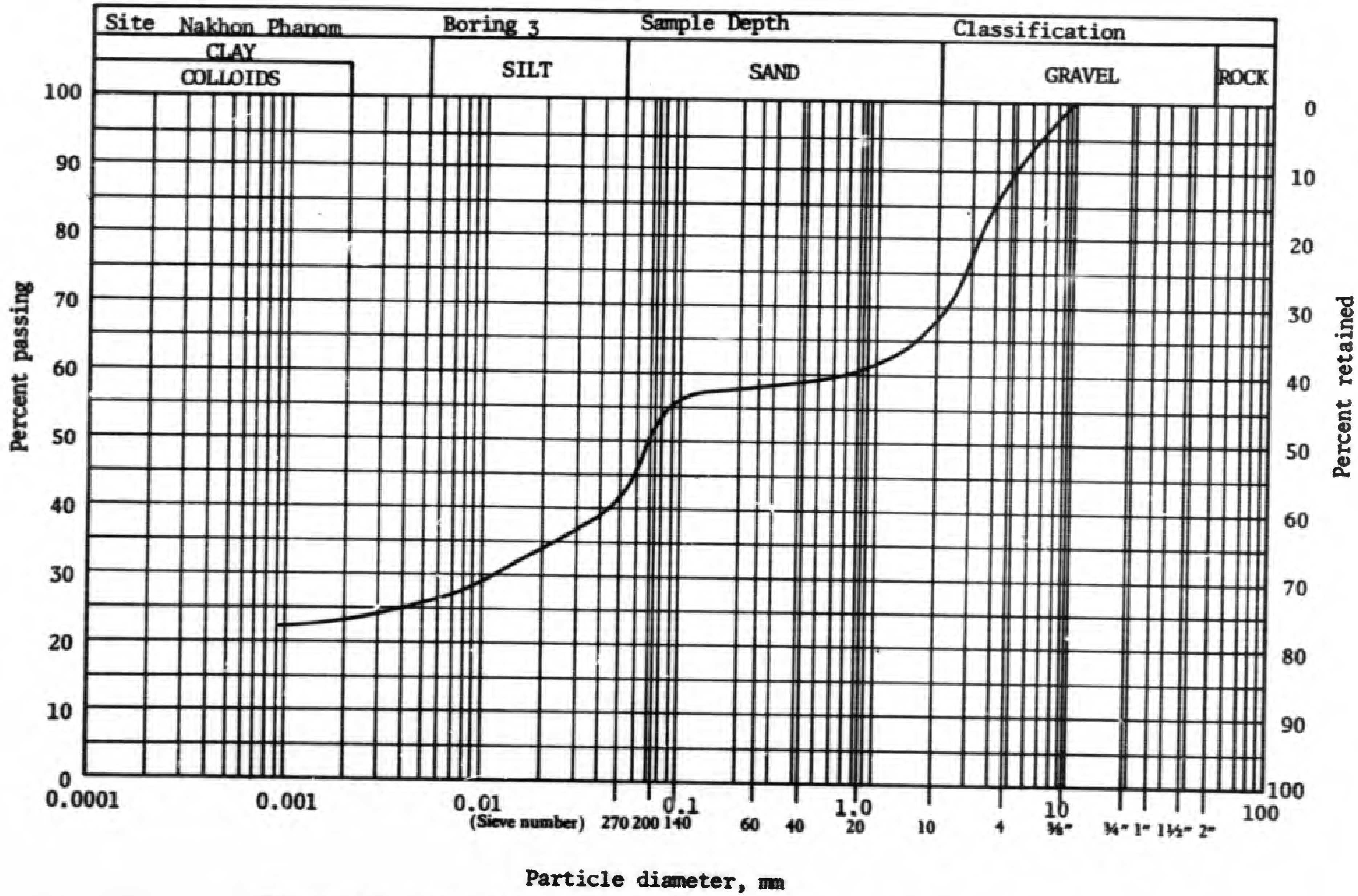


Figure 36. Grain-size distribution curve, Nakhon Phanom sample 3

TABLE 12

PROPERTIES OF SOILS FROM NAKHON PHANOM

Soil	Sample: 1	2	3	4[4]
Textural Composition: %				
Sand (2.0-0.5 mm)	17	11	26	--
Silt (50-5 μ)	4	9	17	--
Clay (<5 μ)	16	16	25	--
Classifications:				
Unified	SC	GC	CL	--
AASHO	A-2-7[1]	A-2-7[1]	A-7-6[8]	--
Physical Properties:				
Liquid limit, %	54	45	44	--
Plastic limit, %	26	26	21	--
Plasticity Index, %	28	19	23	N.P.
Activity[1,2]	0.73	0.61	0.68	--
Specific gravity[1]	3.08	3.00	2.70	3.39
ASTM standard compaction:[3]				
Dry density, lb/cu ft	108.0	92.0	99.0	--
Optimum moisture content, %	22.5	29.0	23.5	--
Chemical Properties:[1]				
Equivalent Fe_2O_3, %	14.9	8.8	2.1	40.8
Total soluble salt, %	0.7	0.8	1.1	--
Organic matter, %	0.3	--	2.5	--
pH	5.17	5.20	6.88	6.86

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

[4]Indurated laterite.

TABLE 13

SOIL MINERALOGY, NAKHON PHANOM

Mineral, %	Sample: 1	2	3	4[1]
Fraction Passing No. 10 Sieve, %	36.0	28.9	67.6	0.0
Quartz	25	20	45	--
Feldspar (perthite)	--	--	5	--
Kaolinite-halloysite	25	25	20	--
Illite	10	10	20	--
Goethite	10	5	2.4	--
Other minerals:			--	--
Hematite	5	5		
Other clays	10	5		
Fraction Retained on No. 10 Sieve				
Quartz	15	5	20	20
Feldspar (perthite)	--	5	--	5
Kaolinite-halloysite	15	15	15	10
Illite	10	10	10	10
Goethite	25	15	30	30
Other minerals:				
Hematite	10	10	15	15
Other clays	5	5		5
Gibbsite		5		
		Percent		
Moisture content of samples when received	13.1	18.0	24.0	--
Air-dry moisture content of material finer than 2 mm	12.2	12.3	3.8	--
Air-dry moisture content of material coarser than 2 mm	5.3	4.2	1.5	4.9

[1]Indurated laterite.

TABLE 14

STABILIZATION OF SOILS FROM NAKHON PHANOM[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.017	0.018	115	126
	10.0% PC	0.020	0.022	255	401
2	5.0% PC	0.017	0.013	29	8
	10.0% PC	0.017	0.020	133	236
	5.0% PC[2]	0.016		277	
	10.0% PC[2]	0.025		774	
3	5.0% PC	0.032	0.019	64	64
	10.0% PC	0.019	0.013	172	168
	6.0% U.S. lime	0.014	0.008	24	16
	6.0% Thailand lime	0.013	0.012	31	26
4	5.0% PC[3]	0.011	0.010	187	230[4]
	10.0% PC[3]	0.038	0.037	913	1105[4]
	5.0% Lumnite[3]	0.011	0.009	46	22[4]
	10.0% Lumnite[3]	0.010	0.011	194	238[4]

[1]Determined for the fraction passing No. 20 sieve.

[2]Material retained on No. 20 sieve pulverized and original soil reconstituted.

[3]Indurated laterite pulverized to -#20-size material.

[4]Tested after 14 days curing time.

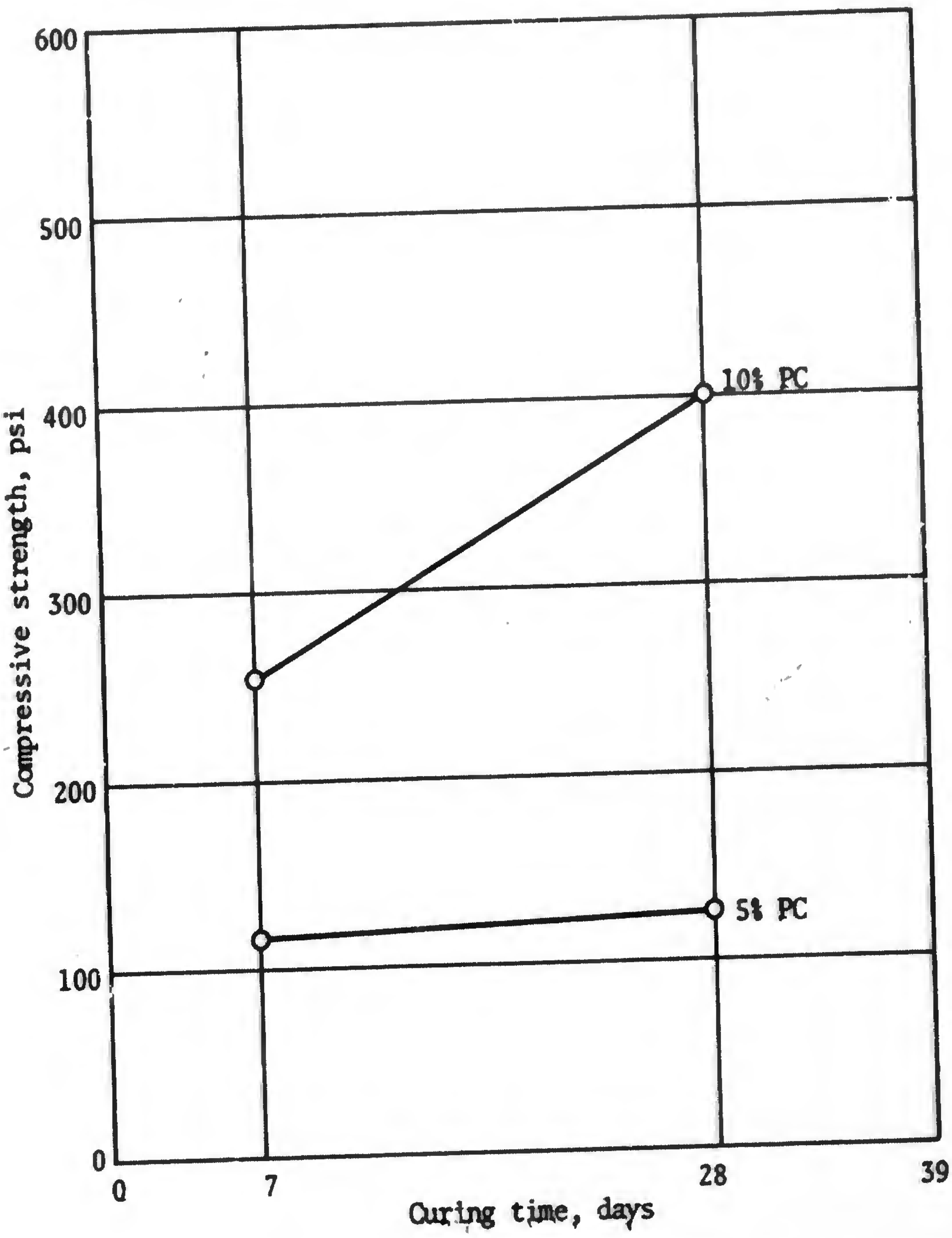


Figure 37. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Nakhon Phanom sample 1

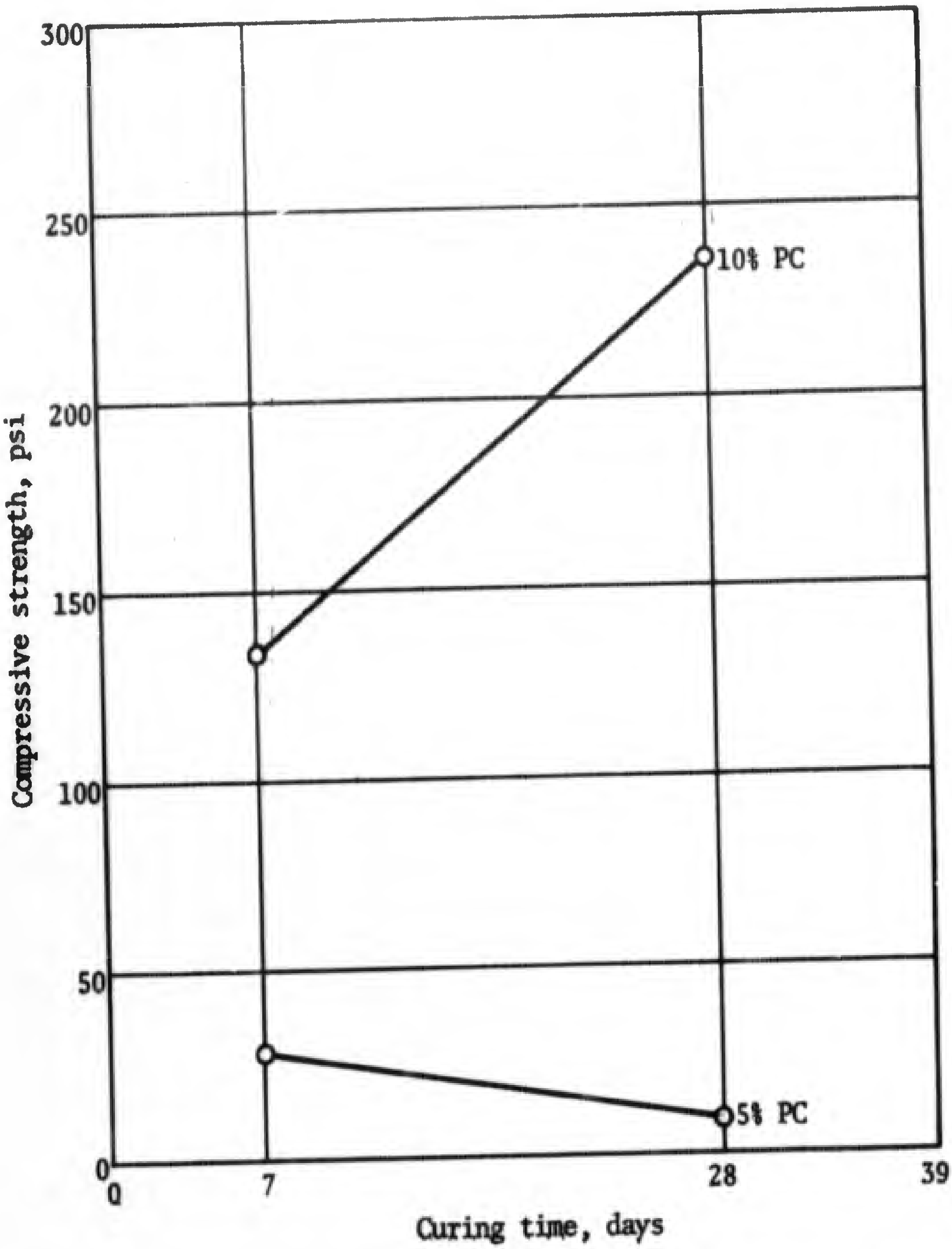


Figure 38. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Nakhon Phanom sample 2

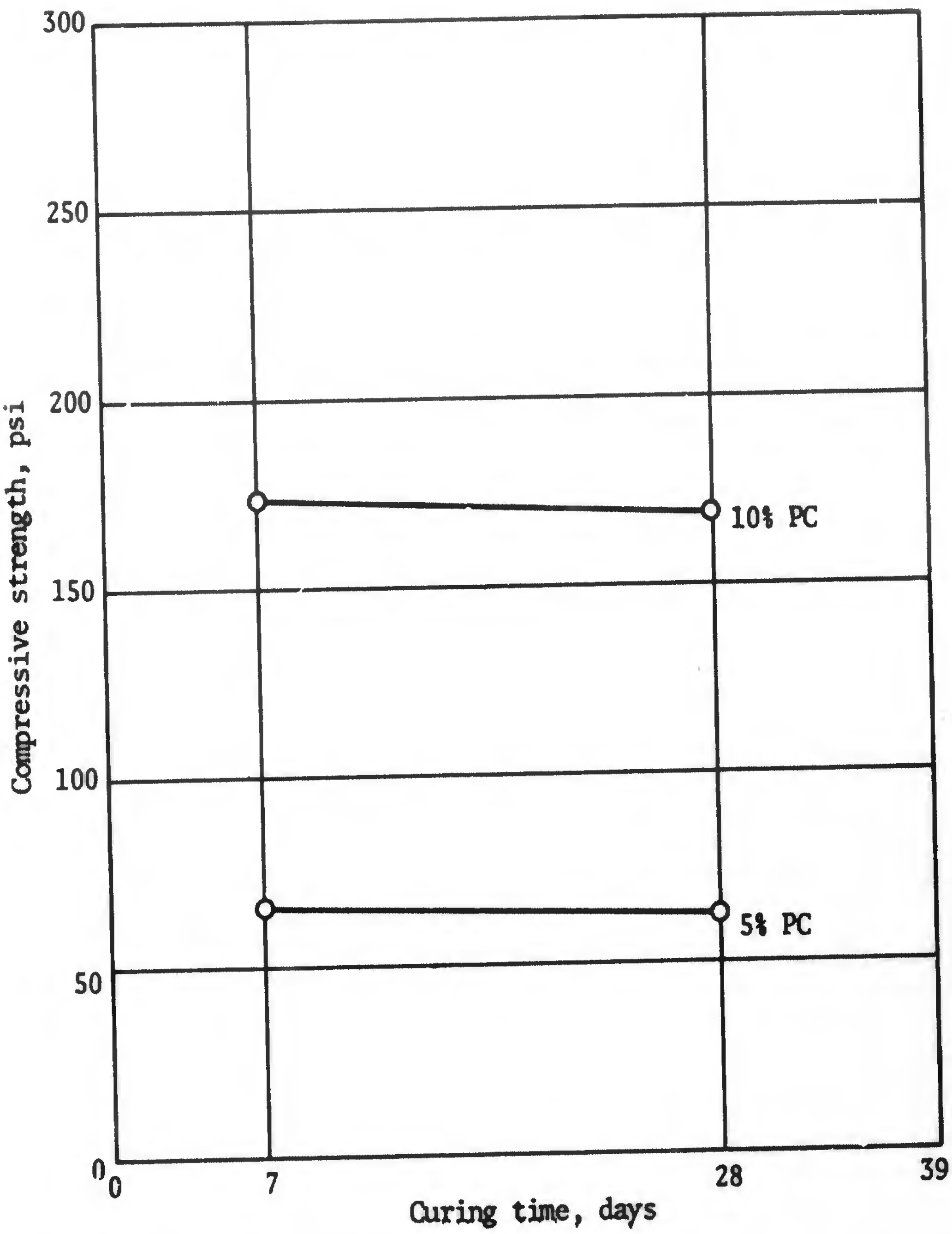


Figure 39. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Nakhon Phanom sample 3

