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EVALUATION OF PHOSPHATIC CLAY DISPOSAL AND RECLAMATION METHODS

Volume 3: Sedimentation Behavior of Phosphatic Clays

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FLORIDA INSTITUTE OF PHOSPHATE RESEARCH

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Research Project FIPR 80-02-002
Final Report, December 1982

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PREFACE

As part of a Florida Institute of Phosphate Research project titled "Evaluation of Phosphatic Clay Disposal and Reclamation Methods", Ardaman & Associates, Inc. performed a comprehensive study to evaluate the engineering properties of a wide range of phosphatic clays and sand-clay mixes, and developed a methodology for forecasting the performance of phosphatic clay settling areas during disposal and reclamation. The findings of this study are presented in a series of six complementary volumes.

Laboratory evaluations of the engineering properties of phosphatic clays and sand-clay mixes were performed on phosphatic clays from twelve different mine sites. Volumes 1, 2 and 3 titled "Index Properties of Phosphatic Clays", "Mineralogy of Phosphatic Clays", and "Sedimentation Behavior of Phosphatic Clays", respectively, present extensive data on the twelve clay sources selected in the study. The findings were used to screen the samples and select six clays covering the full range of anticipated behavioral characteristics. The selected clays were subjected to a comprehensive testing program for determining engineering parameters pertaining to consolidation and strength. Extensive sophisticated strength testing of three of the six phosphatic clays and corresponding sand-clay mixes was then subsequently undertaken. The results are presented in Volumes 4 and 5 titled 'Consolidation Behavior of Phosphatic Clays" and "Shear Strength Characteristics of Phosphatic Clays", respectively.

Concurrent with the laboratory evaluation of phosphatic clay engineering properties, a theoretical model to evaluate disposal systems was developed. The finite difference program SLURRY can also be used in reclamation planning. In an attempt to verify and refine the prediction modeling technique, a preliminary field investigation program at six phosphatic clay settling areas ranging from retired to active sites was undertaken. Volume 6 discusses the theoretical model and presents a comparison of predictions based on laboratory data with actual field measurements.

A more extensive second phase field testing program is proposed to further refine and improve predictive capability based on actual field conditions. Conventional phosphatic clay disposal and the sand-clay mix disposal methods can then be critically evaluated for phosphatic clays with differing characteristics to quantify advantages/disadvantages of disposal/reclamation methods and outline their relative merits. The results should allow mine planners to select an optimum disposal method based on the clay characteristics at a particular mine.

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ABSTRACT

The sedimentation behavior of twelve phosphatic clays was investigated with over 100 laboratory settling tests. The sedimentation behavior of sand-clay mixes for three of the twelve clays were investigated with 22 additional laboratory settling tests. Settling tests on the phosphatic clays consisted of a constant initial height settling test series with an initial height of 24 cm and initial solids contents of 1, 3 and 8%, and a variable initial height settling test series with initial heights of 6, 12, 18 and 24 cm for initial solids contents of 3 and 8%. The final settled solids contents, settling rates, and void ratio versus effective stress relations at low stresses, were determined from these test series. Settling tests on sand-clay mixes investigated the effects of initial clay solids content, sand-clay ratio, and type of sand tailings.

For an initial solids content of 3%, which is similar to the solids content of clay from primary launders, the final 30-day settled solids content of phosphatic clays varied from 5.4 to 17.8% with an average of 10.9%. The lowest settled solids content versus time relationship occurred for the Agrico-Saddle Creek clay and the greatest settled solids content versus time relationship occurred for the CF Mining-Hardee clay. The settling behavior of these two clays bracketed the range of settling behavior encountered for clays tested in this investigation and that reported for other clays. Hence, the sedimentation behavior of the specific Agrico and CF clays sampled for this investigation reflect the range encountered for Florida phosphatic clays.

The behavior of phosphatic clays was generally consistent with the Michaels and Bolger (1962) theory for the settling behavior of flocculated clay suspensions. The Michaels and Bolger methodology, therefore, was used to extrapolate results from the laboratory settling tests in a limited size container to the field situation of an “infinite size container".

A comparison of final settled solids contents for phosphatic clays sampled at different times from the same mines was made from

data reported in the literature. The comparison indicated that the variability in final settled solids content of phosphatic clays produced at a given mine over time may be as large as occurs for clays from all Florida mine sites.