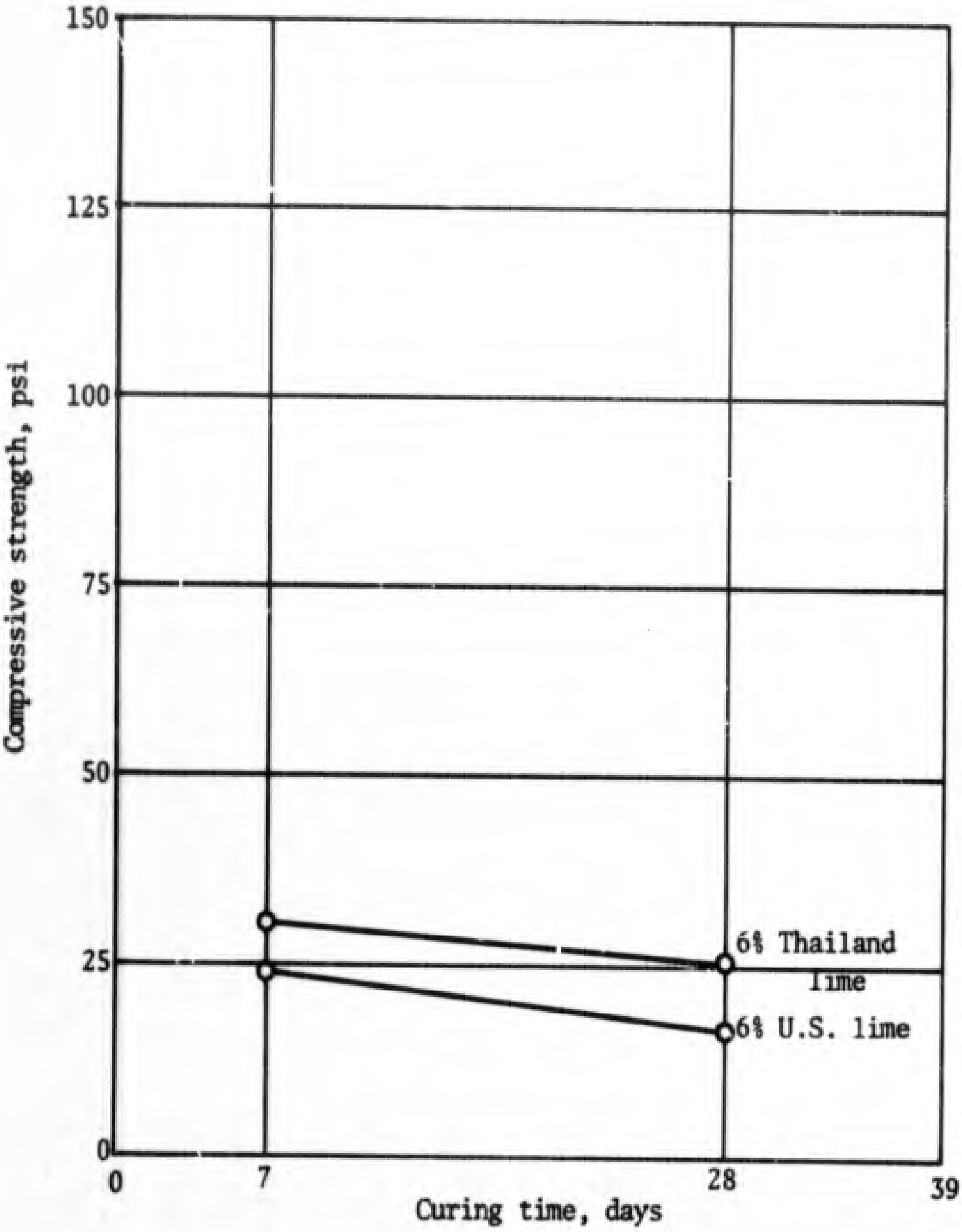
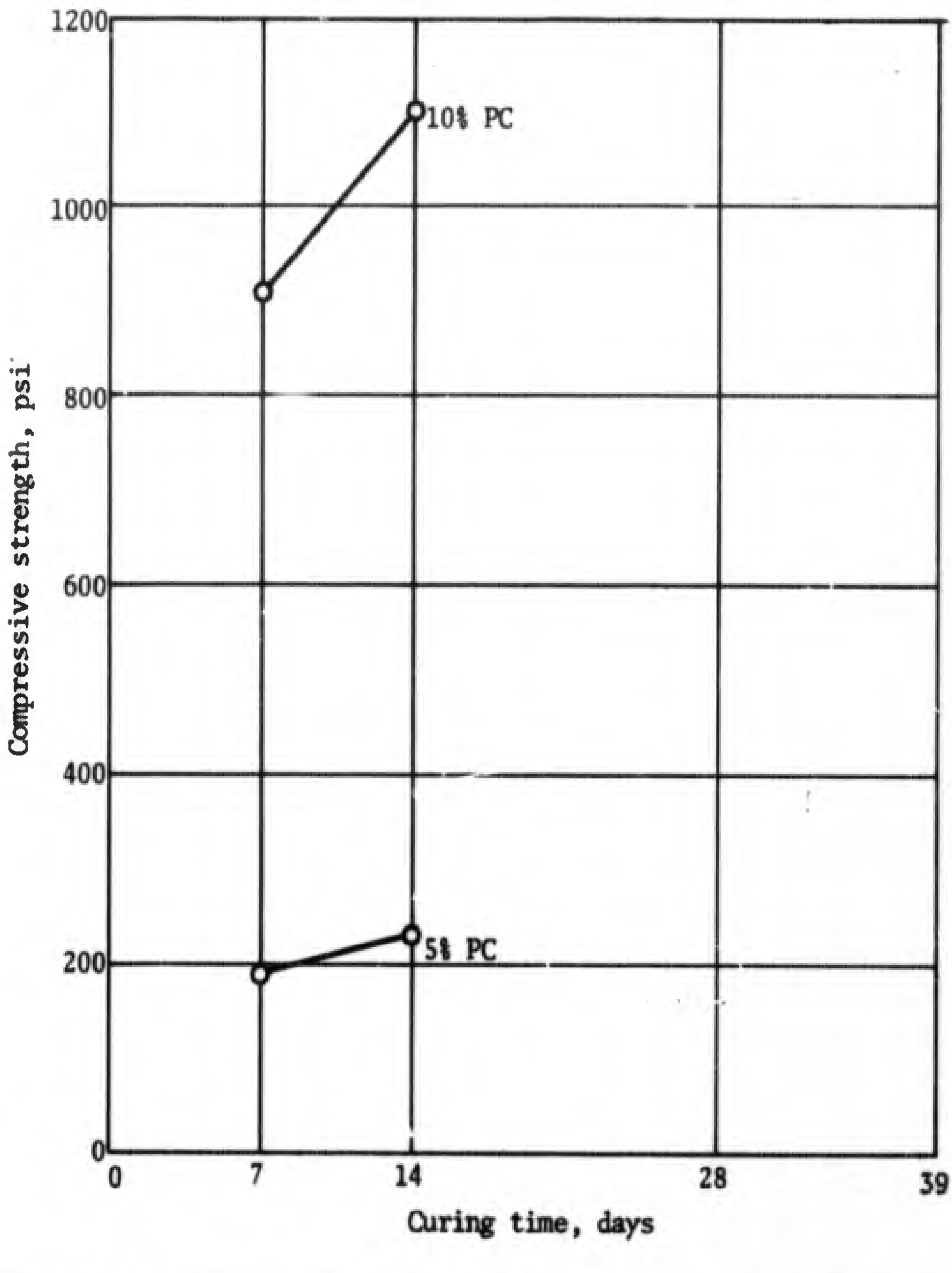
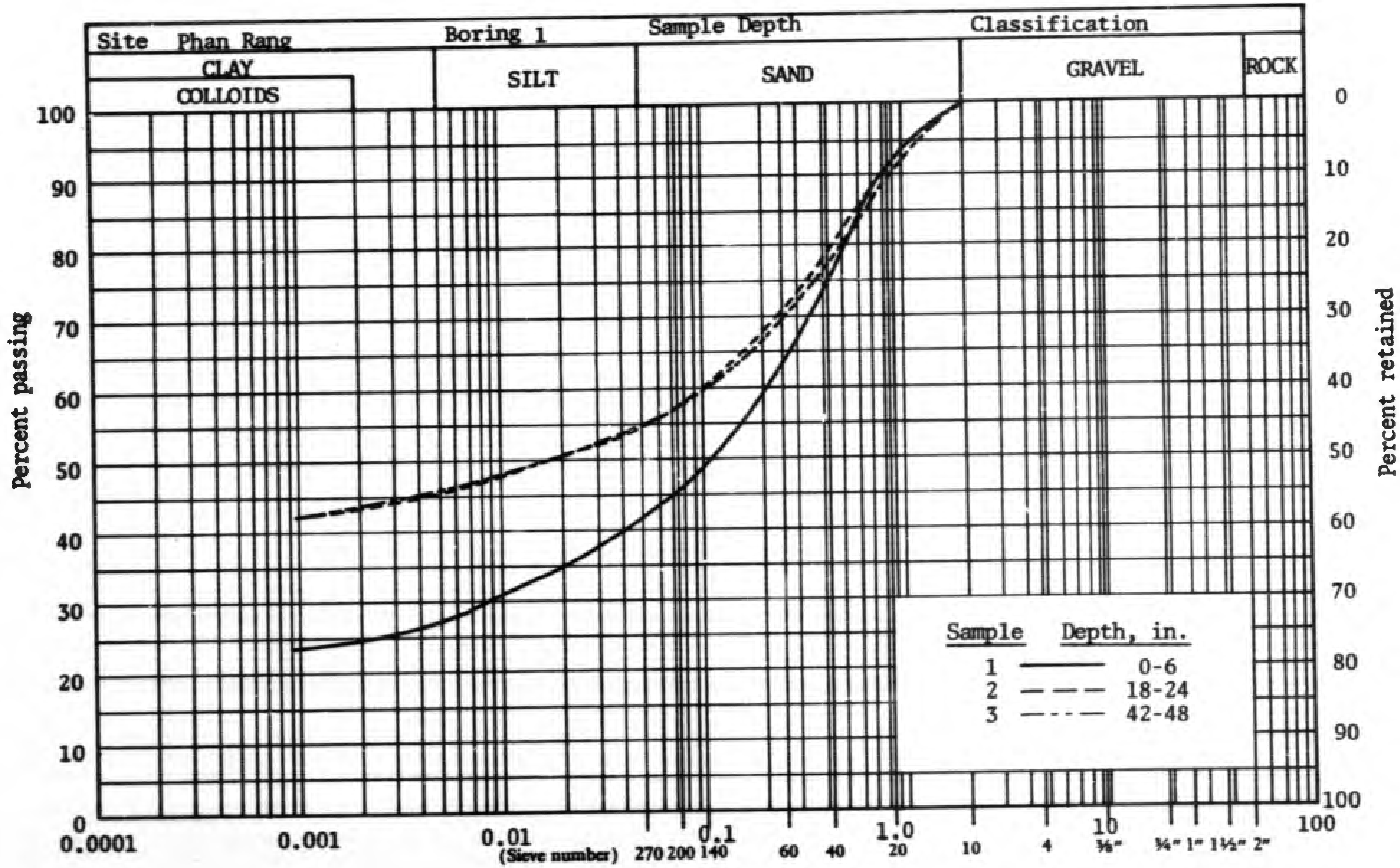


Figure 40. Compressive-strength changes with time in compacted soil-cement mixtures (lime), Nakhon Phanom sample 3



Fiugre 41. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Nakhon Phanom sample 4

PHAN RANG



Particle diameter, mm

Figure 42. Grain-size distribution curves, Phan Rang samples 1, 2, and 3

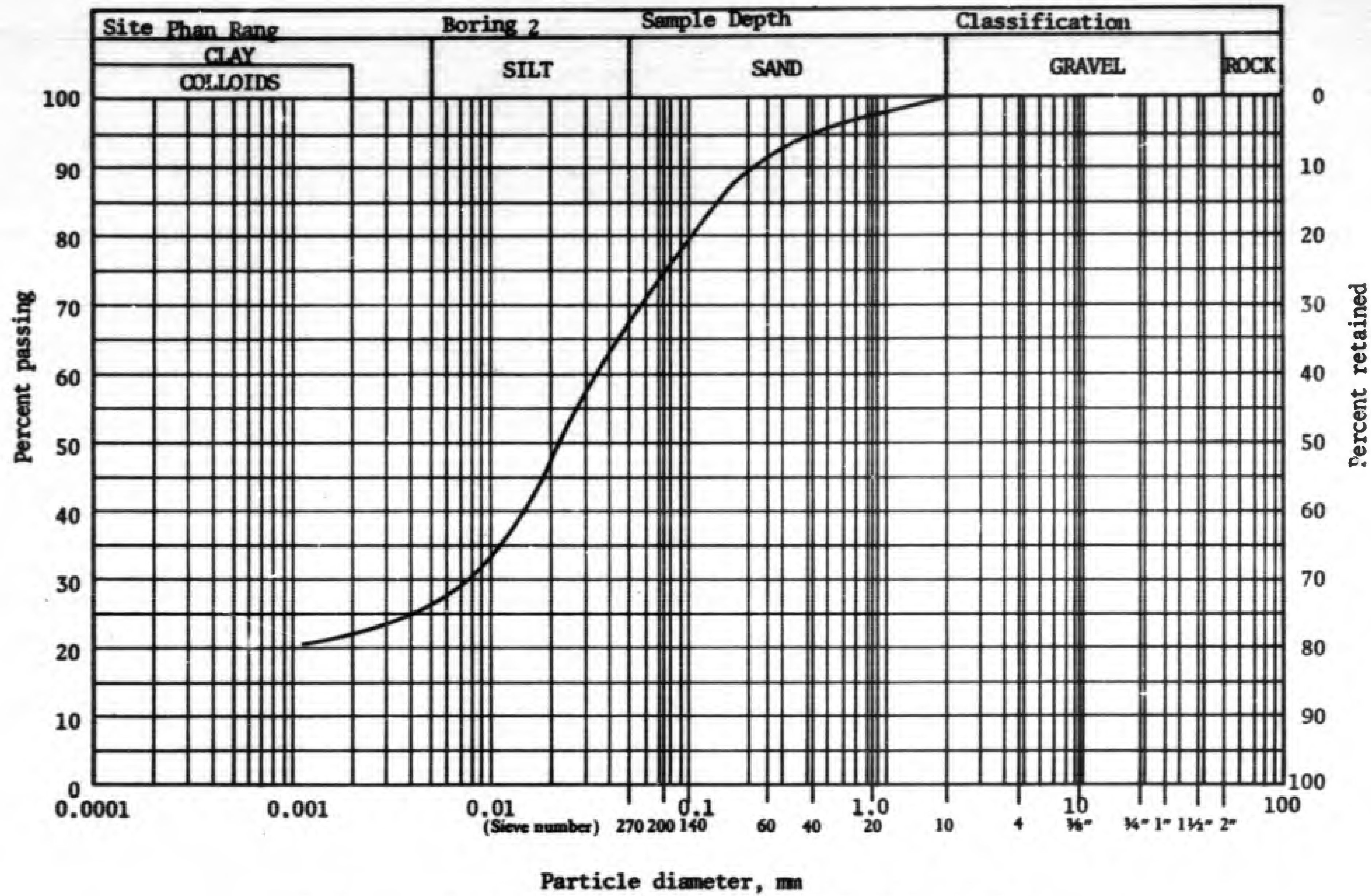


Figure 43. Grain-size distribution curve, Phan Rang sample 4

TABLE 15

PROPERTIES OF SOILS FROM PHAN RANG

Soil Sample:	1	2	3	4
Textural Composition: %				
Sand (2.0-0.05 mm)	58	45	45	33
Silt (50-5 μ)	15	10	10	41
Clay (<5 μ)	27	45	45	26
Classifications:				
Unified	SM	CL	CL	CL
AASHO	A-4[2]	A-7-6[11]	A-7-6[11]	A-4[8]
Physical Properties:				
Liquid limit, %	25	45	48	23
Plastic limit, %	22	19	20	15
Plasticity Index, %	3	26	28	8
Activity[1,2]	0.12	0.61	0.64	0.36
Specific gravity[1]	2.78	2.69	2.60	2.72
ASTM standard compaction:[3]				
Dry density, lb/cu ft	116.5	109.5	110.5	116.4
Optimum moisture content, %	13.7	18.0	18.5	14.0
Chemical Properties:[1]				
Equivalent Fe_2O_3, %	2.2	2.6	3.3	2.6
Total soluble salt, %	1.4	0.7	0.9	0.9
Organic matter, %	0.9	0.5	0.4	1.3
pH	6.17	6.21	6.23	5.93

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 16

SOIL MINERALOGY, PHAN RANG

Mineral, %	Sample: 1	2	3	4
Fraction Passing No. 10 Sieve, %	99.9	99.8	100.0	99.8
Quartz	30	35	15	35
Feldspar (perthite)	10	10	10	5
Kaolinite-halloysite	15	35	30	20
Illite-mica	10	2	3	10
Goethite	2.5	2.9	3.7	2.9
Other minerals:				
Dolomite	2			1
Calcite		1	1	
Other clays		5		
Hornblende	2			3
Chlorite				5
		Percent		
Moisture content of samples when received	4.6	6.8	7.6	3.6
Air-dry moisture content of material finer than 2 mm	3.6	2.7	3.6	2.3

Note: Sample 3 contains "float" rock consisting of dolomitic limestone, comprised of about 25% dolomite and 65% calcite.

TABLE 17

STABILIZATION OF SOILS FROM PHAN RANG[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.017	0.018	344	442
	10.0% PC	0.027	0.038	687	1075
	5.0% Thailand PC	0.012	0.017	213	200
	5.0% Lumnite	0.017	0.004	157	194
	10.0% Lumnite	0.013	0.014	258	584
2	5.0% PC	0.011	0.014	168	192
	10.0% PC	0.023	0.019	427	482
3	5.0% PC	0.010	0.020	152	313
	10.0% PC	0.017	0.027	399	703
4	5.0% PC	0.018	0.021	311	441
	10.0% PC	0.022	0.016	538	645
	4.0% lime	0.014	0.014	3	5

[1]Determined for the fraction passing No. 20 sieve.

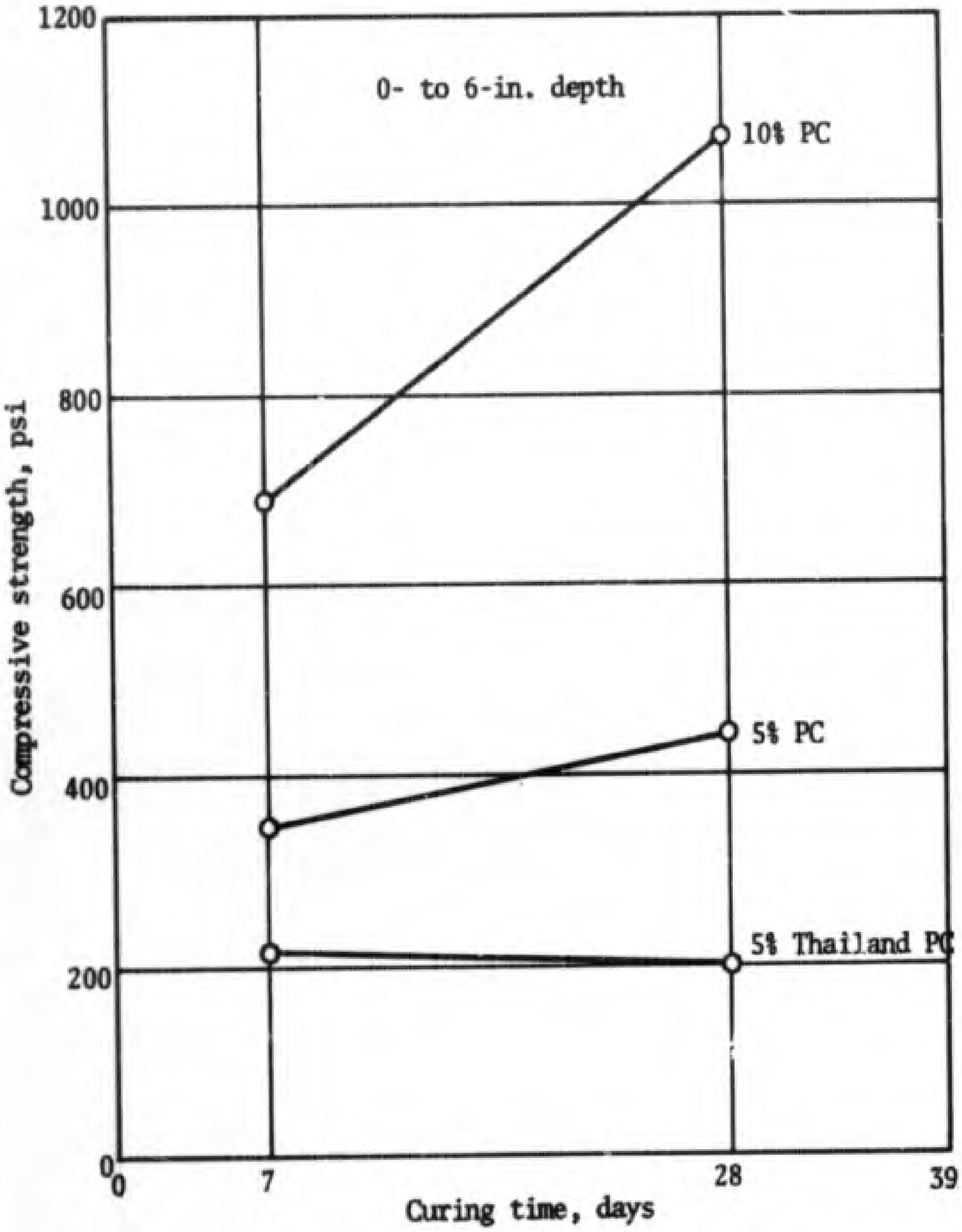


Figure 44. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Phan Rang sample 1

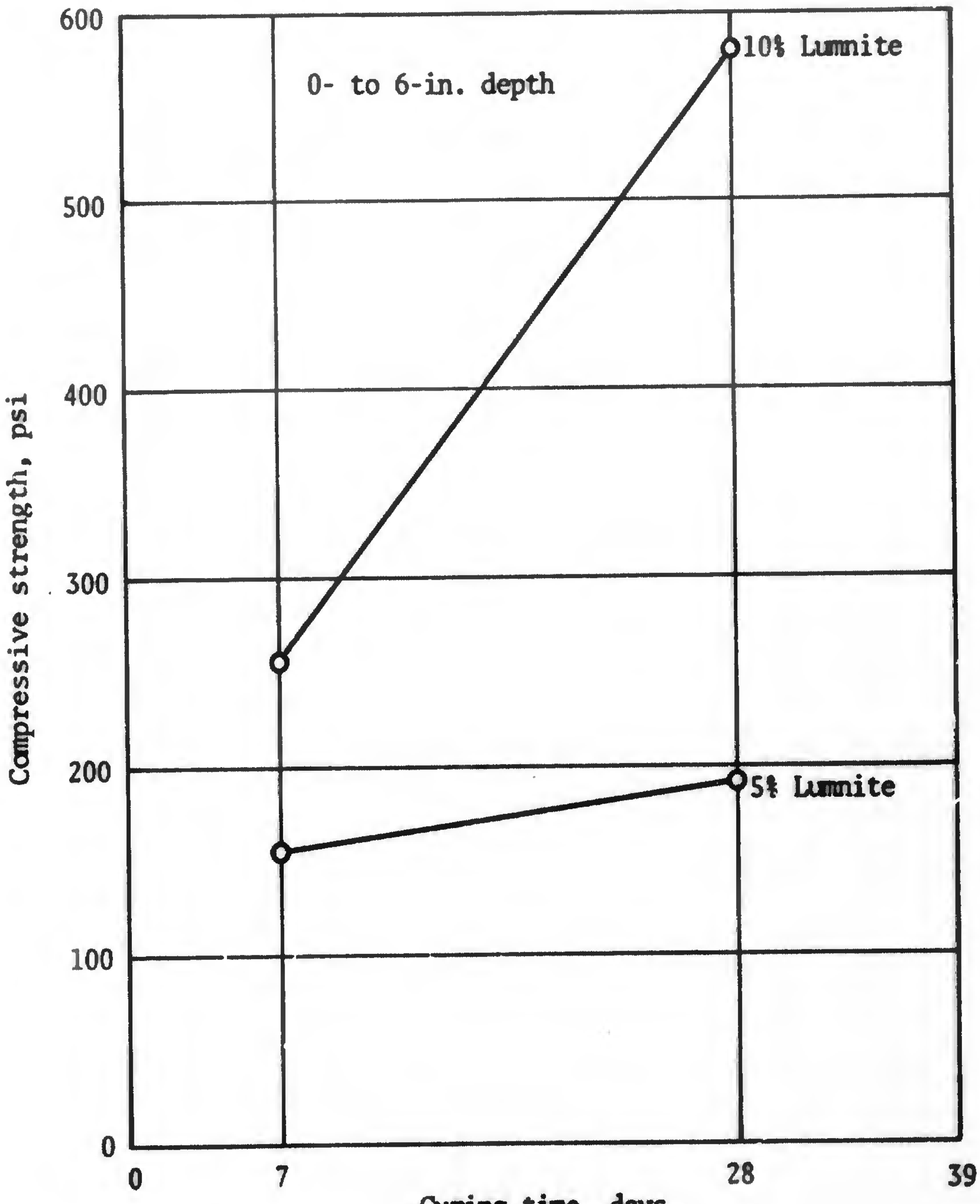


Figure 45. Compressive-strength changes with time in compacted soil-cement mixtures (aluminous cement), Phan Rang sample 1

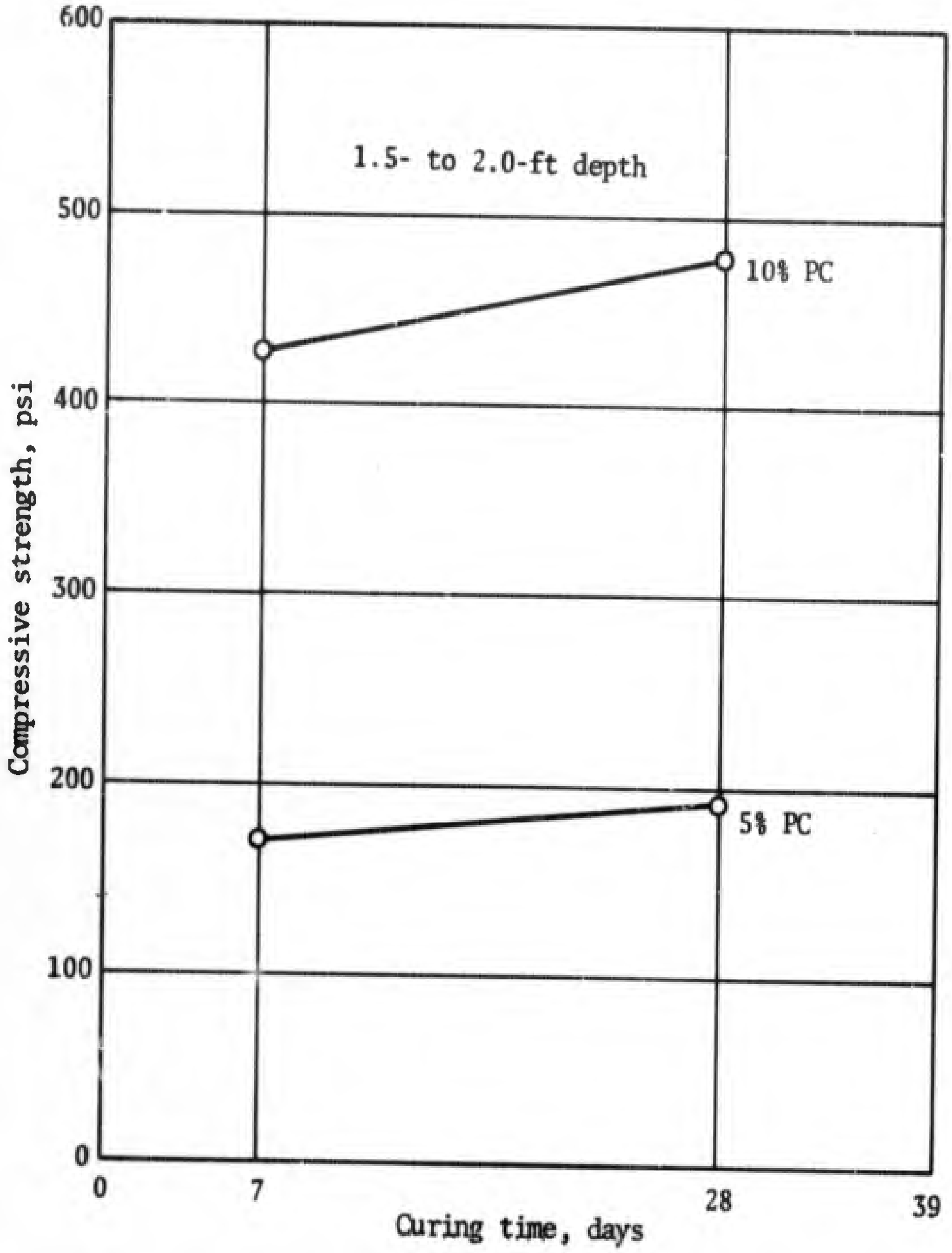


Figure 46. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Phan Rang sample 2

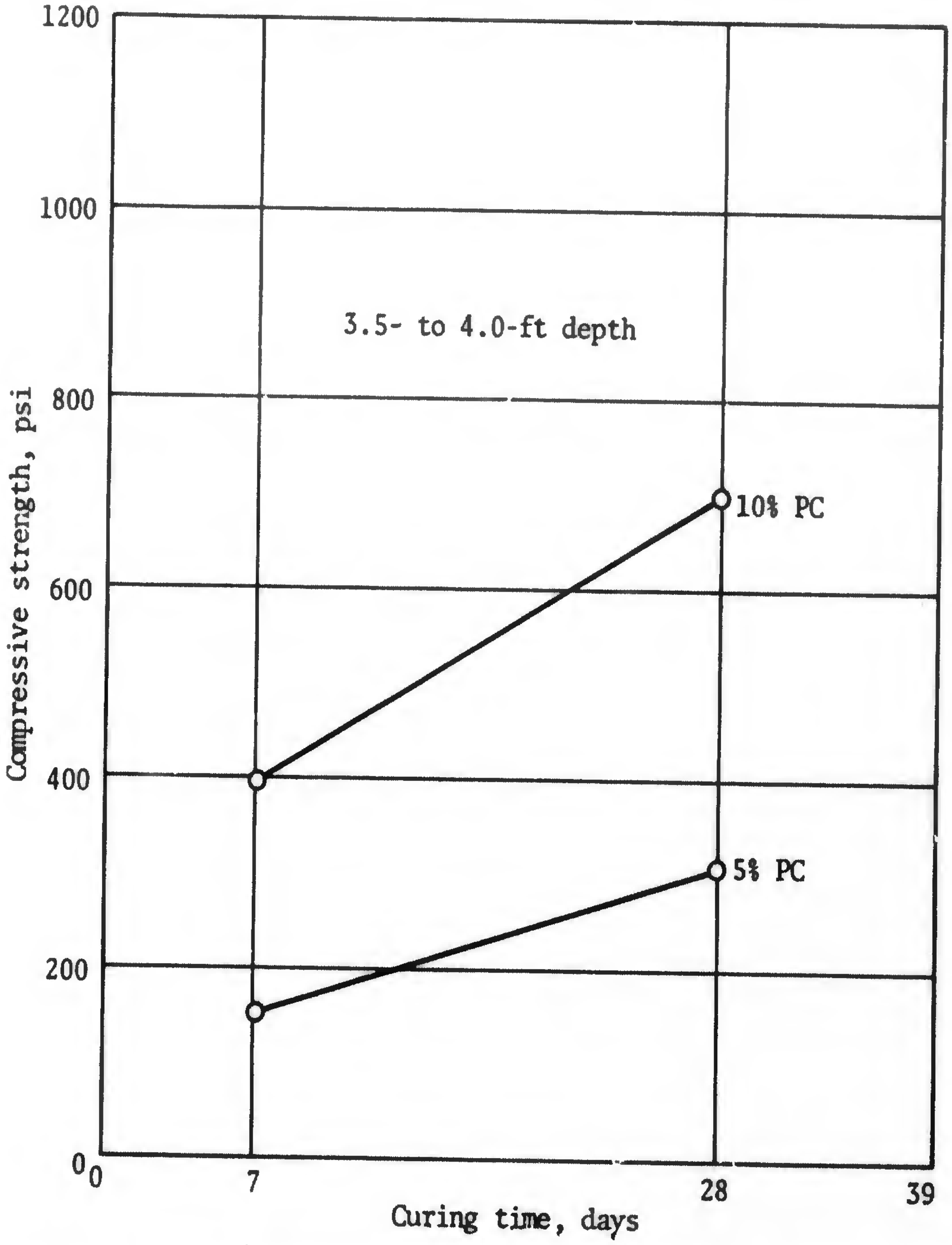


Figure 47. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Phan Rang sample 3

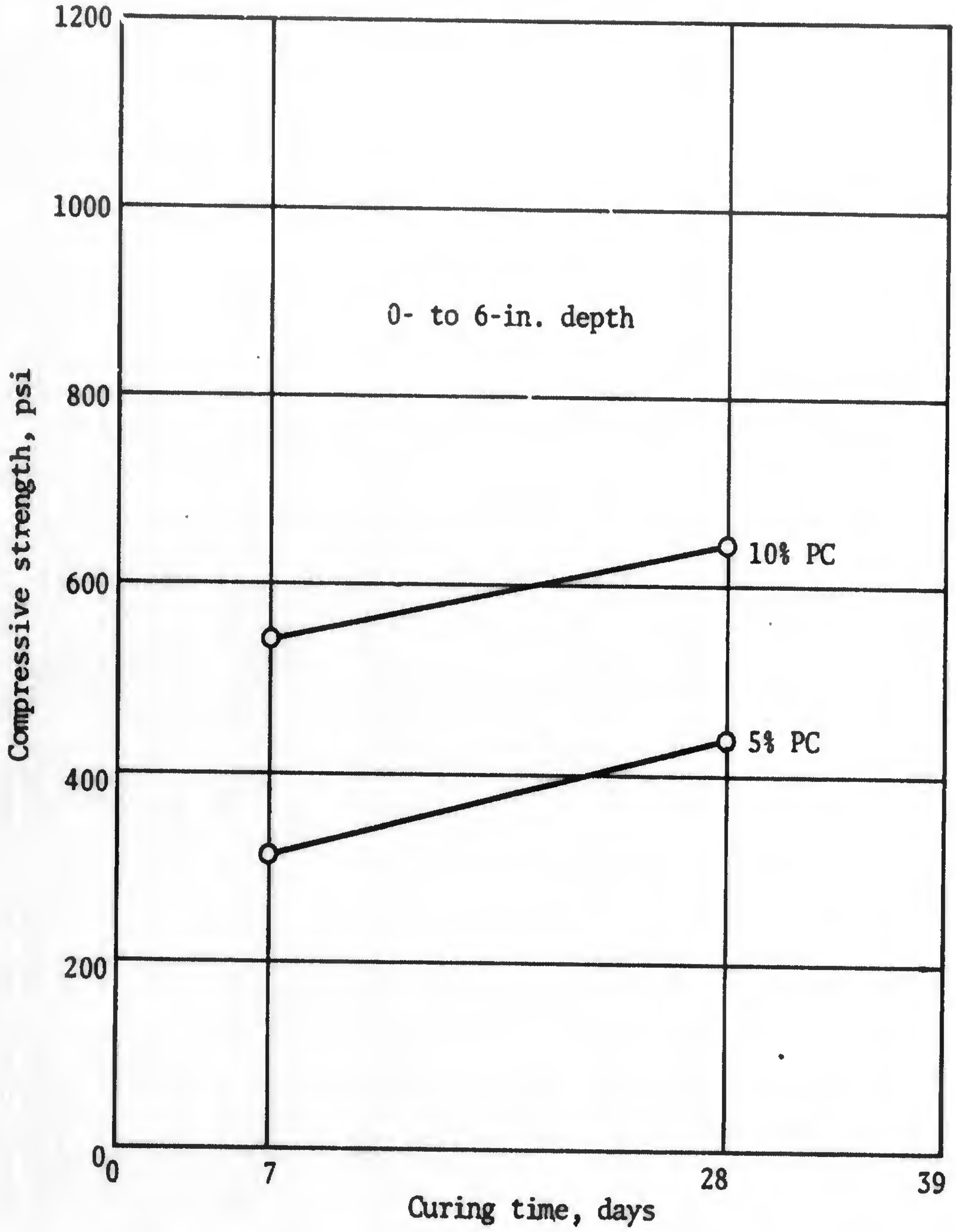


Figure 48. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Phan Rang sample 4

TAN SON NHUT

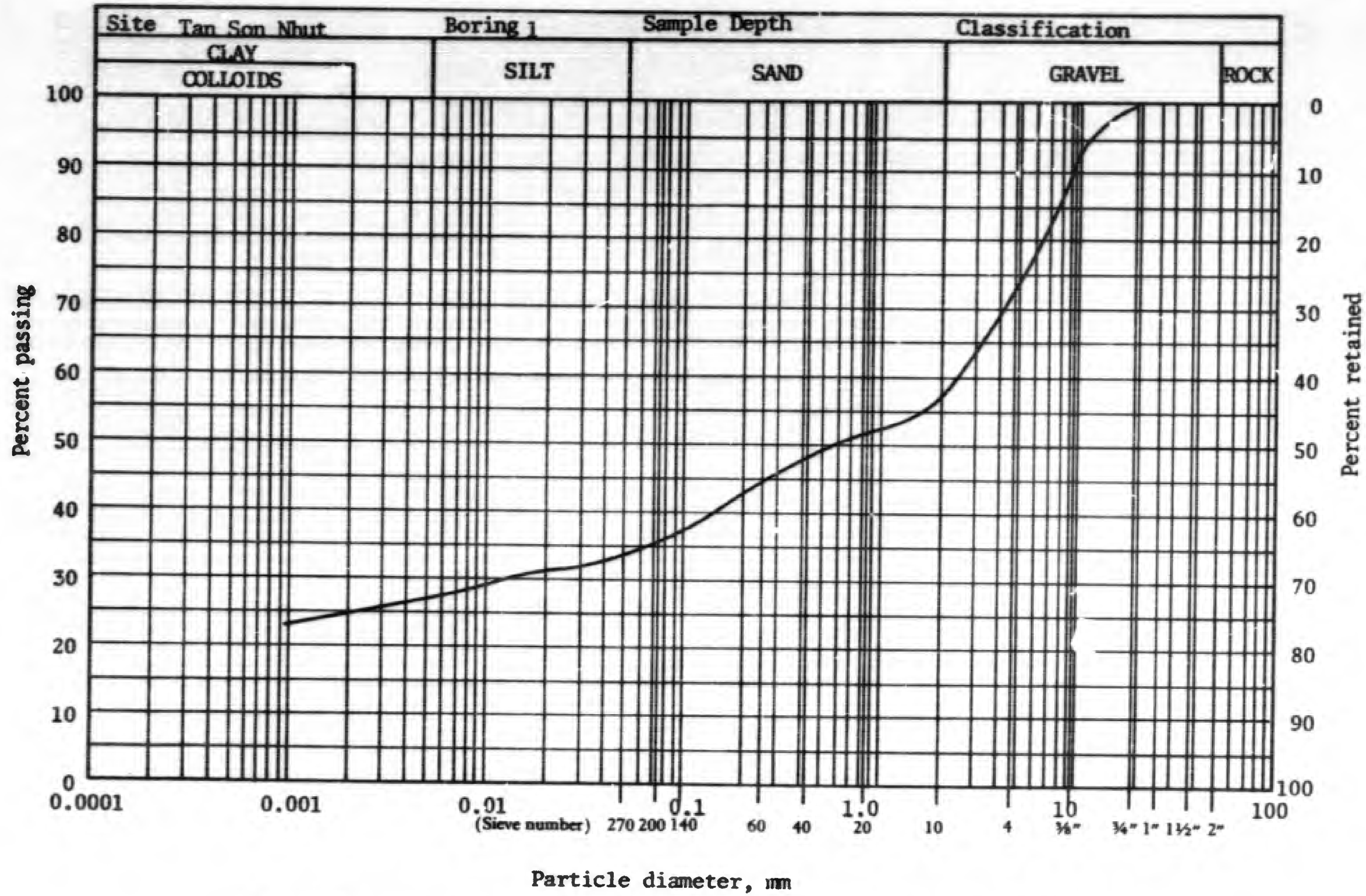


Figure 49. Grain-size distribution curve, Tan Son Nhut sample 1

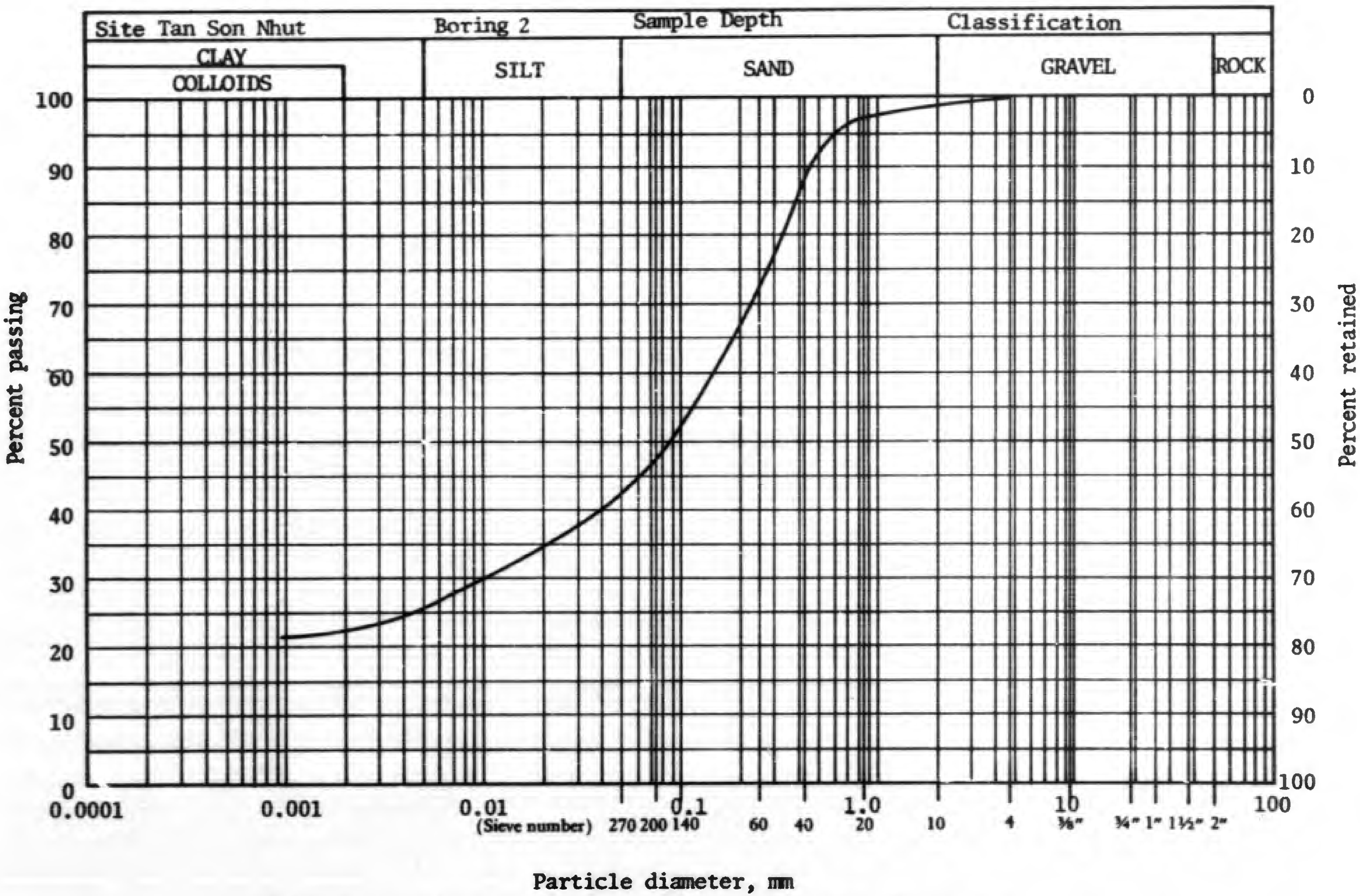


Figure 50. Grain-size distribution curve, Tan Son Nhut sample 2

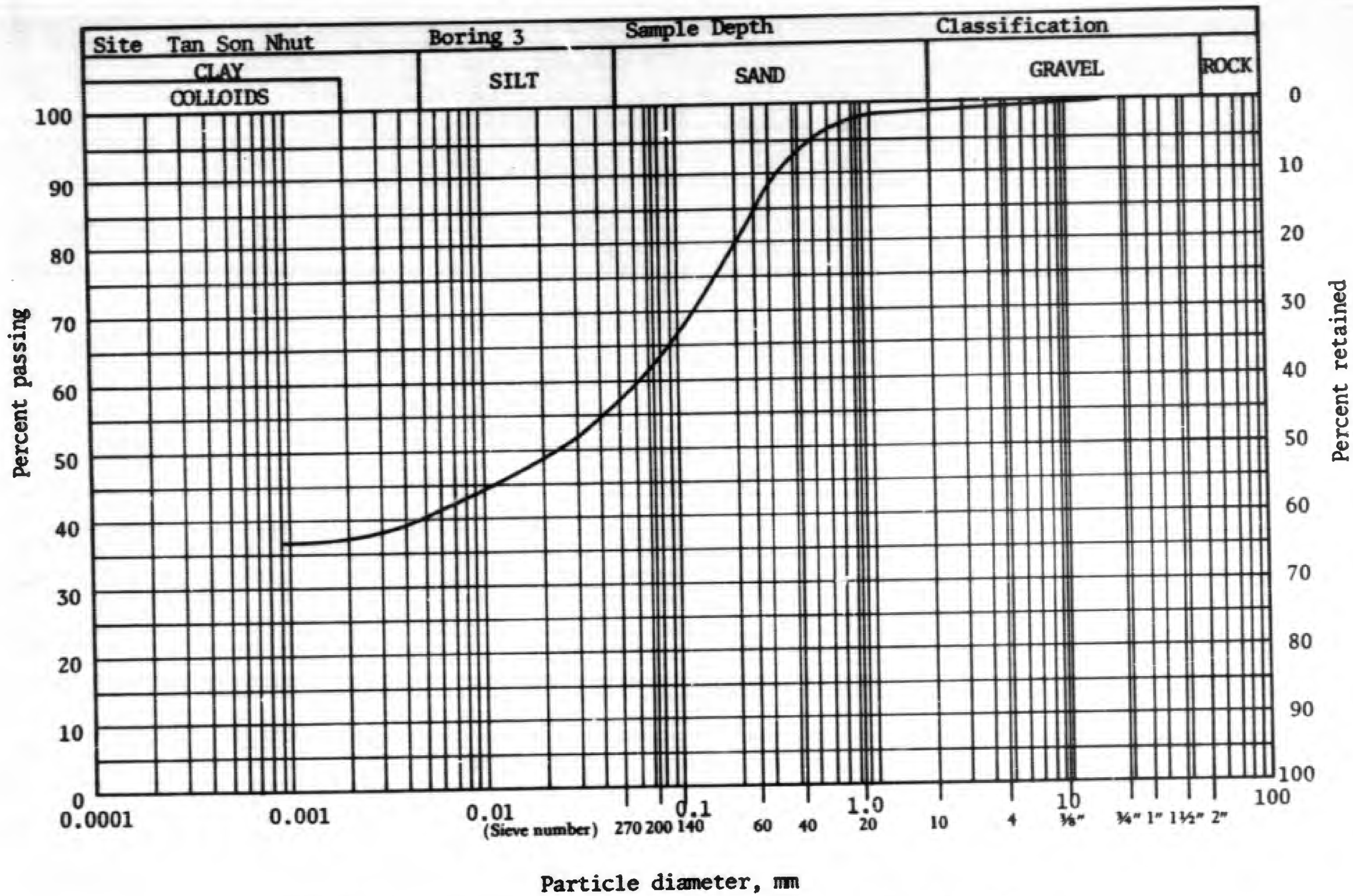


Figure 51. Grain-size distribution curve, Tan Son Nhut sample 3

TABLE 18

PROPERTIES OF SOILS FROM TAN SON NHUT

Soil Sample:	1	2	3
Textural Composition: %			
Sand (2.0-0.05 mm)	23	57	42
Silt (50-5 μ)	8	17	17
Clay (<5 μ)	27	25	40
Classifications:			
Unified	SC	SC	CL
AASHO	A-2-7[3]	A-4[3]	A-6[10]
Physical Properties:			
Liquid limit, %	47	20	34
Plastic limit, %	24	12	14
Plasticity Index, %	23	8	20
Activity[1,2]	0.52	0.31	0.53
Specific gravity[1]	2.71	2.62	2.71
ASTM standard compaction:[3]			
Dry density, lb/cu ft	106.0	126.0	113.0
Optimum moisture content, %	20.0	11.0	15.5
Chemical Properties:[1]			
Equivalent Fe_2O_3, %	5.2	0.7	1.0
Total soluble salt, %	0.8	0.8	0.7
Organic matter, %	0.3	0.5	0.3
pH	4.87	5.35	4.37

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay fraction.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 19

SOIL MINERALOGY, TAN SON NHUT

Mineral, % Sample:	1	2	3
Fraction Passing No. 10 Sieve, %	56.6	99.0	99.4
Quartz	30	65	55
Feldspar (perthite)	2	1	1
Kaolinite	35	25	30
Illite	--	--	--
Goethite	5.8	0.8	1.2
Other minerals:		--	
Other clays	10		10
Fraction Retained on No. 10 Sieve			
Quartz	30	--	--
Feldspar (perthite)	5	--	--
Kaolinite	20	--	--
Illite	--	--	--
Goethite	20	--	--
Other minerals:		--	--
Hematite	15		
		Percent	
Moisture content of samples when received	12.3	12.6	14.7
Air-dry moisture content of material finer than 2 mm	1.6	1.1	1.0
Air-dry moisture content of material coarser than 2 mm	1.7	--	--

TABLE 20

STABILIZATION OF SOILS FROM TAN SON NHUT[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.016	0.014	40	208
	10.0% PC	0.025	0.021	155	418
	6.0% Thailand lime	0.011	0.010	24	16[2]
	6.0% U.S. lime	0.004	0.005	9	8[2]
2	5,0% PC	0.014	0.013	197	262
	10.0% PC	0.022	0.018	436	522
3	5.0% PC	0.010	0.016	166	286
	10.0% PC	0.021	0.022	577	755

[1]Determined for the fraction passing No. 20 sieve.

[2]Tested after 14 days curing time.