The only practical correlation found between the index properties and sedimentation behavior of phosphatic clays was between liquid limit and final settled solids content for a specific initial solids content. The correlation is not universally valid and has a correlation coefficient of about 0.80, but the results are considered applicable for estimates of sedimentation behavior in the absence of settling tests.

Settling tests on sand-clay mixes indicated that clays which settle to a relatively low final clay solids content without sand also settle to a relatively low final clay solids content with sand. The addition of sand tailings does little to increase the final clay solids content of a relatively poor settling clay relative to that of a relatively good settling clay. The final clay solids content at the end of settling increases slightly with increasing sand-clay ratio, but if the volume occupied by the sand is accounted for as an equivalent water phase, the effective clay solids content may be adversely affected at high sand-clay ratios. The initial clay solids content required to prevent segregation of the clay and sand during settling varied significantly for the phosphatic clays. The final settled clay solids content achieved for clay alone from an initial solids content of 3% appeared adequate to prevent segregation. Variations in mineralogy of sand tailings from 60% quartz and 40% apatite to 85% quartz and 15% apatite were found to have no effect on sand-clay mix sedimentation behavior.

ACKNOWLEDGEMENTS

The support and sponsorship provided by the Florida Institute of Phosphate Research to conduct this investigation is gratefully acknowledged. The cooperation. and assistance provided by the various mining companies named in this report and their representatives during collection of clay samples is greatly appreciated, namely:

- Agrico Chemical Company
- AMAX Phosphate, Inc.
- Beker Phosphates
- Brewster Phosphates
- CF Mining Corporation
- Estech, Inc.
- Hopewell Land Corporation
- International Minerals and Chemicals Corporation
- Mobil Chemical Company
- Occidental Chemical Company
- United States Steel Corporation Agrichemicals Division
- WR Grace & Company

The permission to publish information provided by Mr. John Cameron of New Wales Chemicals, International Minerals and Chemicals Corporation, Mr. Steve Olson of Agrico Chemical Company, and Mr. Troy Deal of Aztec Development Company from in-house reports prepared by Ardaman & Associates, Inc. is appreciated.

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SYMBOLS

b	Ordinate Intercept of $Z_o\phi_K$ vs. Z_F
C_{AF}	Ratio of ϕ_A/ϕ_F
C.V.	Coefficient of Variation
d_p	Average Pore Diameter
Do	Container Diameter
Dy	Yield Diameter
e	Void Ratio
e_c	Clay Void Ratio
$\bar{e}_c$	Effective Clay Void Ratio
e_f	Final Void Ratio
e_{fc}	Final Clay Void Ratio
e_{ft}	Final Total Void Ratio
g	Gravitational Accleration
G	Specific Conductance
LL	Liquid Limit
Q	Settling Rate of Slurry-Supernatent Interface
Q_o	Initial Settling Rate
Q_s	Average Secant Settling Rate
Q_1	Maximum Laboratory Settling Rate
Q'_1	Maximum Field Settling Rate
r	Correlation Coefficient
S	Solids Content
S_c	Clay Solids Content
$\bar{S}_c$	Effective Clay Solids Content
S_i	Initial Solids Content
S_F	Final Solids Content
S_{it}	Initial Total Solids Content
S_{ic}	Initial Clay Solids Content
S_{Ft}	Final Total Solids Content
S_{Fc}	Final Clay Solids Content
S_{t1}	Solids Content at Time of Maximum Settling Rate
S_k	Solids Content at Time k
SCR	Sand-Clay Ratio
t	Time
t_1	Time of Maximum Settling Rate
Z	Height of Slurry-Supernatent Interface
Z_o	Initial Height of Slurry-Supernatent Interface

SYMBOLS (Cont'd)

Z_F	Final Height of Slurry-Supernatent Interface
Zy	Yield Height
$Zy1$	Yield Height at Time of Maximum Settling Rate
α	Regression Coefficient
β	Regression Coefficient
γ_w	Unit Weight of Water
μ_w	Absolute Viscosity of Water
ρ	Specific Gravity
ρ_w	Specific Gravity of Water
ρ_c	Specific Gravity of Clay
ρ_s	Specific Gravity of Sand
$\bar{\sigma}_{vc}$	Effective Vertical Consolidation Stress
τ_y	Yield Stress
ϕ_A	Aggregate Volume Concentration
ϕ_F	Floc Volume Concentration
ϕ_K	Clay Volume Concentration

Section 1

RESEARCH BACKGROUND AND OBJECTIVES

1.1 **Introduction**

The sedimentation or settling behavior of phosphatic clays is of interest to determine the initial solids contents of clays after deposition within an impoundment and the time required to reach a given solids content due to gravity settling. The settling behavior is also required in adequately sizing settling areas to provide sufficient retention time for sedimentation. Moreover, it could qualitatively indicate the relative compressibility of phosphatic clays.