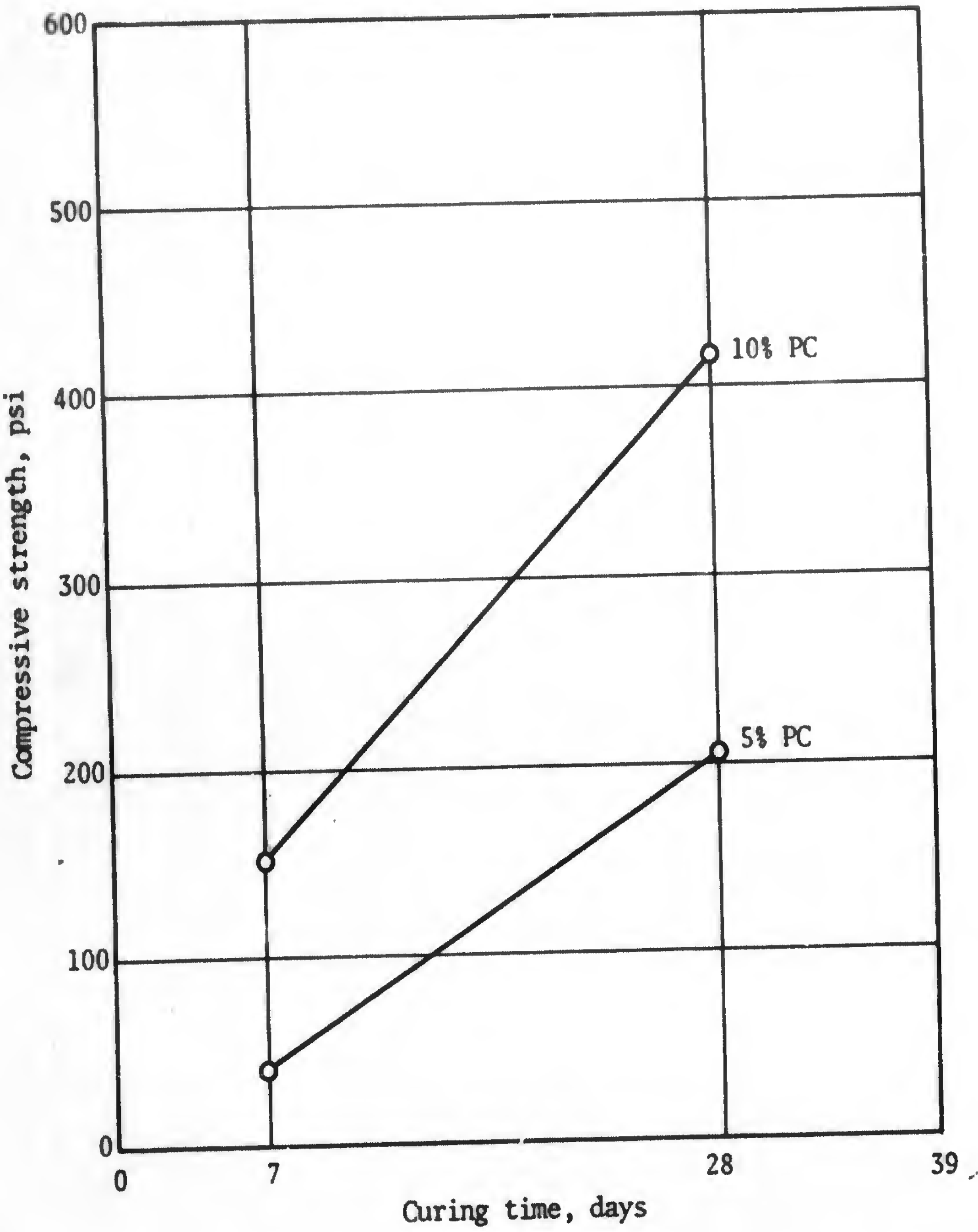


Figure 52. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Tan Son Nhut sample 1

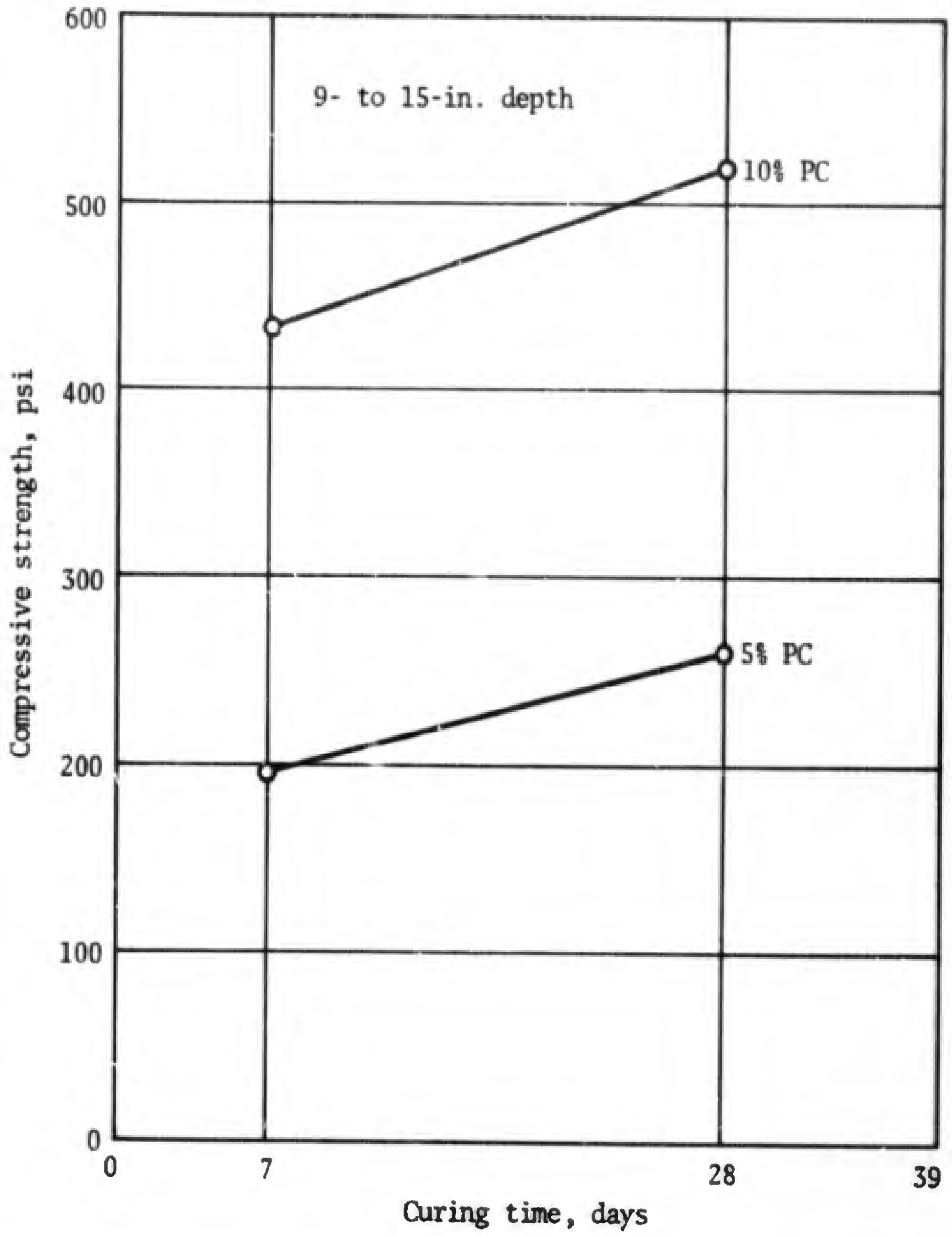


Figure 53. Compressive-strength changes with time compacted soil-cement mixtures (portland cement), Tan Son Nhut sample 2

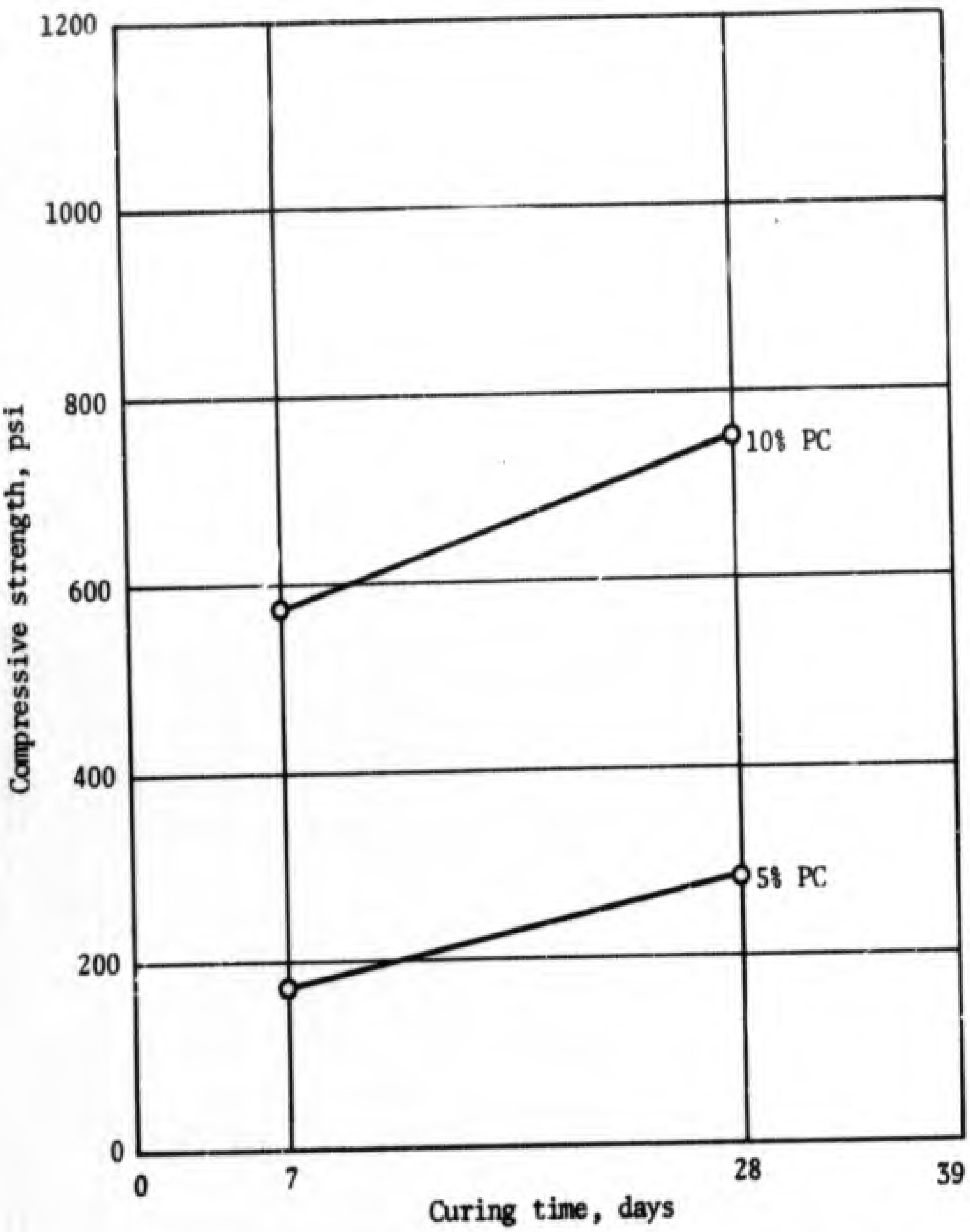


Figure 54. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Tan Son Nhut sample 3

TUY HOA

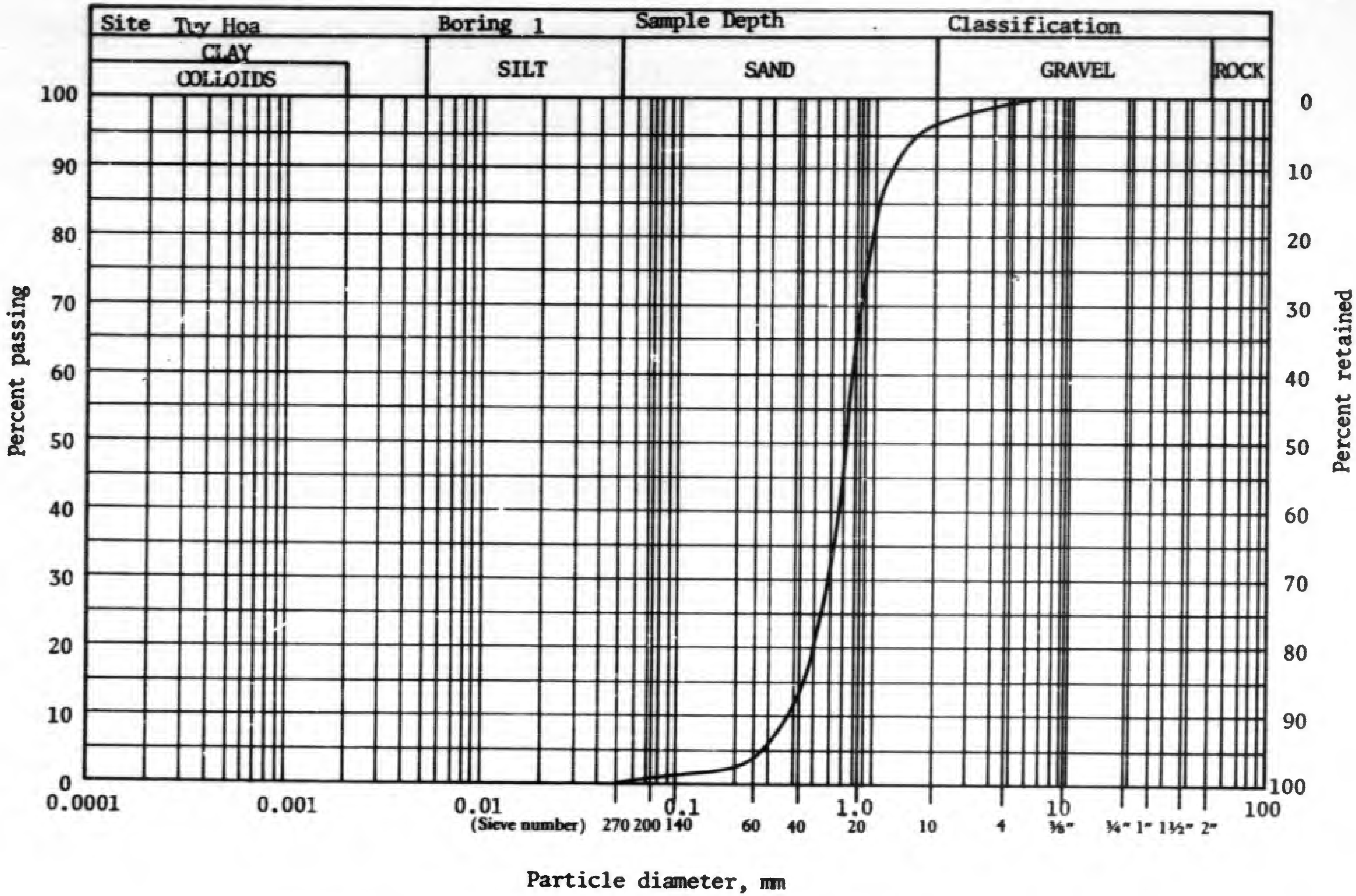


Figure 55. Grain-size distribution curve, Tuy Hoa sample 1

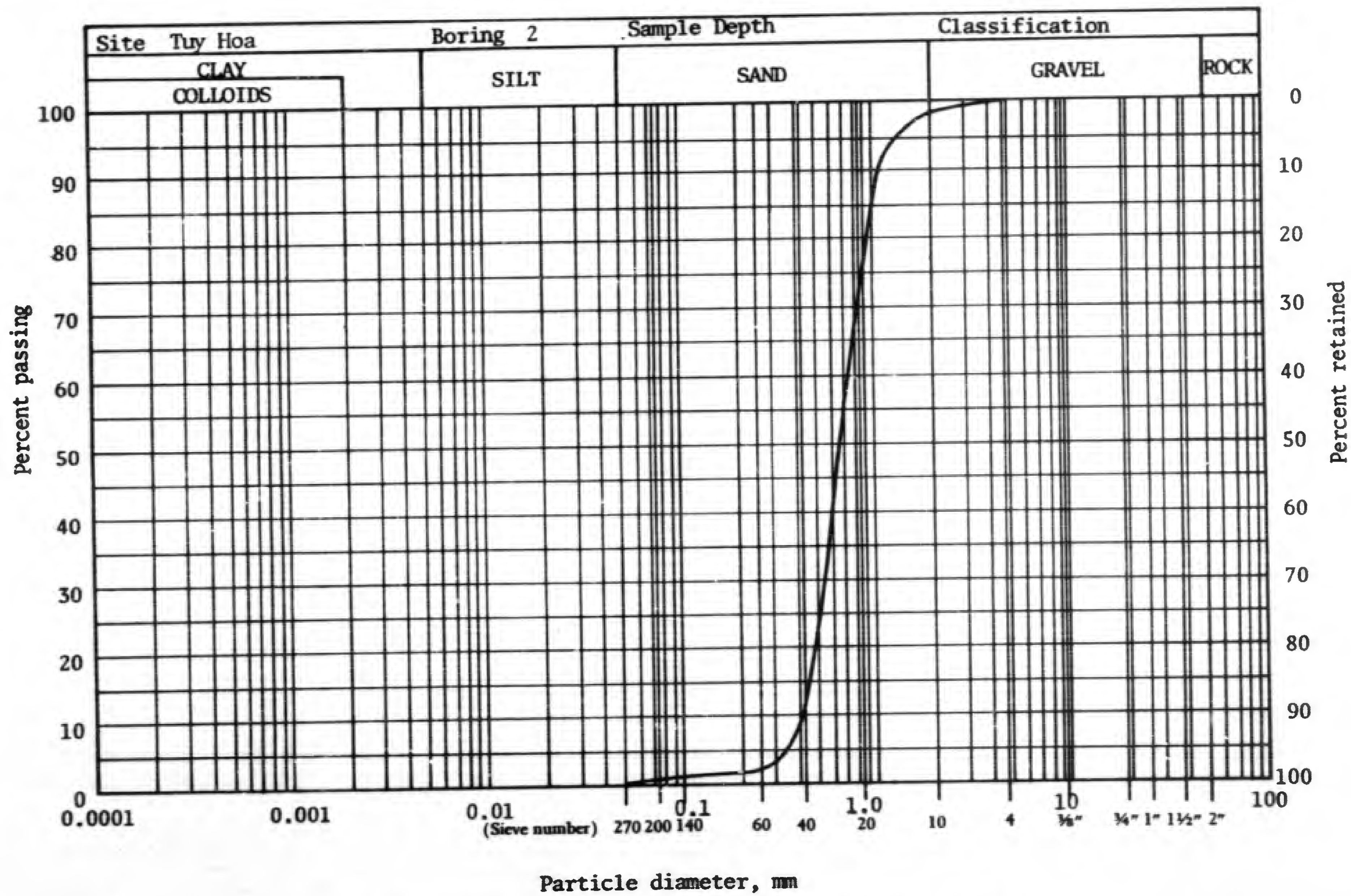


Figure 56. Grain-size distribution curve, Tuy Hoa sample 2

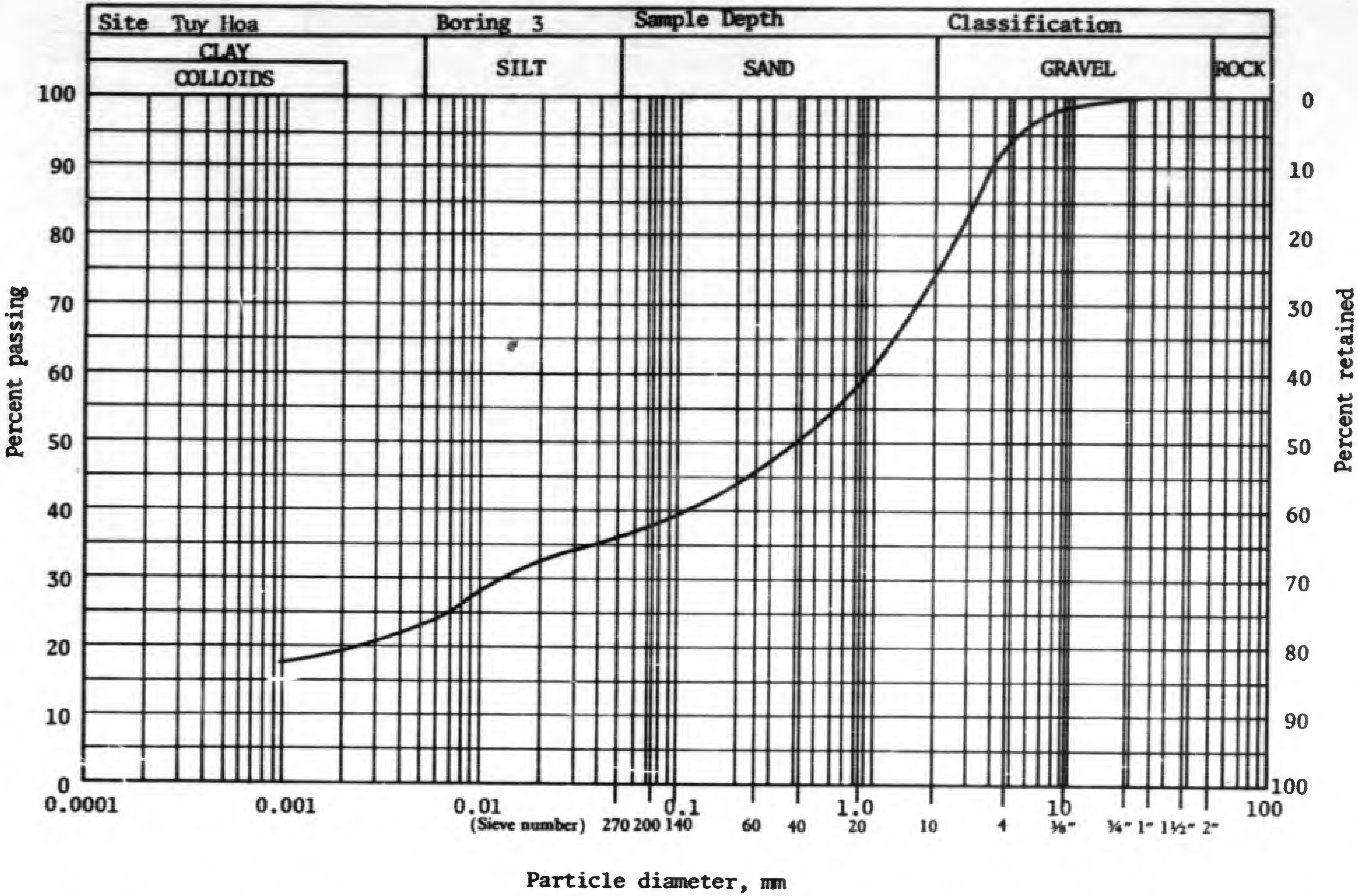


Figure 57. Grain-size distribution curve, Tuy Hoa sample 3

TABLE 21

PROPERTIES OF SOILS FROM TUY HOA

Soil Sample:	1	2	3
Textural Composition: %			
Sand (2.0-0.05 mm)	97	98	38
Silt (50-5 μ)	0	0	13
Clay (<5 μ)	0	0	23
Classifications:			
Unified	SP	SP	SM
AASHO	A-1-b[0]	A-1-b[0]	A-7-6[2]
Physical Properties:			
Liquid limit, %	--	--	42
Plastic limit, %	--	--	28
Plasticity Index, %	N.P.	N.P.	14
Activity[1,2]	--	--	0.54
Specific gravity[1]	2.63	2.66	2.60
ASTM standard compaction:[3]			
Dry density, lb/cu ft	99.5	100.0	99.5
Optimum moisture content, %	11.0	10.0	22.0
Chemical Properties:[1]			
Equivalent Fe_2O_3, %	0.7	1.0	3.1
Total soluble salt, %	0.7	0.8	0.7
Organic matter, %	0.0	0.1	0.2
pH	7.02	6.98	5.78

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay fraction.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 22

SOIL MINERALOGY, TUY HOA

Mineral, %	Sample: 1	2	3
Fraction Passing No. 10 Sieve, %	96.5	98.5	74.3
Quartz	60	55	20
Feldspar (perthite)	25	25	15
Kaolinite	1	1	30
Illite-mica	3	2	5
Goethite	0.7	1.1	3.5
Other minerals:	--	--	
Chlorite			5
Fraction Retained on No. 10 Sieve			
Quartz	--	--	55
Feldspar (perthite)			20
Kaolinite			5
Illite-mica			5
Goethite			2.0
Other minerals:			
Chorite			5
		Percent	
Moisture content of samples when received	3.1	3.1	19.8
Air-dry moisture content of material finer than 2 mm	0.1	0.2	1.2
Air-dry moisture content of material coarser than 2 mm	--	--	0.3

TABLE 23

STABILIZATION OF SOILS FROM TUY HOA[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.015	0.017	32	94
	10.0% PC	0.014	0.015	217	377
	5.0% PC + 10.0% clay[2]	0.015	0.013	199	258
	5.0% PC + 20.0% clay[2]	0.010	0.013	178	282
	10.0% PC + 10.0% clay[2]	0.019	0.028	564	708
	10.0% PC + 20.0% clay[2]	0.012	0.019	339	569
2	5.0% PC	0.010	0.014	77	168
	10.0% PC	0.015	0.015	229	525
3	5.0% PC	0.012	0.009	129	132
	10.0% PC	0.021	0.016	654	383
	6.0% Thailand lime	0.008	0.008	38	41
	6.0% U.S. lime	0.012	0.007	24	24
	5.0% Lumnite	0.011	0.011	58	82
	10.0% Lumnite	0.012	0.011	171	187

[1]Determined for the fraction passing No. 20 sieve.

[2]Florida kaolinite was used.

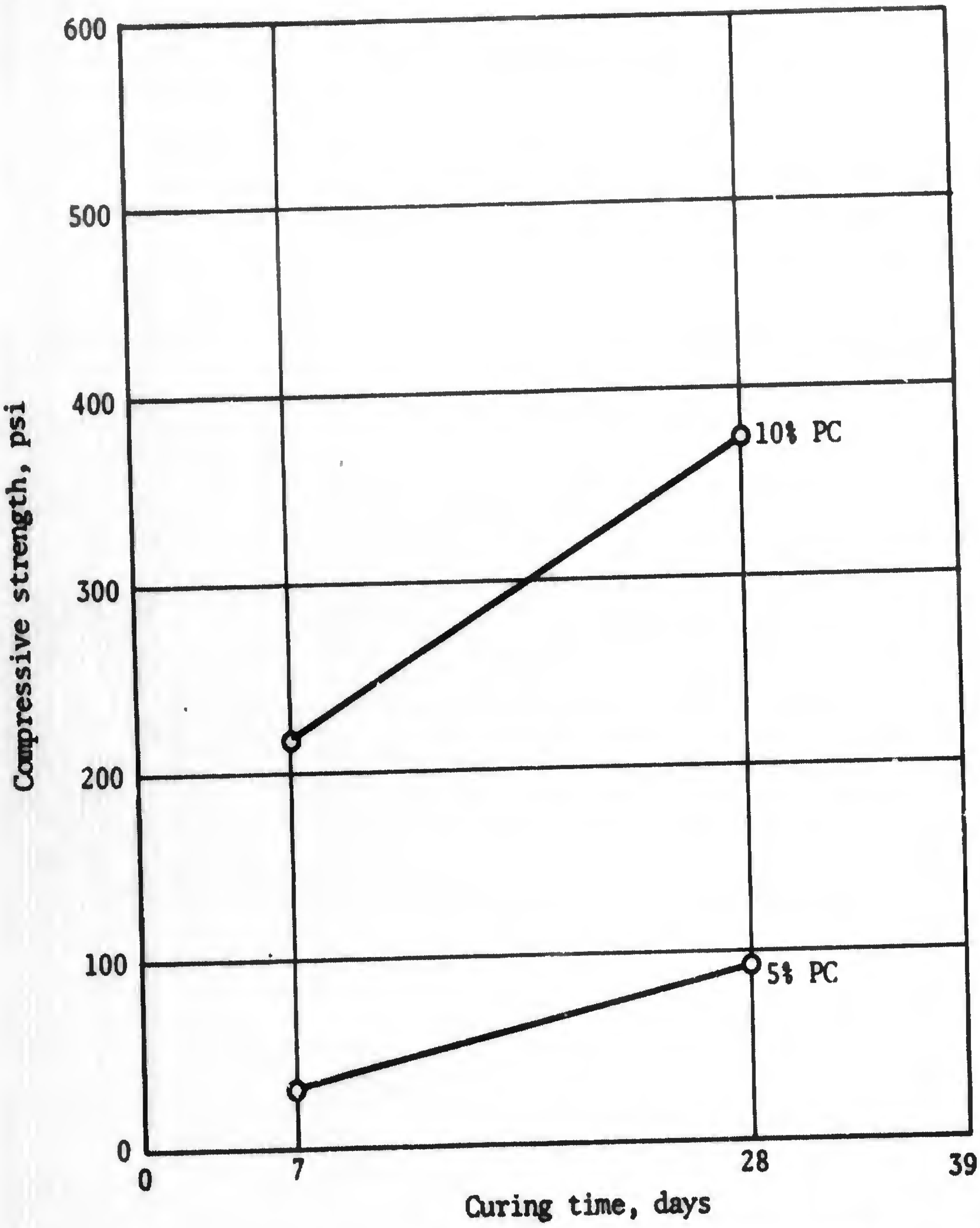


Figure 58. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Tuy Hoa sample 1

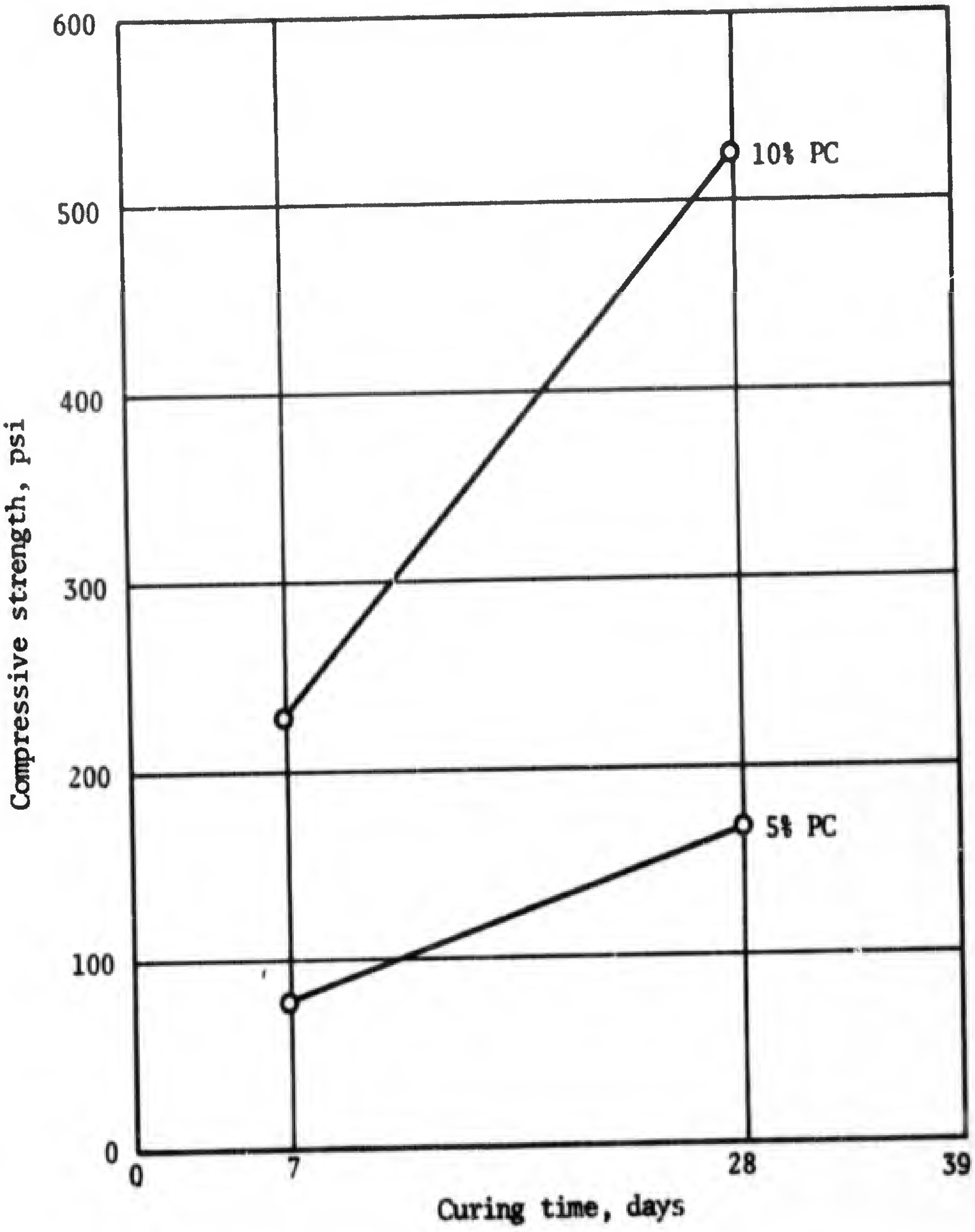


Figure 59. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Tuy Hoa sample 2

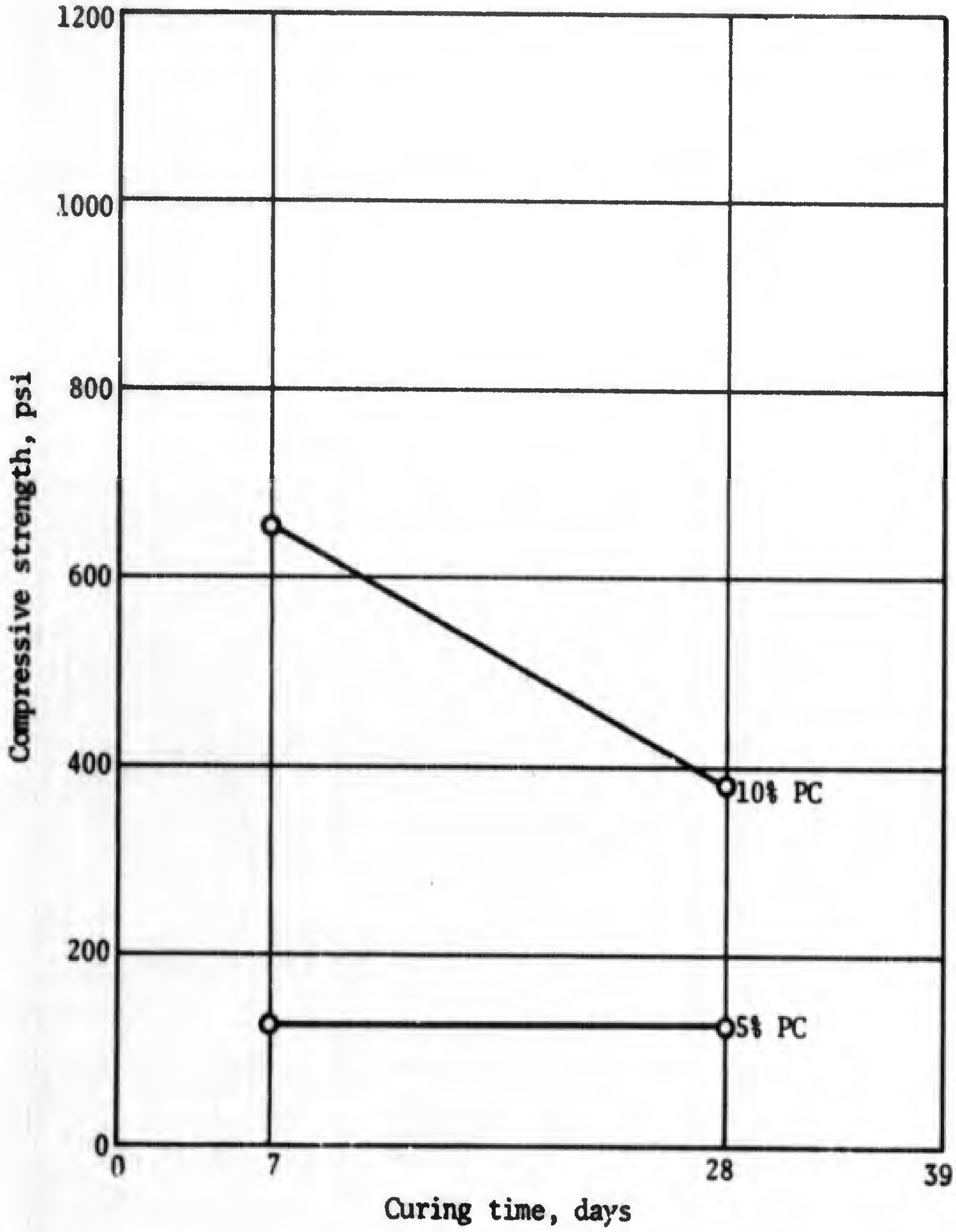


Figure 60. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Tuy Hoa sample 3

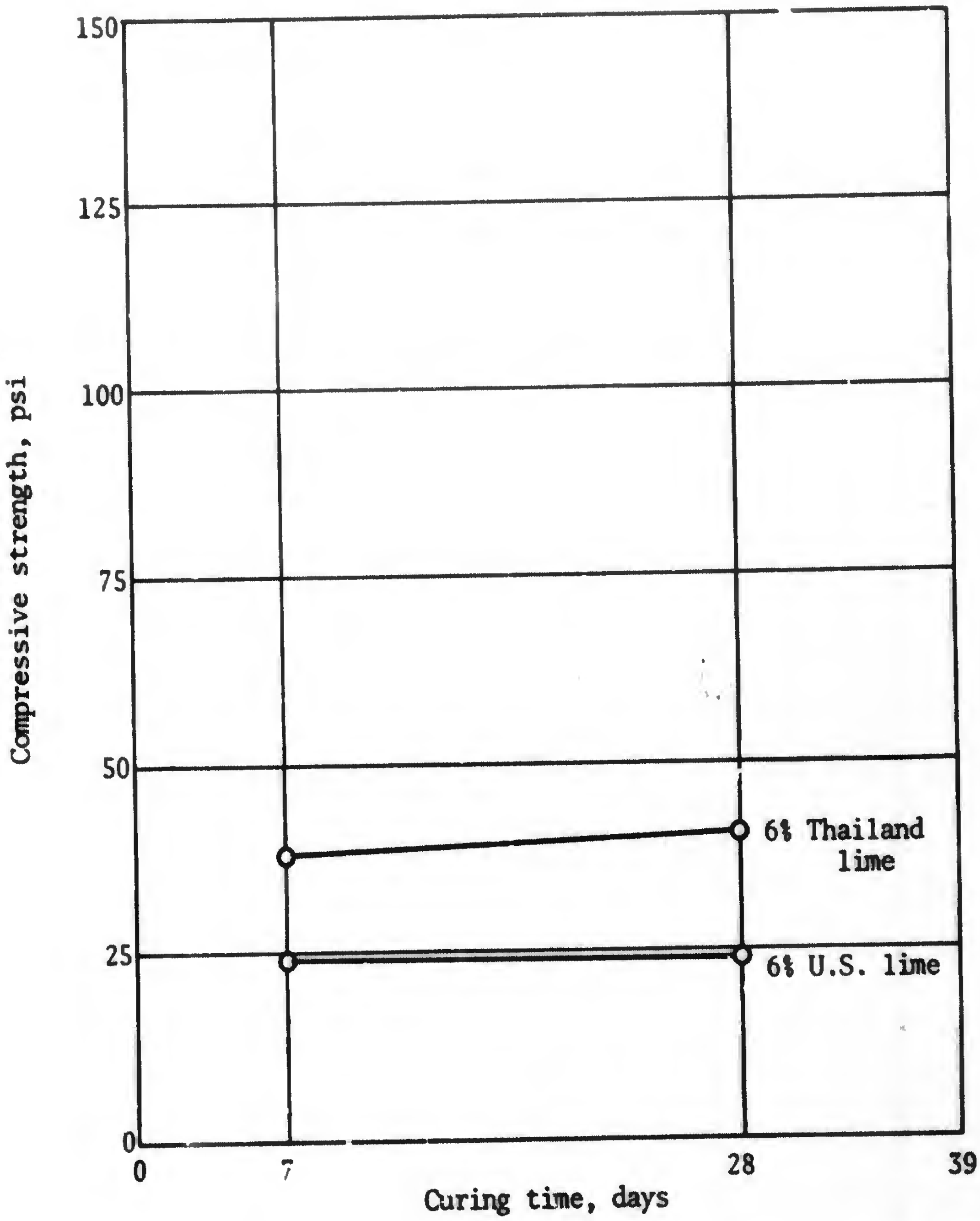


Figure 61. Compressive-strength changes with time in compacted soil-cement mixtures (lime), Tuy Hoa sample 3

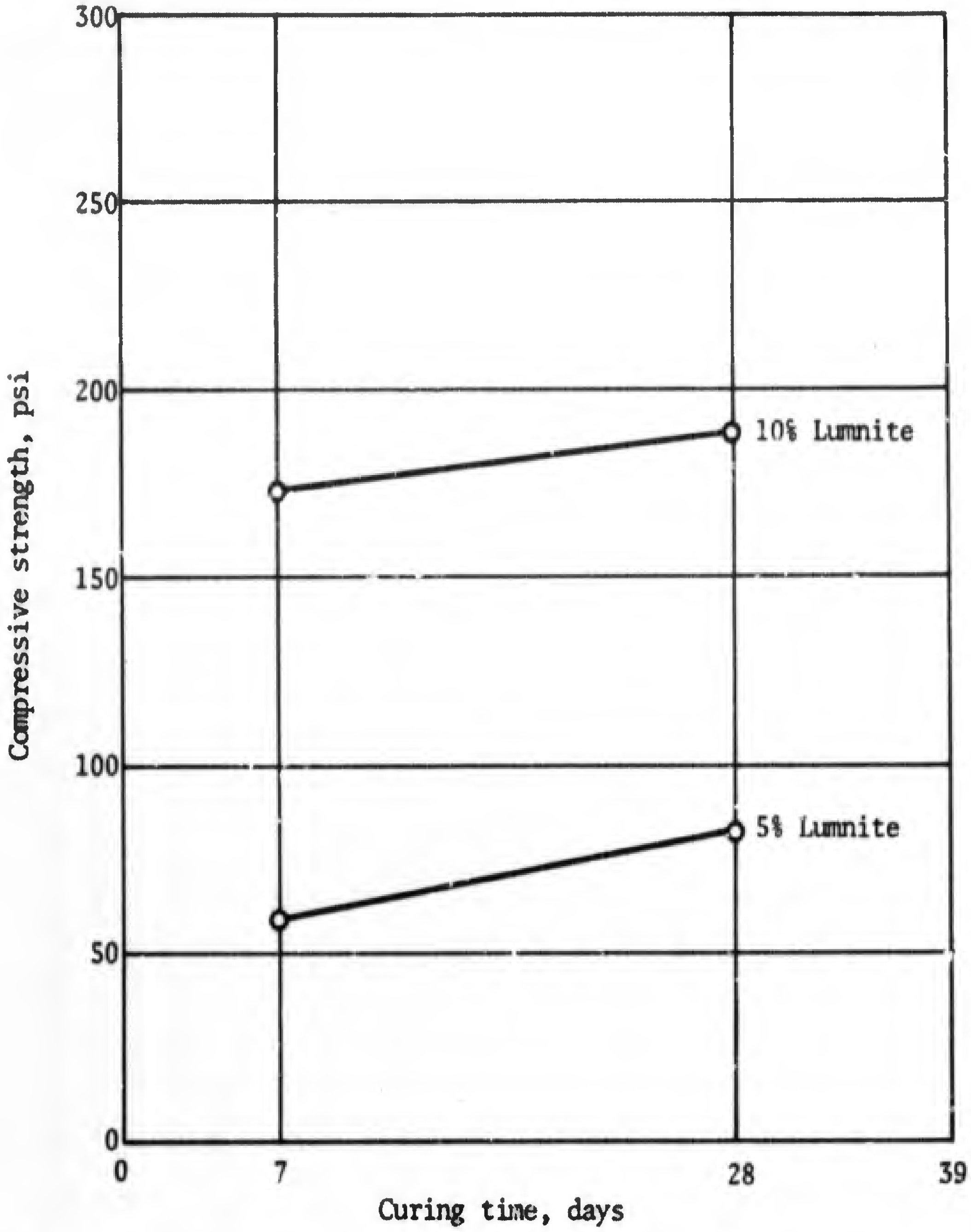


Figure 62. Compressive-strength changes with time in compacted soil-cement mixtures (aluminous cement), Tuy Hoa sample 3