A wide range of settling behavior has been reported for Florida phosphatic clays (Lamont et al., 1975; Roma, 1976; and Keshian et al., 1977). The range of settled solids contents achieved after 30 days is generally reported to vary from 6-16% when starting from initial solids contents of 3-4%.

1.2 **Previous Research**

A series of sedimentation tests were reported by Lamont et al. (1975) on 15 phosphatic clays collected from 15 of 16 beneficiation plants in operation in Florida at the time the study was performed. The clays, therefore, represent a broad range of geographic location and, hence, a potentially broad range in sedimentation behavior.

Results from the Lamont et al. (1975) settling tests are presented in Table 1-1 and Figure 1-1. The settling tests were reportedly performed from an initial solids content, S_i, of 3.7% in 1,000 cm glass graduated cyclinders. As shown, phosphatic clays exhibit a wide range of settling characteristics with "final" settled solids contents at 30 days of 5.7 to 15.9%. Therefore, some phosphatic clays exhibit little gravitional settling increases in solids content from 3.7 to 5.7% in 30 days; while other phosphatic clays exhibit substantial increases in solids content from 3.7 to 15.9% in 30 days. The average final settled solids content for the 15 clays was 10.8%.

The laboratory settling rate, Q, measured at the clay/supernatent interface during the first 4 hours of each test is shown in Figure l-2 versus the final settled solids content, The maximum settling rate for each test was measured during this time increment, and ranged from 0.16 to 1.77 in/hour for the 15 clays tested. Over the range of test data, we found a linear relation of increasing settling rate with increasing final solids content of the form shown in Figure 1-2. The correlation coefficient, r, of 0.81 indicates that 66% of the variability in settling rate is explained by the final settled solids content.

Data from a series of sedimentation tests reported by Roma (1976) on phosphatic clay from the USSAC-Rockland and Mobil-Fort Meade mines are shown and re-interpreted in Figures 1-3, 1-4 and 1-5. The clays were highly plastic with plasticity indices and liquid limits of 103% and 145% and 125% and 160% for the Mobil and USSAC clays, respectively. The reported specific gravities were 2.94 and 2.86, respectively, for the Mobil and USSAC clays.

Results from the series of sedimentation tests on Mobil phosphatic clay for initial solids contents of 2.86, 4.79 and 8.78% are shown in Figure l-3. These tests were performed in 6 cm diameter containers from an initial height, Z_o of 28 em. As shown, the Mobil clay "settles" to average final solids contents at about 100 days of 10.8, 12.0 and 14.0% from initial solids contents of 2.9, 4.8 and 8.8%, respectively. The results indicate that for a given clay, a slurry prepared at an initially lower solids content will not obtain as high a settled solids content with time as a slurry prepared at an initially higher solids content.

Figures 1-4 and 1-5 present our interpretation of results reported by Roma (1976) from a series of five variable height sedimentation tests on USSAC phosphatic clay at an initial solids content of 7.46%. These tests were performed in 6 cm diameter containers. The initial sample heights tested were 15.3, 28.4, 39.2, 60.5 and 103.1 cm. As shown in Figure 1-4, the average solids content at 21 days varies from 11.6 to 11.9% for initial sample heights of 28.4 to 103.1 cm, indicating that for a sufficiently large initial sample height, for a given initial solids content and container diameter, the settling behavior is relatively independent of the initial sample height.

A plot of maximum laboratory settling rate Q_1, versus the inverse initial sample height ($1/Z_0$) is found to yield a linear relation for initial sample heights of 28.4 to 103.1 cm as shown in Figure 1-4. The theory of Michaels and Bolger (1962)* indicates a linear relationship should exist between these variables for naturally flocculated clay suspensions. The ordinate intercept from this relation indicates a maximum "field" settling rate, Q_1', of 1.92 cm/hour for an infinitely large initial height (i.e., $1/Z_o = 1/\infty = 0$). The abscissa intercept from this relation indicates a yield height, Z_{v1} , of 27.3 cm for the 6 cm container diameter and initial solids content of 7.45%. The yield height is defined as the minimum height at which the clay will exhibit free-fall gravity settling in a given size container. The differing solids content versus time behavior obtained from the settling test with an initial height of 15.3 cm resulted therefore, because the initial height was less than the yield height, and hence presumably no free-fall gravity settling occurred.**