UBON

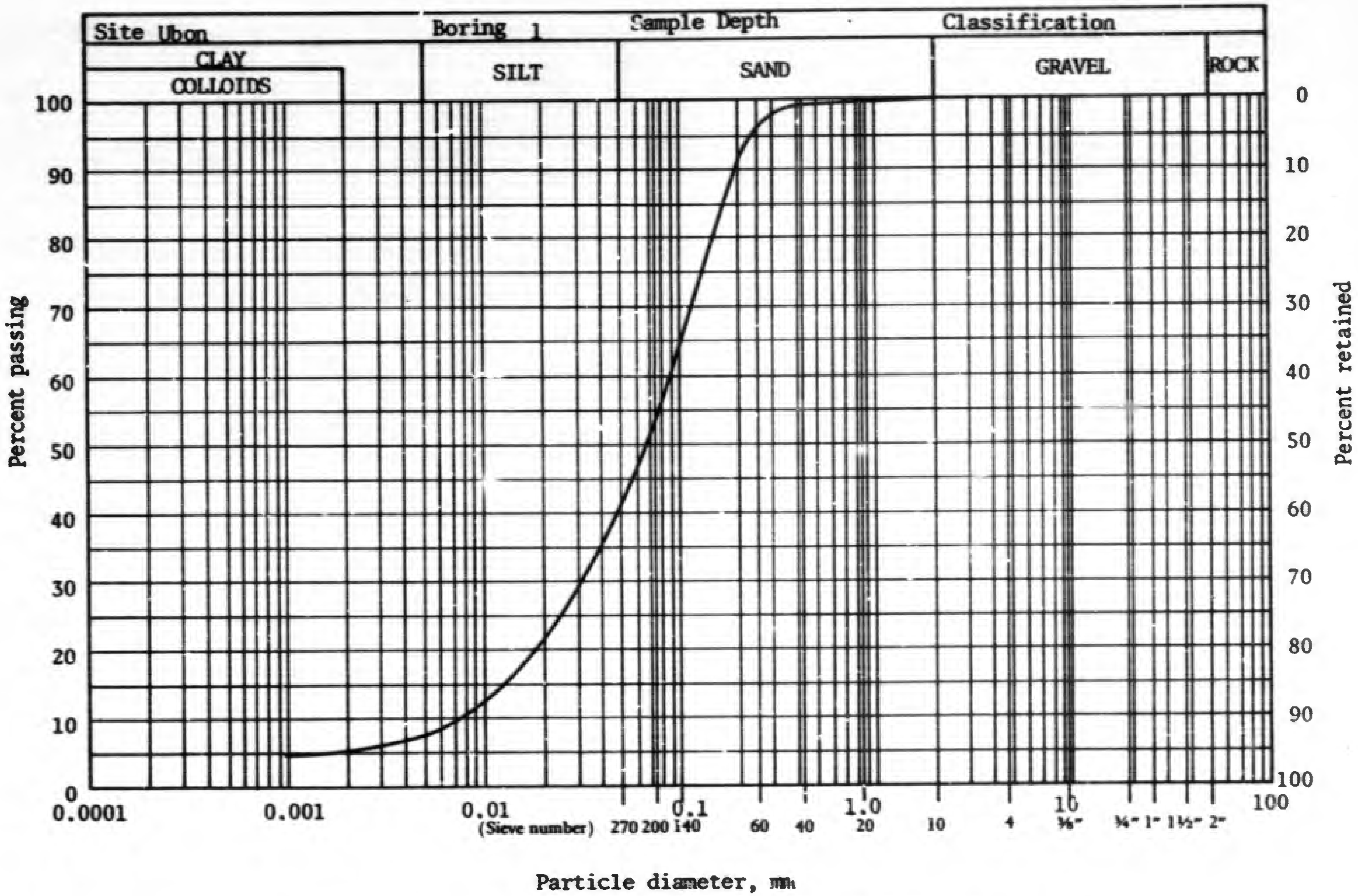


Figure 63. Grain-size distribution curve, Ubon sample 1

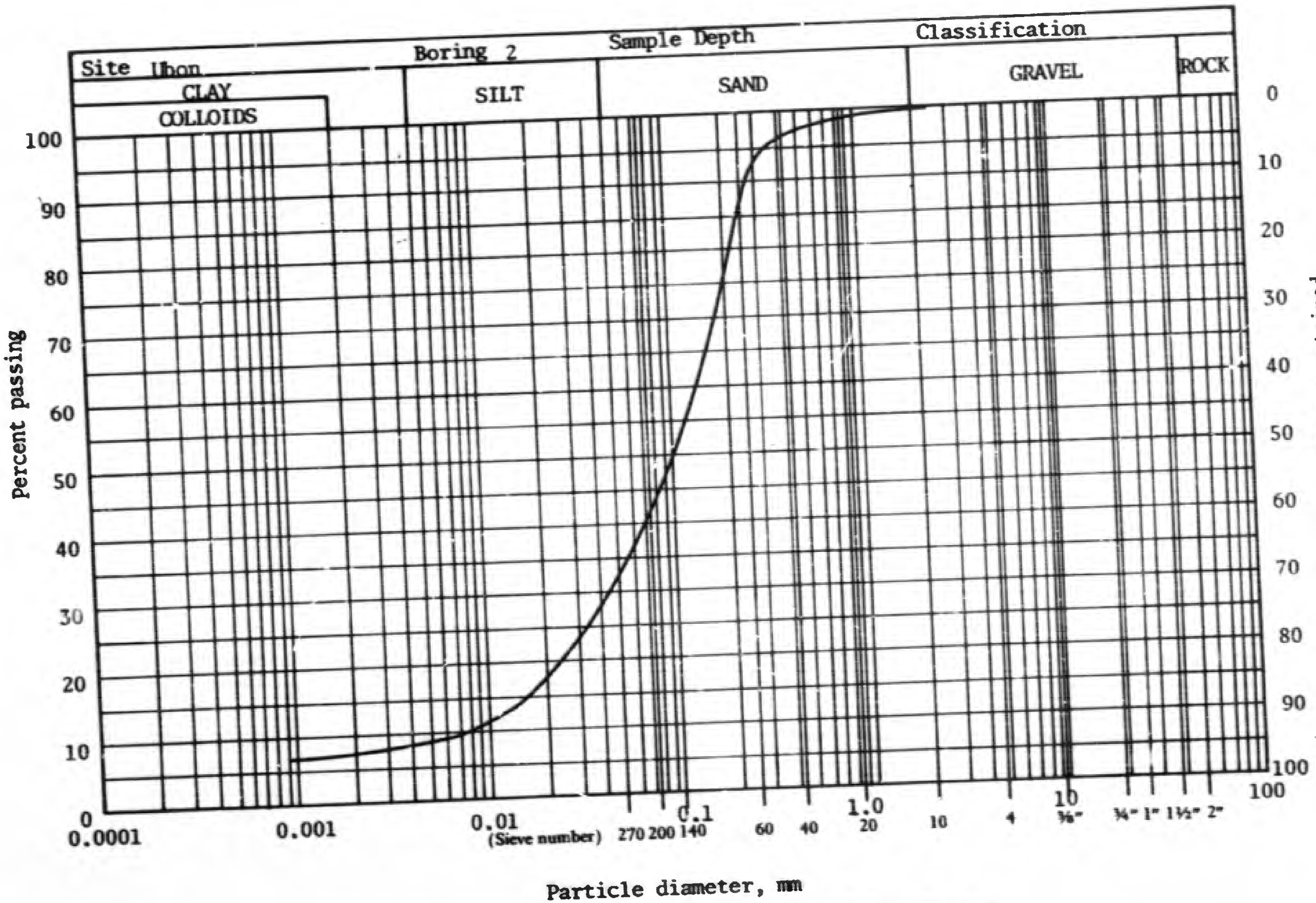


Figure 64. Grain-size distribution curve, Ubon sample 2

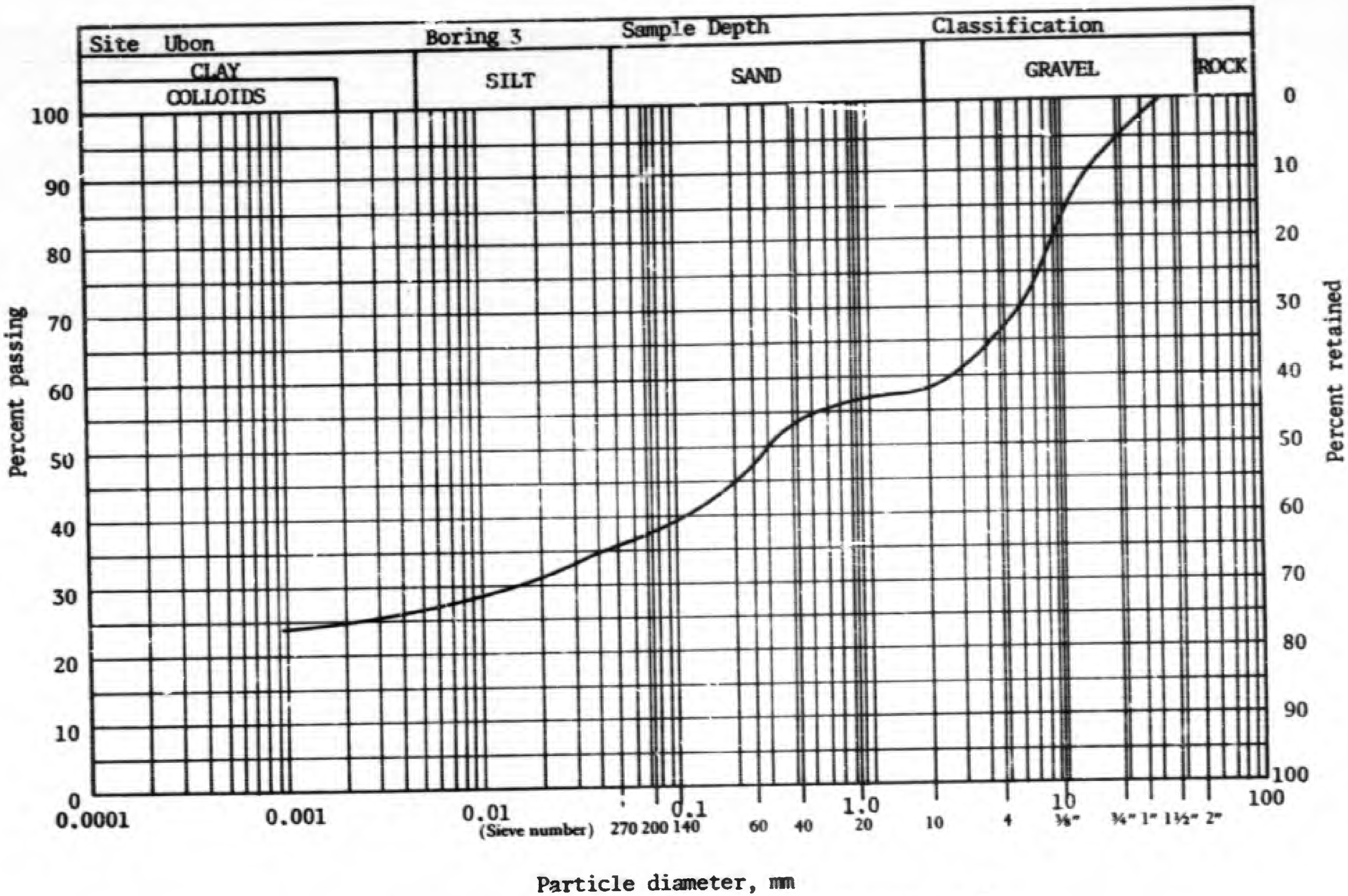


Figure 65. Grain-size distribution curve, Ubon sample 3

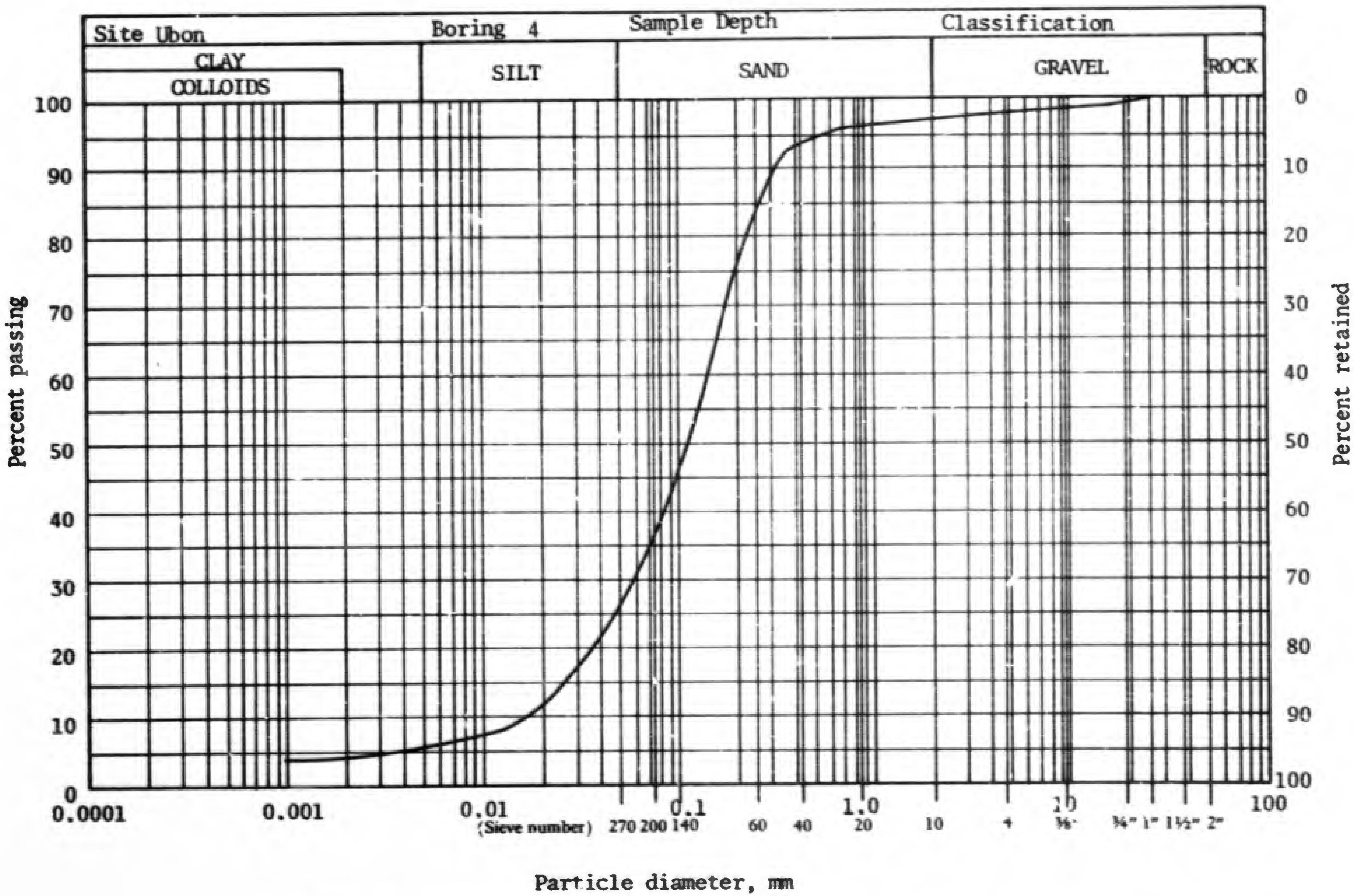


Figure 66. Grain-size distribution curve, Ubon sample 4

TABLE 24

PROPERTIES OF SOILS FROM UBON

Soil Sample:	1	2	3	4
Textural Composition: %				
Sand (2.0-0.05 mm)	59	68	22	66
Silt (50-5 μ)	34	23	9	20
Clay (<5 μ)	7	9	27	6
Classifications:				
Unified	ML	SM	GC	SM
AASHO	A-4[4]	A-4[1]	A-7-6[4]	A-2-4[0]
Physical Properties:				
Liquid limit, %	--	--	44	--
Plastic limit, %	--	--	23	--
Plasticity Index, %	N.P.	N.P.	21	N.P.
Activity[1,2]	--	--	0.49	--
Specific Gravity[1]	2.60	2.66	2.72	2.62
ASTM Standard Compaction:[3]				
Dry density, lb/cu ft	112.5	120.0	103.5	110.0
Optimum moisture content, %	14.5	9.0	22.0	12.0
Chemical Properties:[1]				
Equivalent Fe_2O_3, %	0.4	1.2	6.8	0.5
Total soluble salt, %	0.9	0.7	0.7	0.8
Organic matter, %	1.1	0.1	0.3	0.5
pH	5.76	6.37	5.27	6.69

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay fraction.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 25

SOIL MINERALOGY, UBON

Mineral, % Sample:	1	2	3	4
Fraction Passing No. 10 Sieve, %	99.7	99.7	58.1	97.0
Quartz	85	90	40	90
Feldspar (perthite)	--	2	--	2
Kaolinite	--	--	40	2
Illite-mica	2	--	--	--
Goethite	0.5	1.4	7.5	0.6
Other minerals:				
Amphibole	3			
Other clays	5	5	5	3
Fraction Retained on No. 10 Sieve				
Quartz	--	--	20	--
Feldspar (perthite)	--	--	--	--
Kaolinite	--	--	15	--
Illite	--	--	10	--
Goethite	--	--	20	--
Other minerals:	--	--		--
Hematite			10	
Other clays			5	
		Percent		
Moisture content of samples when received	5.0	11.5	18.2	1.6
Air-dry moisture content of material finer than 2 mm	0.3	0.2	1.3	0.3
Air-dry moisture content of material coarser than 2 mm	--	--	1.7	--

TABLE 26

STABILIZATION OF SOILS FROM UBON[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.006	0.009	30	84
	10.0% PC	0.012	0.021	197	708
	5.0% PC + 4.0% lime	0.009	0.010	16	28[2]
2	5.0% PC	0.021	0.011	522	511
	10.0% PC	0.041	0.018	1245	1585
3	5.0% PC	0.013	0.015	265	259
	10.0% PC	0.019	0.020	455	504
4	5.0% PC	0.011	0.016	136	272
	10.0% PC	0.024	0.024	356	739
	5.0% Thailand PC	0.014	0.016	183	257[2]
	10.0% Thailand PC	0.019	0.022	604	770[2]

[1]Determined for the fraction passing No. 20 sieve.

[2]Tested after 14 days curing time.