The linear relation between final settled height and height of clay solids suggested by Michaels and Bolger was applied to the Roma (1976) data and is shown in Figure l-5. In this figure, the height of clay solids is represented as $Z_o\phi_K$, where $\phi_K = S/(S + (1-S)\rho)$, Z_o is the initial height, S is the initial solids content, and p is the specific gravity of clay solids. Based on the agreement in behavior exhibited by tests reported by Roma (1976) for USSAC phosphatic clay with the Michaels and

*See Section 2.4 for a detailed explanation of the Michaels and Bolger (1976) methodology for interpretating settling tests.

**The increase in solids content observed for this sample is due to compression settling and consolidation of the clay suspension.

Bolger (1962) theory for both the Q_1 versus $1/Z_o$ and Z_F versus $Z_o\phi_K$ relations, the theory appears applicable to interpretating results from settling tests on phosphatic clays.

1.3 Purpose of Investigation

Although the range of final settled solids contents and settling velocities reported by Lamont et al. (1975) probably represent the range of values likely to occur for phosphatic clays, there is a lack of settling test results reported for phosphatic clays where quantitative mineralogic composition and engineering index and consolidation properties are also known. Settling test results reported in the literature for phosphatic clays have also generally not been evaluated with methodologies available for extrapolating data obtained in the laboratory to field conditions. Moreover, there is no comprehensive data reported on the settling characteristics of sand-clay mixes. Accordingly, as part of research project FIPR 80-02-002 “Evaluation of Phosphatic Clay Disposal and Reclamation Methods” performed for the Florida Institute of Phosphate Research, twelve phosphatic clays, sampled from various sites, were subjected to detailed laboratory settling tests and interpretated with the theory of Michaels and Bolger (1962) for the settling behavior of flocculated clay suspensions. Detailed settling tests on sand-clay mixes prepared from three phosphatic clays were also performed. The sites were selected to provide a range of geographic locations and mining concerns. The locations of the mine sites are illustrated in Figure 1-6 and the specific settling areas and sampling dates are summarized in Table 1-2.

The purpose of performing settling tests for the present investigation was to determine the range of initial solids contents and settling behavior occurring for phosphatic clays where index properties, consolidation properties and mineralogy are well established. The effects of various sand-clay ratios and initial solids contents on the settling behavior of phosphatic clays, therefore, can be thoroughly investigated for a wide range of index and consolidation properties and mineralogy. The settling test results can also be used to characterize the relative consolidation behavior of the clays and sand-clay mixes by determining the increase in solids content with time, and the final self-weight solids contents at low effective stresses.

1.4 Scope of Investigation

The scope of the investigation of the sedimentation behavior of phosphatic clays included determining the settling characteristics of twelve phosphatic clays to allow us to screen the behavior and select clays with differing settling characteristics for evaluation of phosphatic clay disposal and reclamation methods. The settling characteristics of sand-clay mixes were investigated for three of the twelve clays.

The sedimentation behavior of the phosphatic clays was investigated with over 100 laboratory settling tests. The sedimentation behavior of sand-clay mixes was investigated with 22 laboratory settling tests. The procedures used to perform and interpret the settling tests are described in Section 2. The settling test results are reported in Sections 3 and 4 for phosphatic clays and sand-clay mixes, respectively. In Section 4, correlations between sedimentation behavior and index properties are also presented.

Table 1-1

FINAL SETTLED SOLIDS CONTENTS FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 3.7%

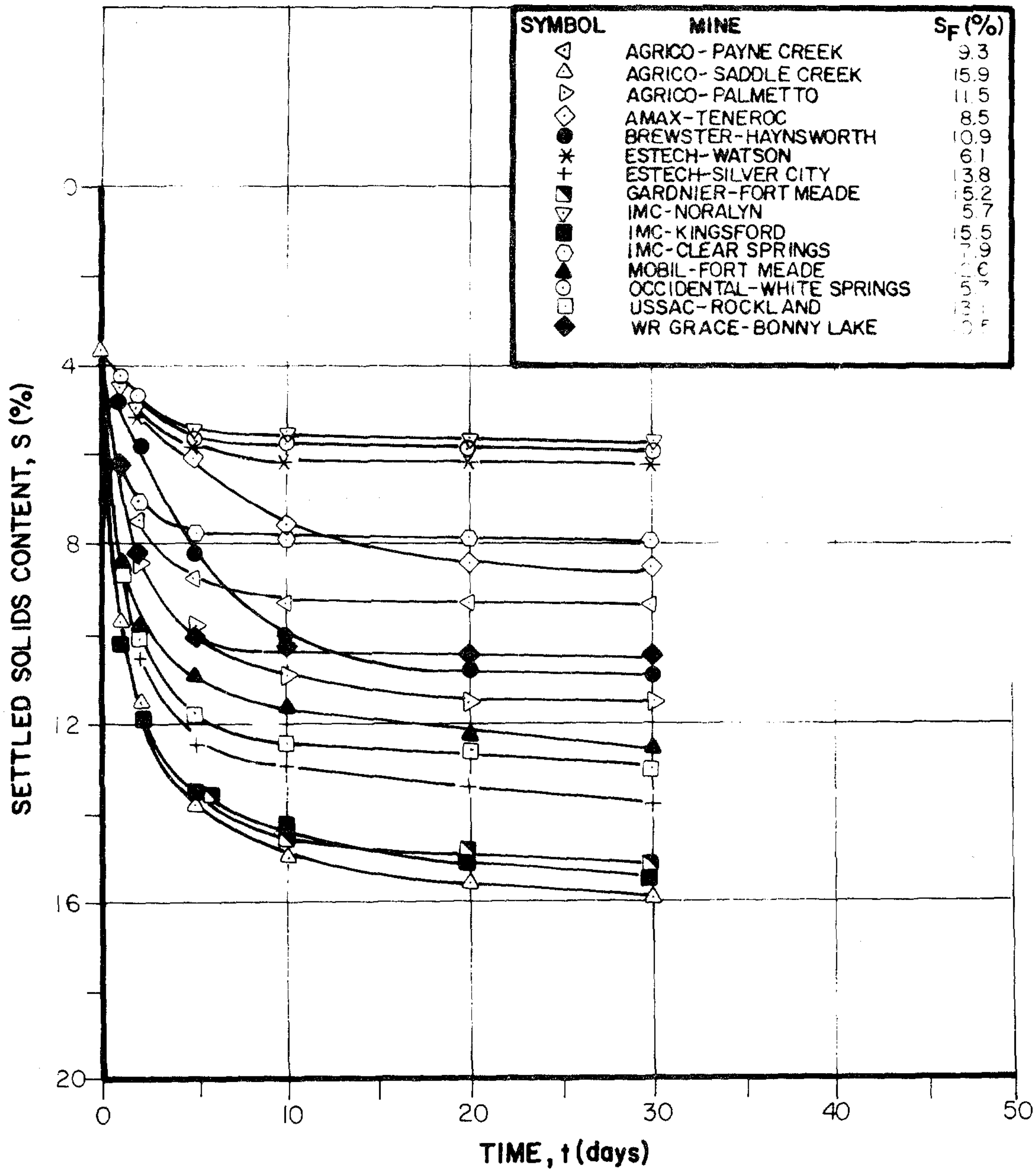
Sample	Settled Solids Content, S (%)				
	1 day	5 days	10 days	20 days	30 days
Agrico-Payne Creek	6.1	8.7	9.2	9.2	9.3
Agrico-Saddle Creek	9.7	13.8	15.0	15.5	15.9
Agrico-Palmetto	7.5	9.9	10.9	11.5	11.5
AMAX-Teneroc	4.3	6.0	7.5	8.4	8.5
Brewster-Haynsworth	4.8	8.2	10.0	10.8	10.9
Estech-Watson	4.7	5.8	6.1	6.1	6.1
Estech-Silver City	8.7	12.4	12.8	13.3	13.8
Gardinier-Fort Meade	9.9	13.5	14.5	14.9	15.2
IMC-Noralyn	4.5	5.4	5.6	5.7	5.7
IMC-Kingsford	10.2	13.5	14.3	15.2	15.5
IMC-Clear Springs	6.1	7.7	7.8	7.8	7.9
Mobil-Fort Meade	8.7	10.9	11.6	12.2	12.6
Occidental-White Springs	4.3	5.4	5.6	5.7	5.7
USSAC-Rockland	8.7	11.8	12.4	12.6	13.1
WR Grace-Bonny Lake	6.2	10.1	10.2	10.5	10.5
Statistics					
Mean	7.0	9.5	10.2	10.6	10.8
C.V. (%)	31.7	32.2	31.5	31.9	32.8

Source: Adapted from Lamont, et al. (1975). "Characterization Studies of Florida Phosphate Slimes." U.S. Bureau of Mines, Report of Investigation 8089.