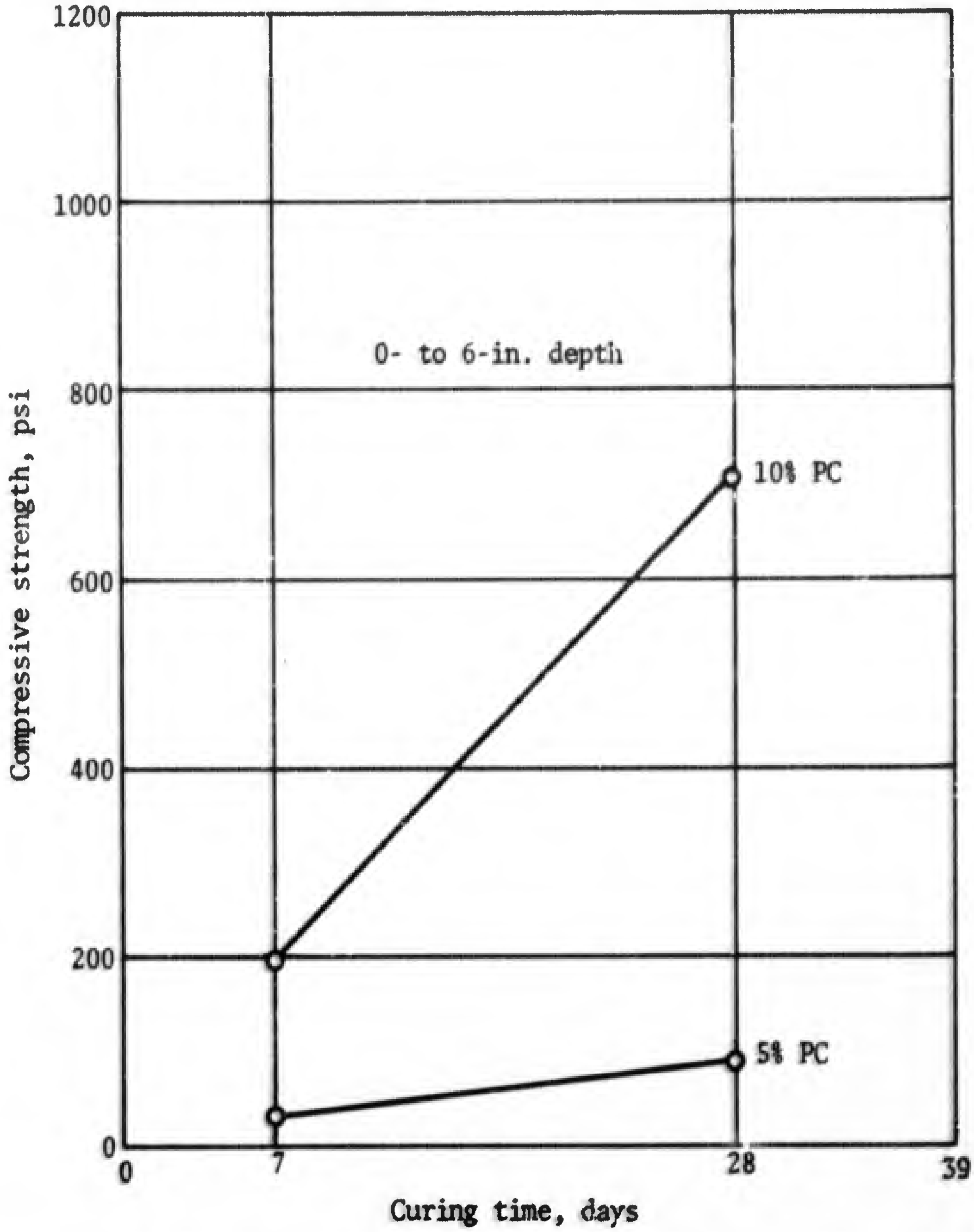


Figure 67. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Ubon sample 1

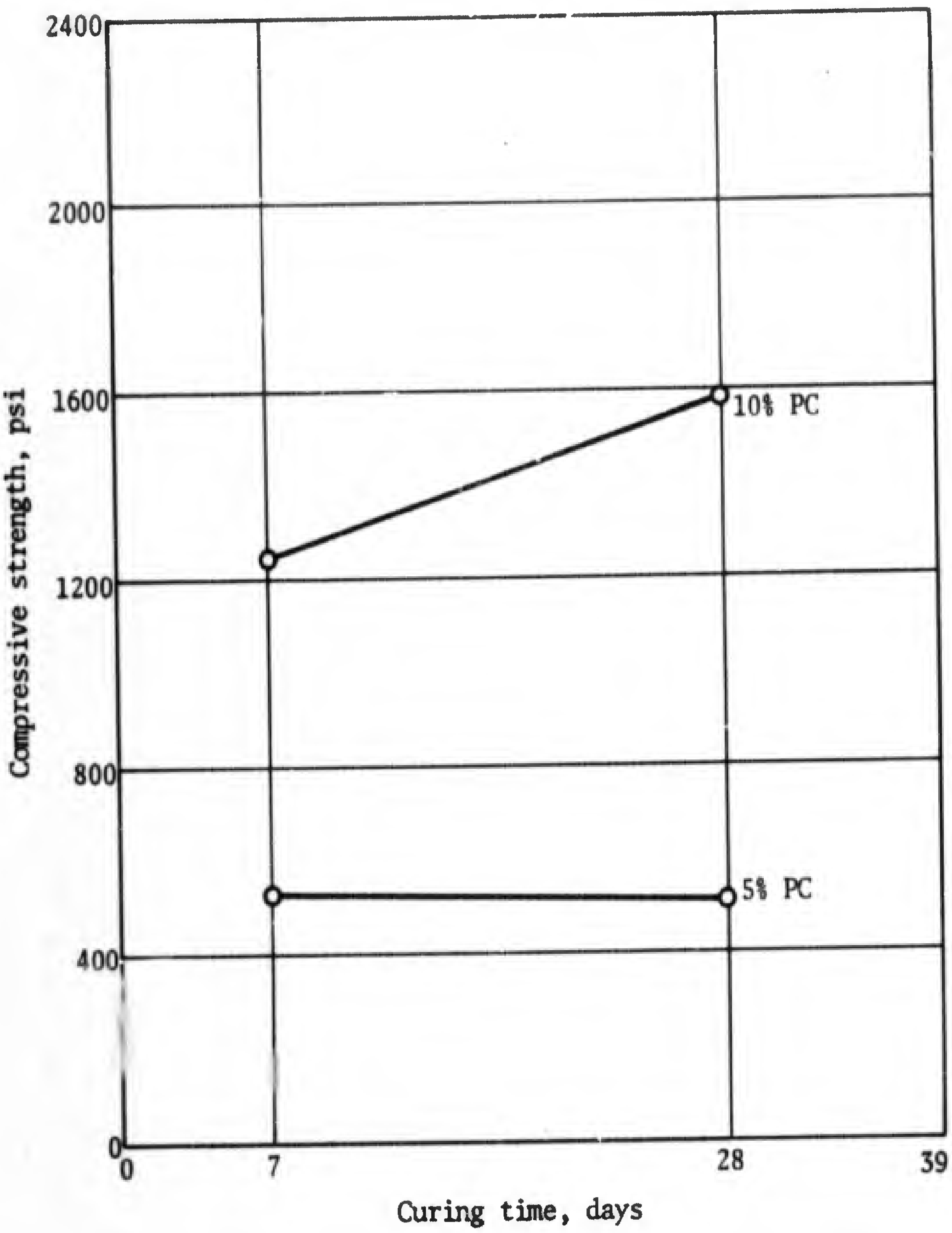


Figure 68. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Ubon sample 2

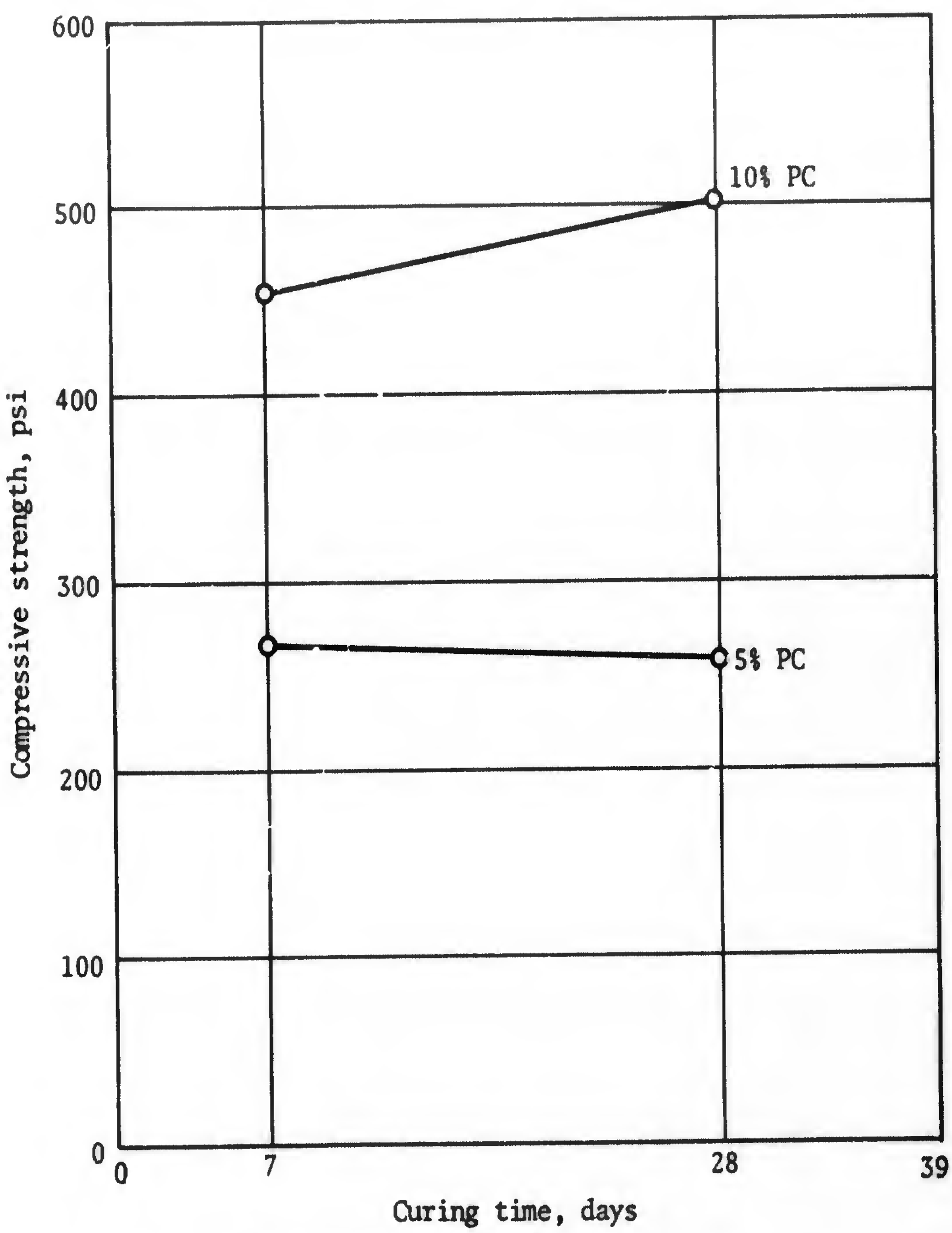


Figure 69. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Ubon sample 3

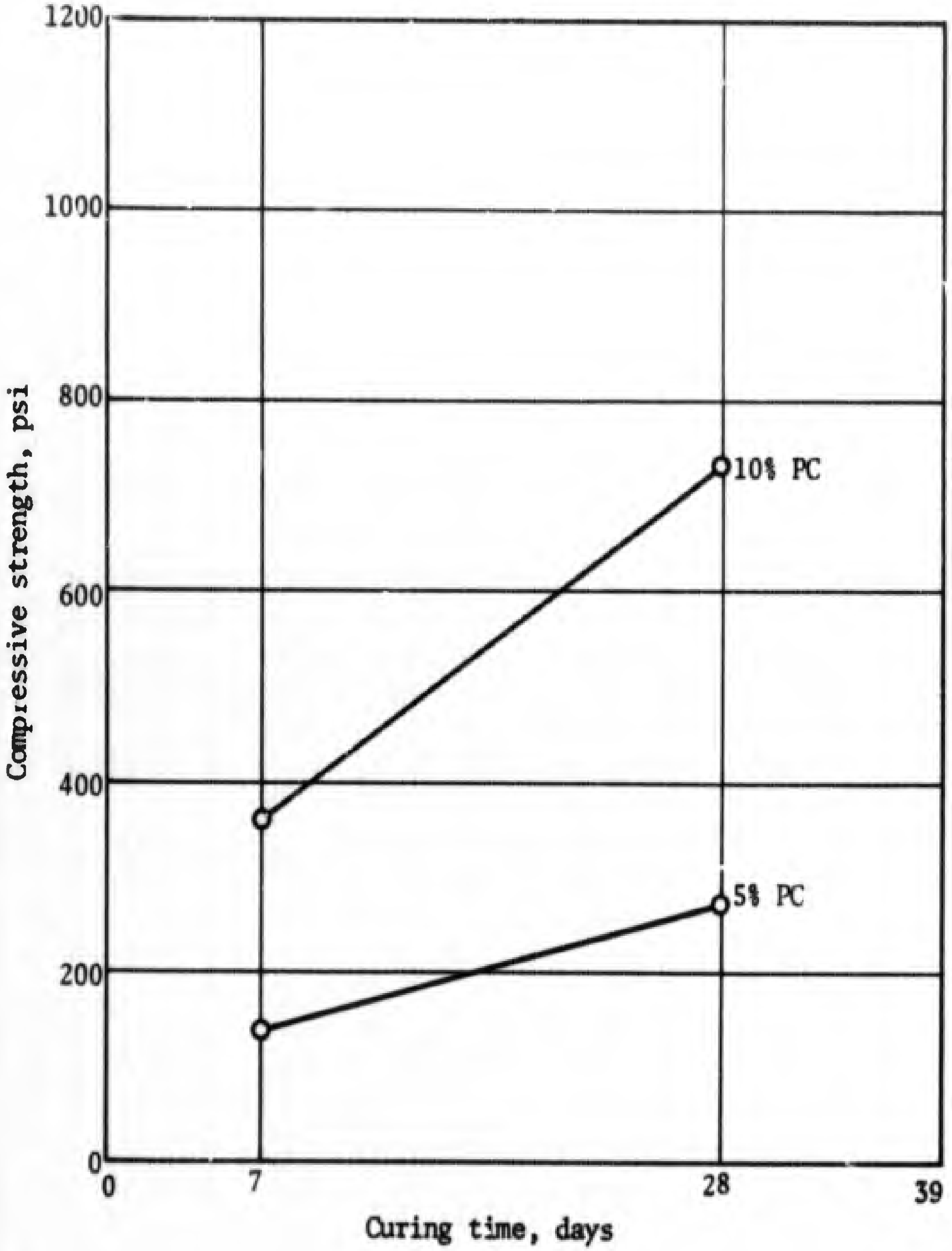


Figure 70. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Ubon sample 4

UDORN

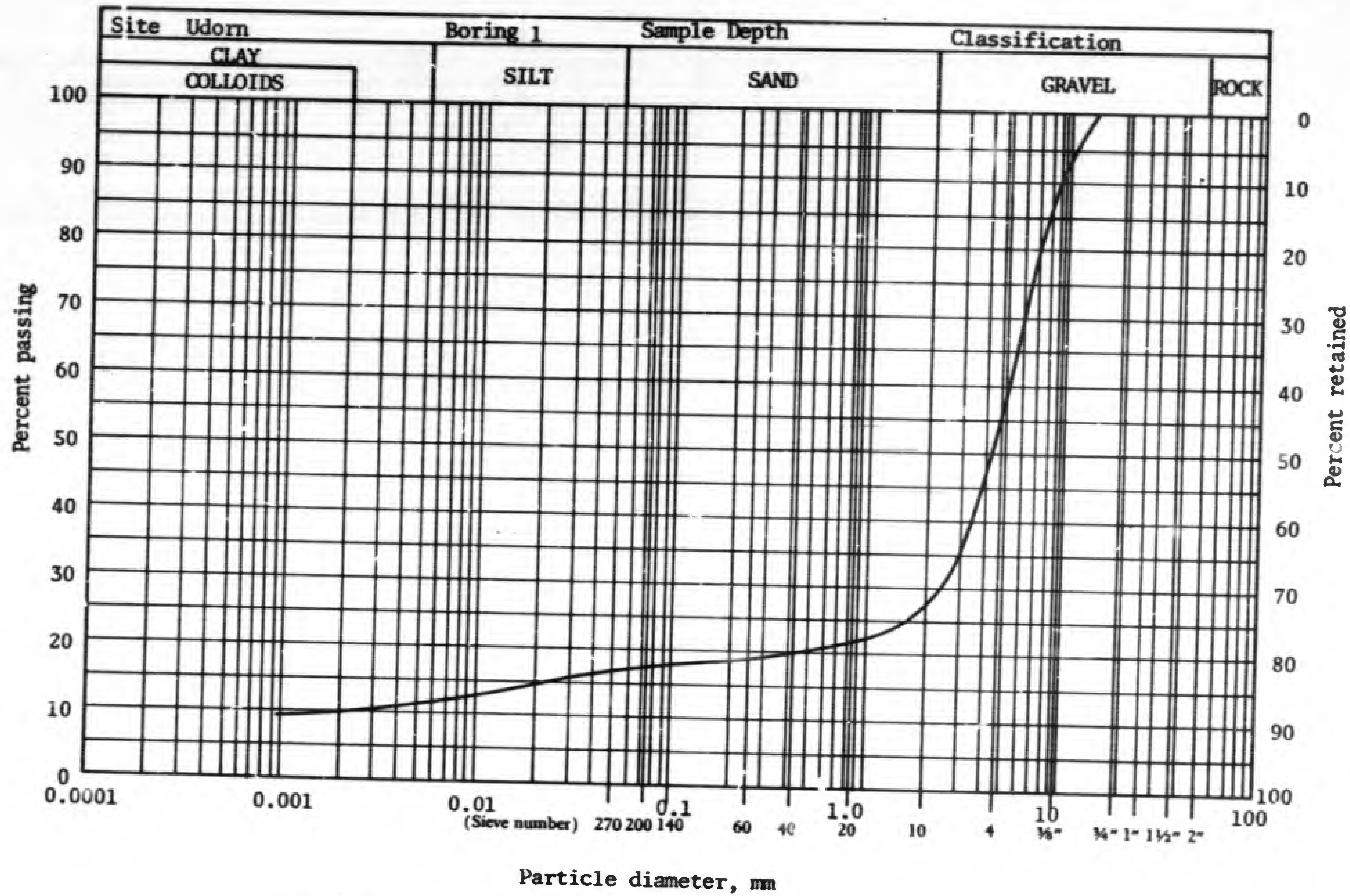


Figure 71. Grain-size distribution curve, Udorn sample 1

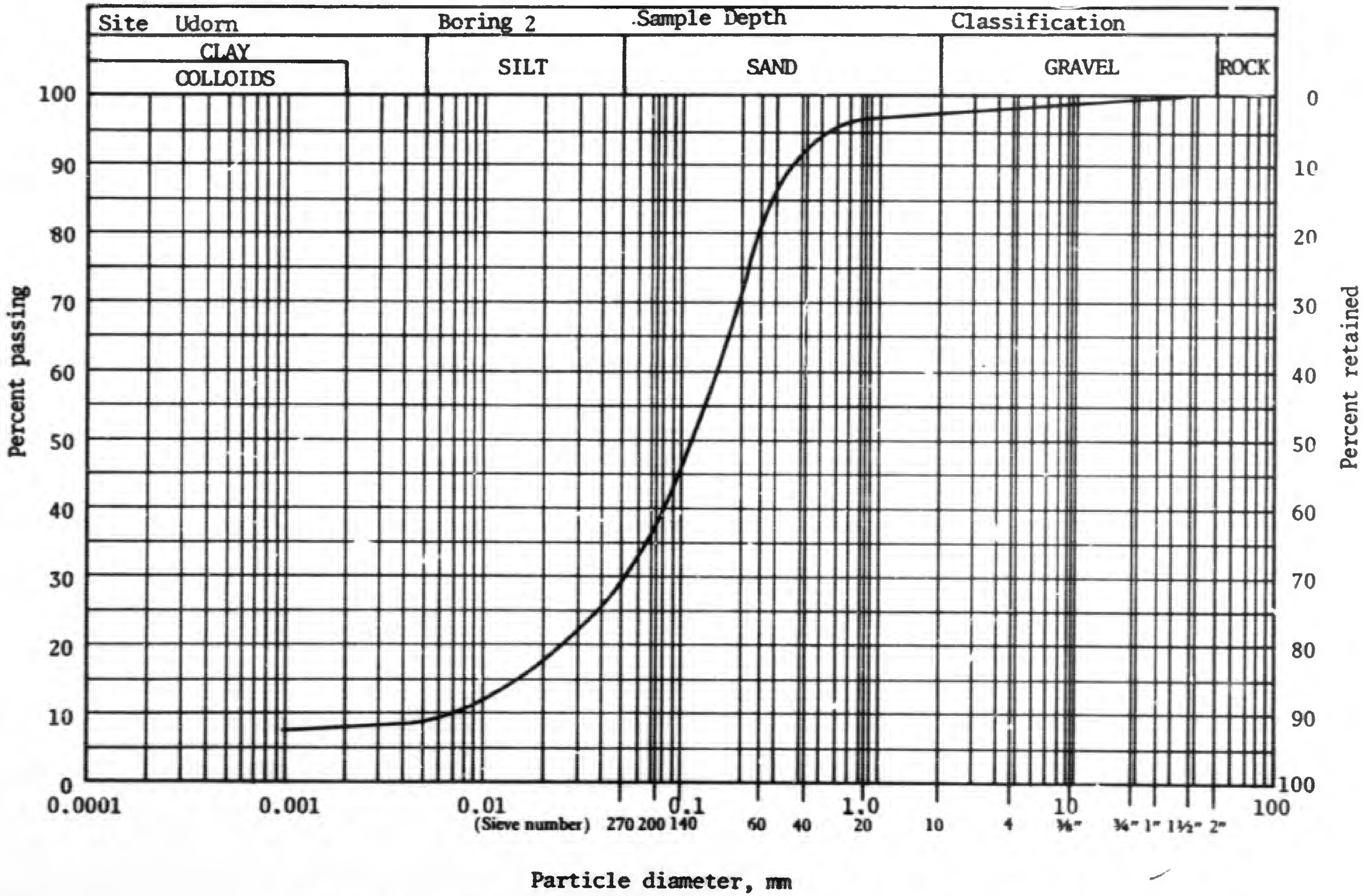


Figure 72. Grain-size distribution curve, Udorn sample 2

TABLE 27

PROPERTIES OF SOILS FROM UDORN

Soil Sample:	1	2
Textural Composition: %		
Sand (2.0-0.05 mm)	10	69
Silt (50-5 μ)	6	20
Clay (<5 μ)	11	9
Classifications:		
Unified	GC	SM
AASHO	A-2-7[0]	A-4[0]
Physical Properties:		
Liquid limit, %	60	--
Plastic limit, %	23	--
Plasticity Index, %	37	N.P.
Activity[1,2]	0.74	--
Specific gravity[1]	2.85	2.57
ASTM standard compaction:[3]		
Dry density, lb/cu ft	104.0	115.0
Optimum moisture content, %	22.0	10.0
Chemical Properties:[1]		
Equivalent Fe_2O_3, %	12.2	0.9
Total soluble salt, %	0.8	1.0
Organic matter, %	0.4	0.8
pH	4.54	6.33

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

TABLE 28

SOIL MINERALOGY, UDORN

Mineral, %	Sample: 1	2
Fraction Passing No. 10 Sieve, %	26.2	98.0
Quartz	30	80
Feldspar (perthite)	--	--
Kaolinite	20	5
Illite	10	--
Goethite	10	1.0
Other minerals:		
Hematite	3	
Magnetite	2	
Other clays	10	4
Fraction Retained on No. 10 Sieve		
Quartz	20	--
Feldspar (perthite)	--	--
Kaolinite	15	--
Illite	5	--
Goethite	25	--
Other minerals:		--
Hematite	15	
	Percent	
Moisture content of samples when received	9.9	1.9
Air-dry moisture content of material finer than 2 mm	5.0	0.5
Air-dry moisture content of material coarser than 2 mm	4.0	--

TABLE 29

STABILIZATION OF SOILS FROM UDORN[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.010	0.013	157	199
	10.0% PC	0.016	0.021	365	552
2	5.0% PC	0.014	0.013	171	336
	10.0% PC	0.018	0.033	473	867
	5.0% Thailand PC	0.016	0.013	238	351[2]
	10.0% Thailand PC	0.020	0.028	657	884[2]

[1]Determined for the fraction passing No. 20 sieve.

[2]Tested after 14 days curing time.

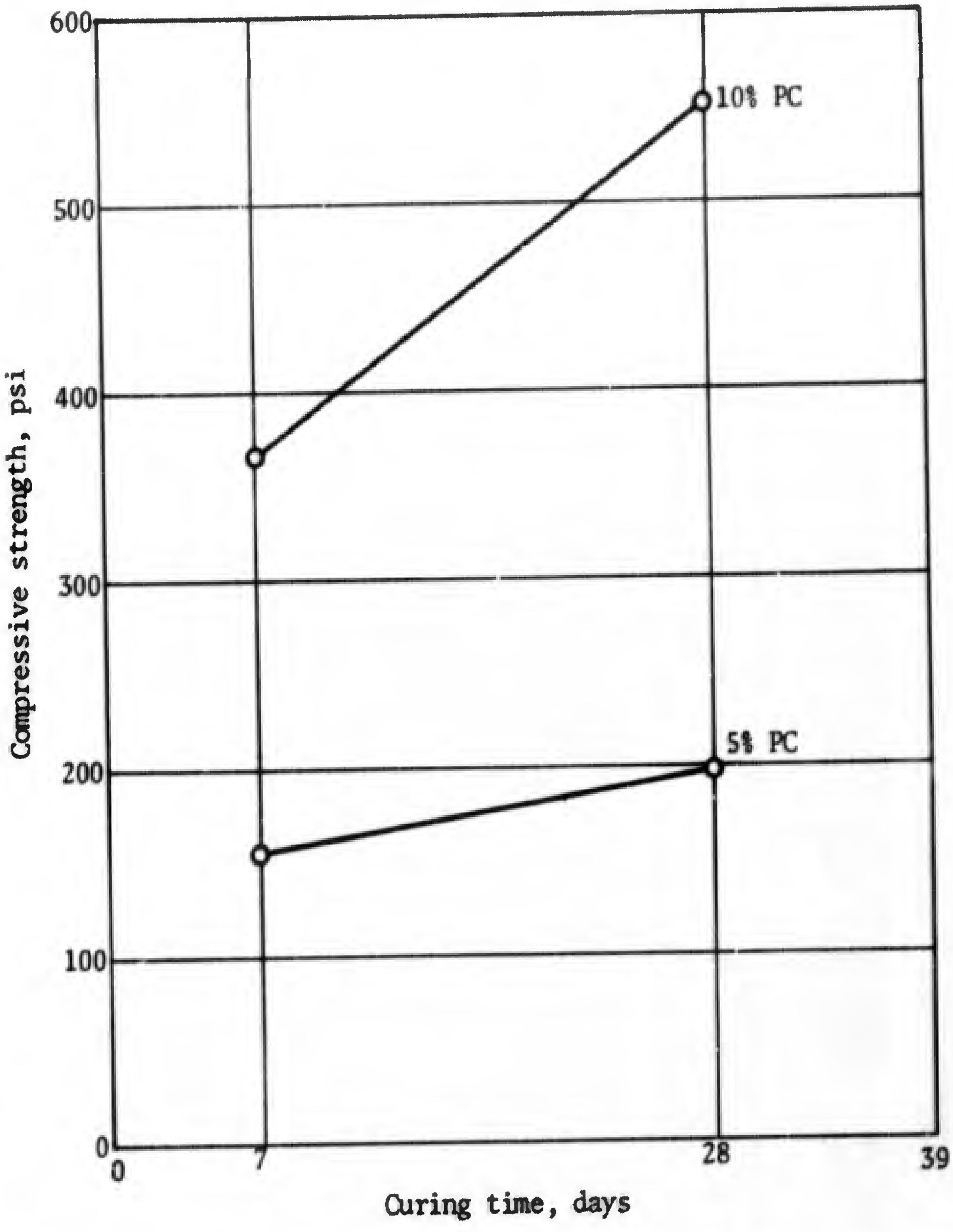


Figure 73. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Udorn sample 1

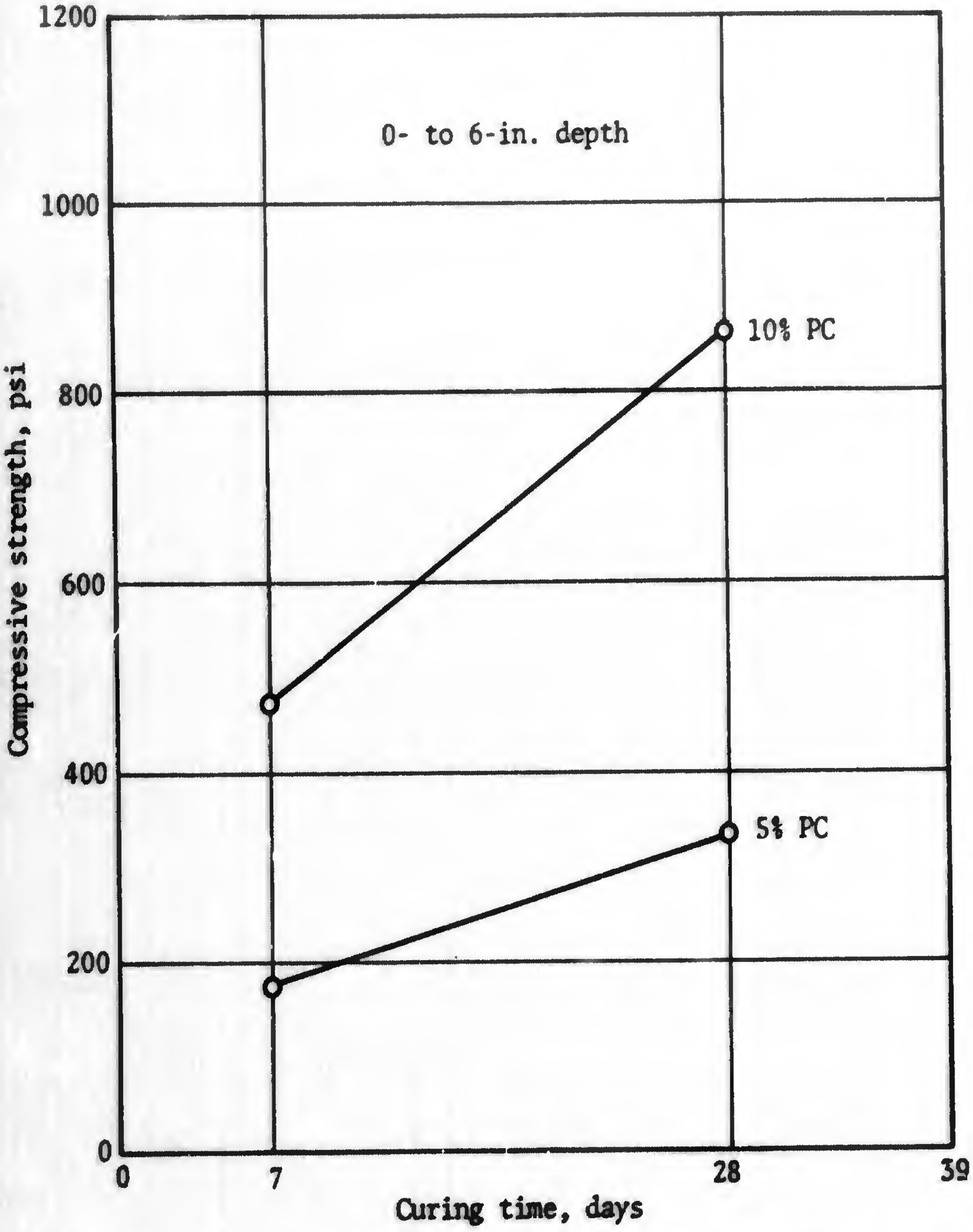


Figure 74. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), Udorn sample 2

U TAPAO

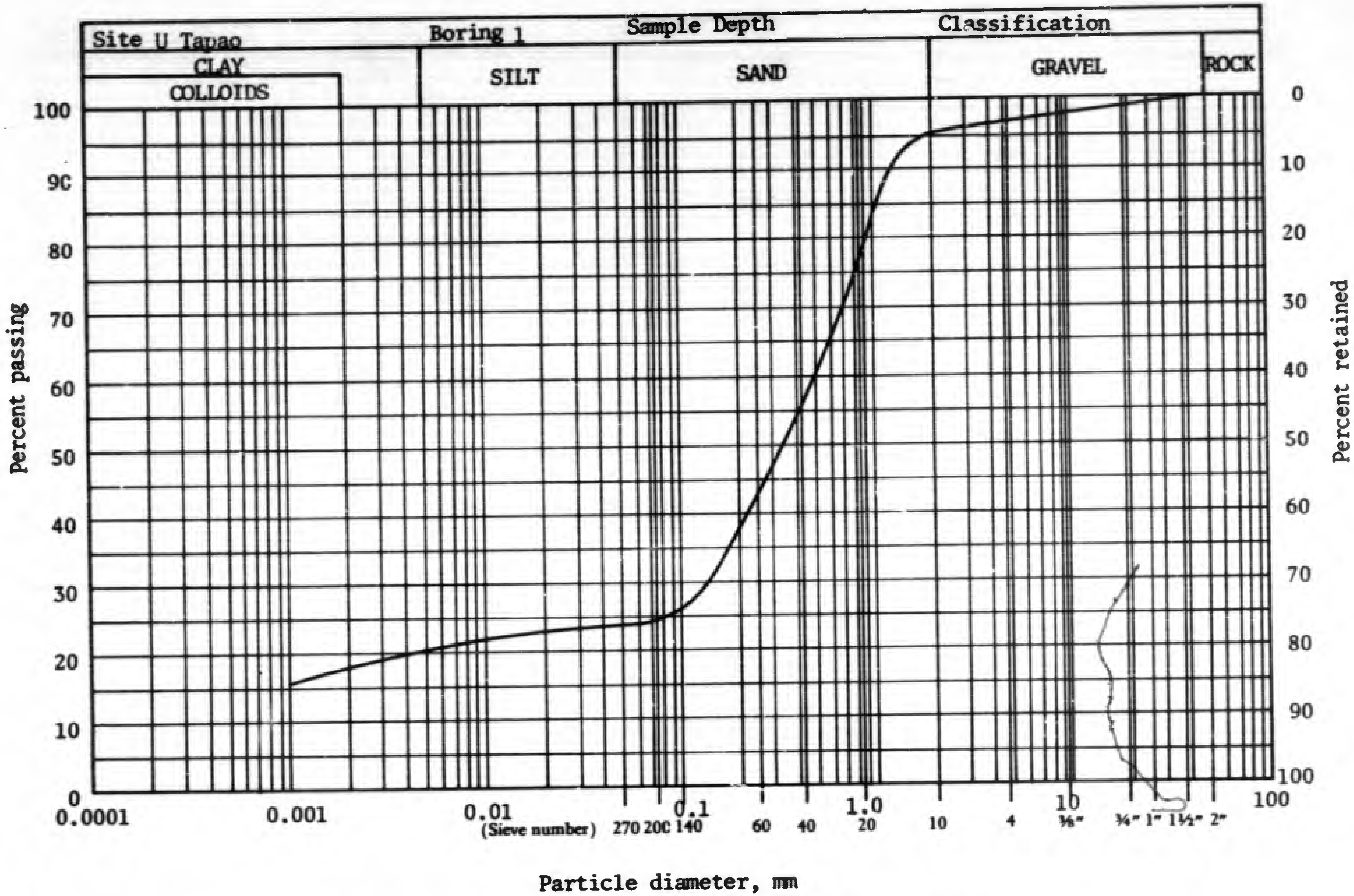


Figure 75. Grain-size distribution curve, U Tapao sample 1

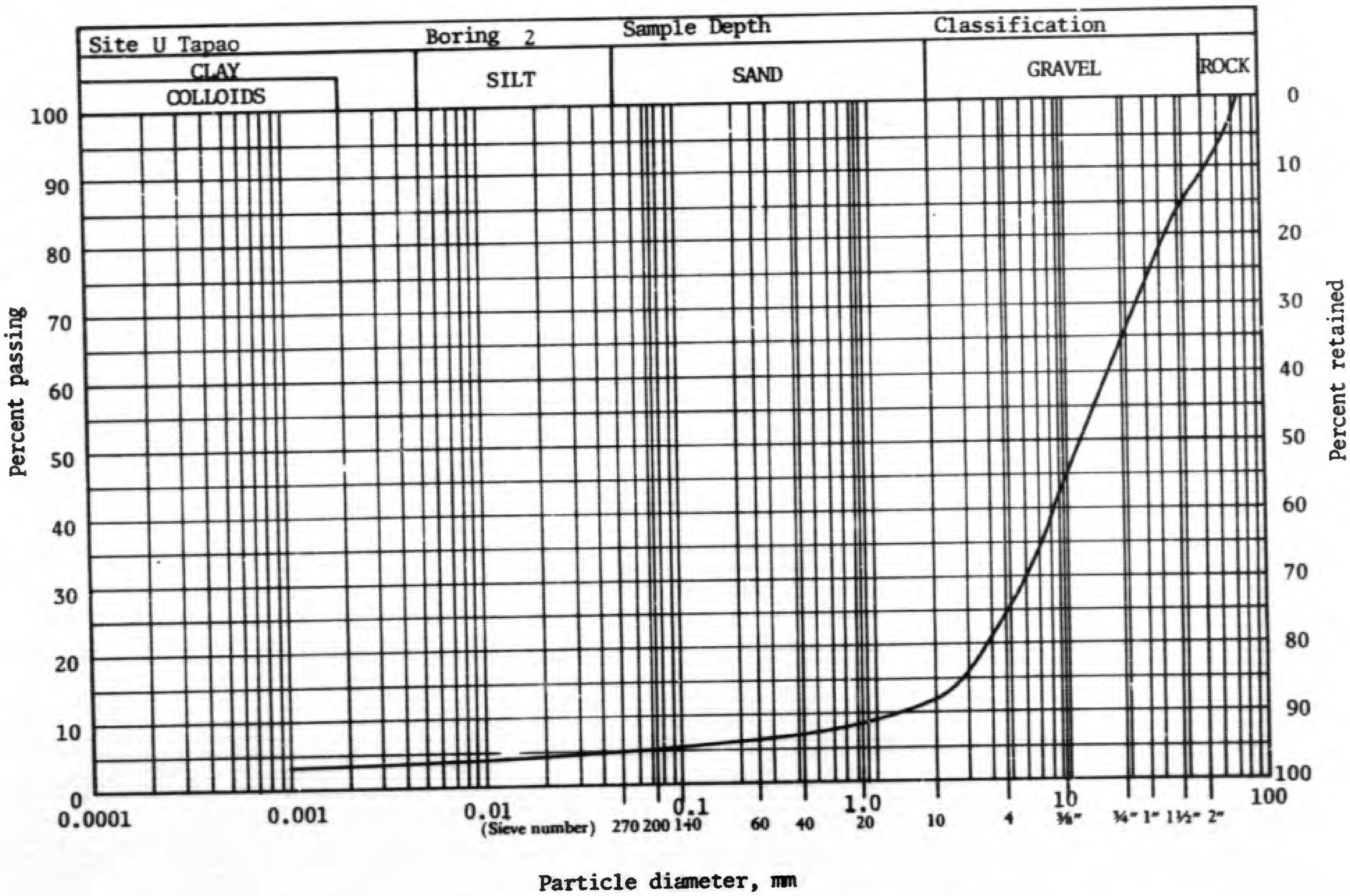


Figure 76. Grain-size distribution curve, U Tapao sample 2

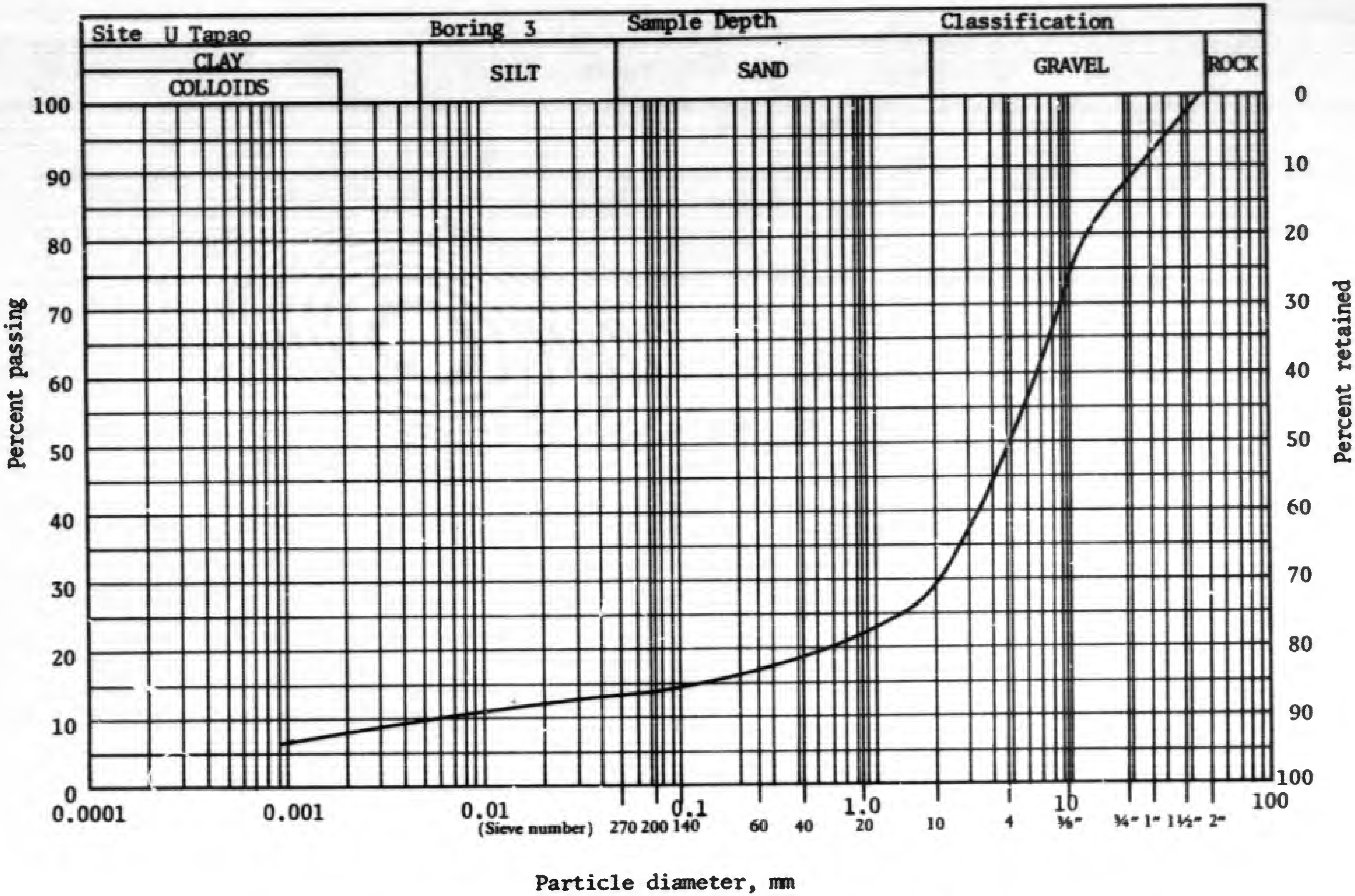


Figure 77. Grain-size distribution curve, U Tapao sample 3

TABLE 30

PROPERTIES OF SOILS FROM U TAPAO

Soil Sample:	1	2[4]	3
Textural Composition: %			
Sand (2.0-0.05 mm)	71	7	15
Silt (50-5 μ)	3	1	4
Clay (<5 μ)	20	4	10
Classifications:			
Unified	SM	GC	GC
AASHO	A-2-4[0]	A-1-a[0]	A-2-4[0]
Physical Properties:			
Liquid limit, %	--	--	22
Plastic limit, %	--	--	14
Plasticity Index, %	N.P.	--	8
Activity[1,2]	--	--	0.28
Specific gravity[1]	2.61	2.65	2.65
ASTM standard compaction:[3]			
Dry density, lb/cu ft	131.5	--	121.5
Optimum moisture content, %	7.5	--	12.5
Chemical Properties:[1]			
Equivalent Fe_2O_3, %	0.3	5.5	2.7
Total soluble salt, %	2.3	--	--
Organic matter, %	0.1	--	--
pH	6.43	6.65	6.62

[1]Determined for the fraction passing No. 10 sieve.

[2]Activity = Plasticity Index/(-2 μ) clay content.

[3]Determined by Harvard Miniature Compaction Method, compacted in five layers with a 25-lb tamper, 25 blows per layer.

[4]"Jinglestone" aggregate.

TABLE 31

SOIL MINERALOGY, U TAPAO

Mineral, %	Sample: 1	2[1]	3
Fraction Passing No. 10 Sieve, %	90.4	11.5	28.5
Quartz	80	35	70
Feldspar (perthite)	2	--	--
Kaolinite	5	25	15
Illite-mica	--	25	10
Goethite	0.3	6.1	3.0
Other minerals:			
Amphibole	3		
Other clays	5		
Fraction Retained on No. 10 Sieve			
Quartz	--	80	75
Feldspar (perthite)	--	2	--
Kaolinite	--	--	10
Illite-mica	--	2	5
Goethite	--	0.5	2.3
Other minerals:	--		
Amphibole		2	
Other clays		2	5
		Percent	
Moisture content of samples when received	8.1	3.9	6.2
Air-dry moisture content of material finer than 2 mm	0.5	4.5	0.6
Air-dry moisture content of material coarser than 2 mm	--	--	0.6

[1]From "Jinglestone" aggregate.

TABLE 32

STABILIZATION OF SOILS FROM U TAPAO[1]

Sample	Additive and amount	Strain at failure, in./in.		Unconfined compressive strength, psi	
		7-day	28-day	7-day	28-day
1	5.0% PC	0.021	0.032	623	993
	10.0% PC	0.037	0.024	1284	1650
	5.0% Thailand PC	0.016	0.018	610	695[4]
	10.0% Thailand PC	0.028	0.033	1048	1255[4]
2[2]					
3	5.0% PC	0.014	0.013	258	366
	10.0% PC	0.023	0.028	589	990
	5.0% PC[3]	0.021	0.020	502	656[4]
	10.0% PC[3]	0.025	0.032	820	1124[4]

[1]Determined for the fraction passing No. 20 sieve.

[2]"Jinglestone" aggregate material.

[3]Material retained on No. 20 sieve pulverized and used.

[4]Tested after 14 days curing time.

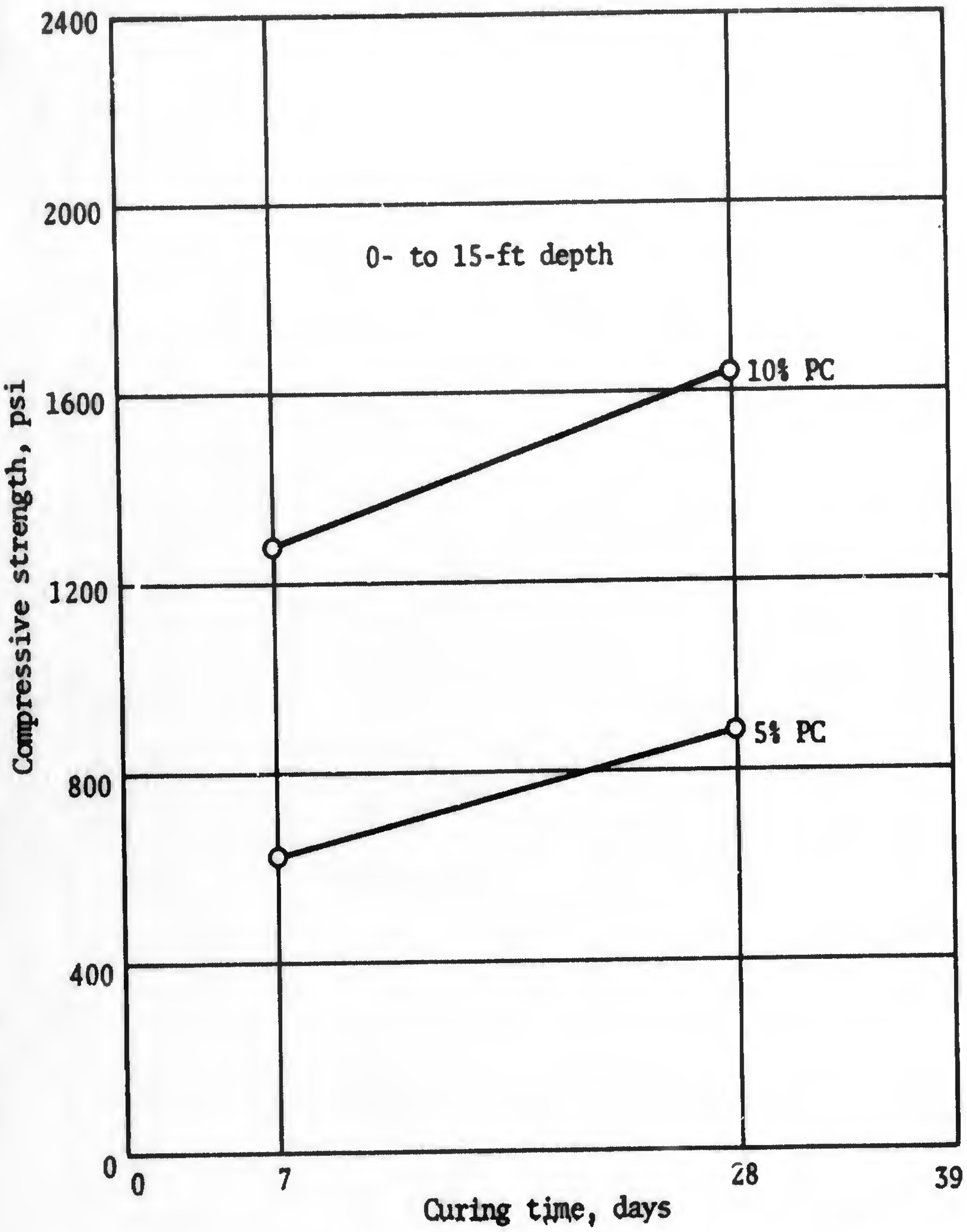


Figure 78. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), U Tapao sample 1

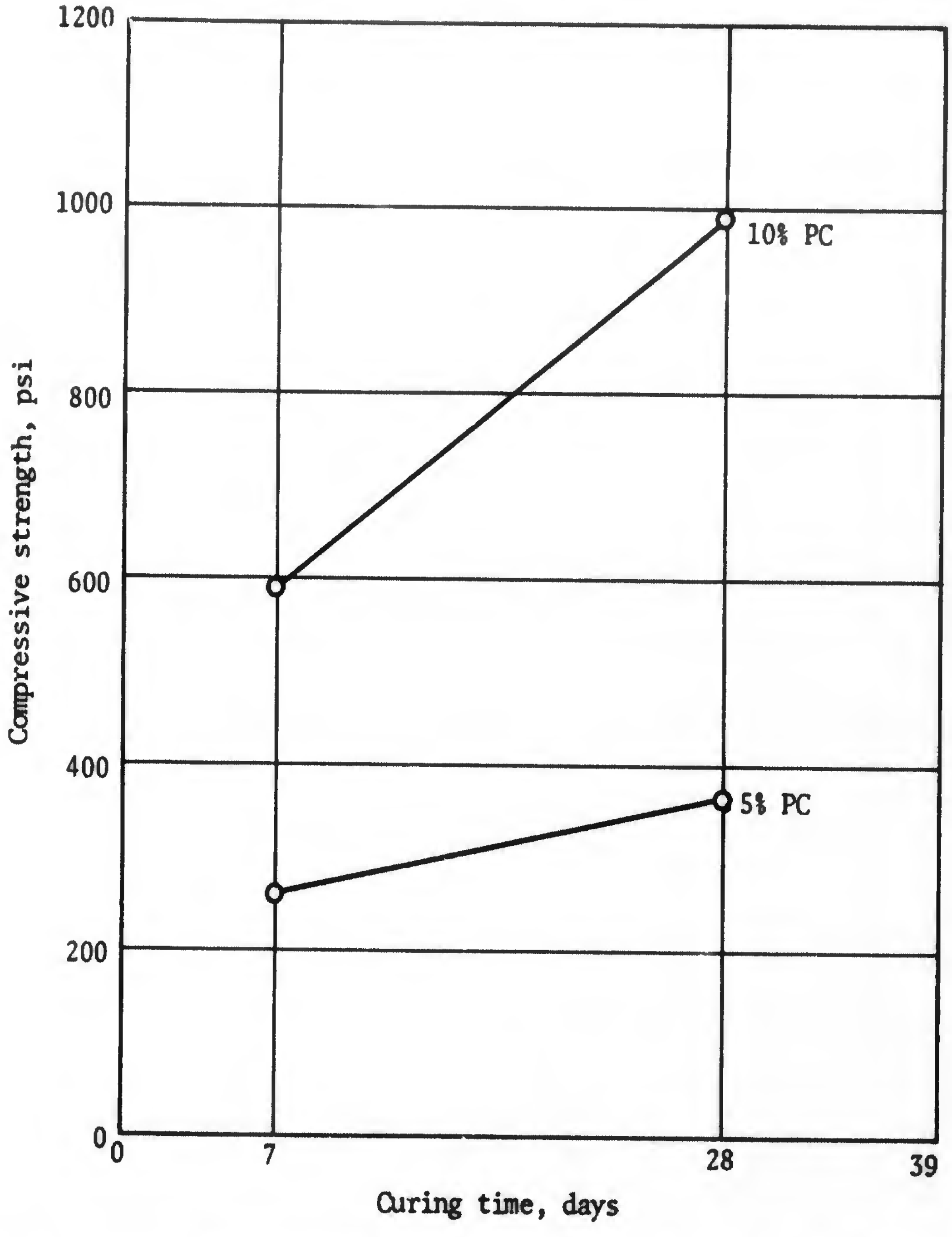


Figure 79. Compressive-strength changes with time in compacted soil-cement mixtures (portland cement), U Tapao sample 3

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13. ABSTRACT
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The physical characteristics and the chemical and mineralogical compositions of soils from selected sites in Southeastern Asia were investigated to determine soil properties and effective chemical stabilants. The effect of additives on soil-cement was determined, and the influence of the grain-size distribution of the soil gradation on soil-cement compressive strength was investigated. The unconfined compressive strengths of the cured soil-cements, compacted at ASTM standard optimum moisture-densities, were determined and correlated with mineralogical and chemical soil characteristics. The soil samples were mostly sandy soils and lateritic soils, composed mainly of quartz, perthite, kaolinite, illite, and goethite, or some combination of these minerals. Portland cement proved to be the most effective soil stabilization agent that gave adequate compressive strength to the soil-cement mixtures. Thailand portland cement and lime products were found to be of good quality, comparable to U.S. products. Aluminous cement additive was effective with some soils but was not very reliable, and lime additive proved to be of little value. The compressive strength of the soil-cements depended mainly on gradation of the soils and was not affected adversely by the sesquioxides in the lateritic soils. Additional tests are required to more accurately delineate the most beneficial soil gradations for soil-cements.

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