Table 1-2

MINE SITES AND SETTLING AREAS SELECTED FOR PHOSPHATIC CLAY LABORATORY INVESTIGATIONS

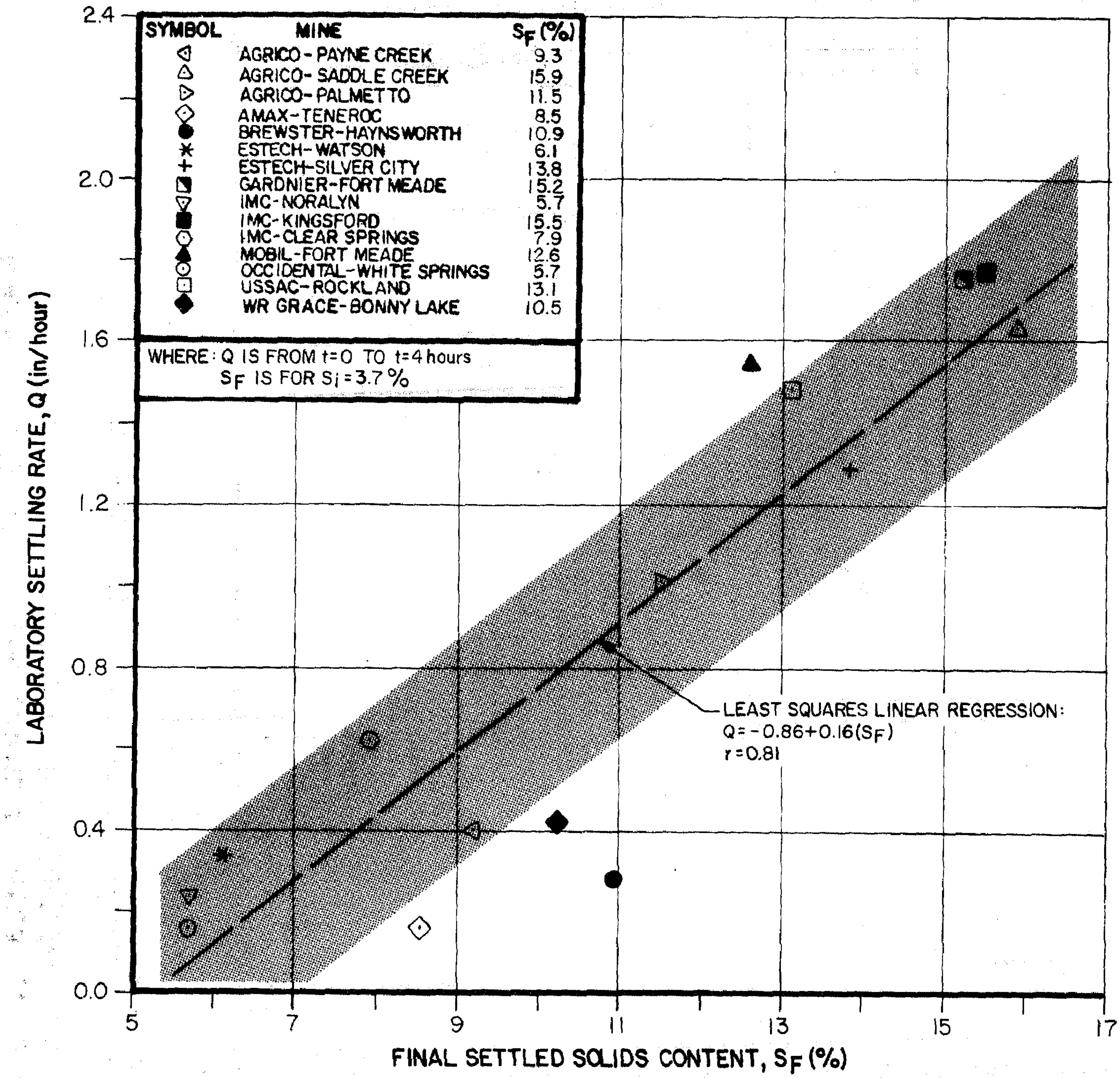
Mine	Settling Area	Sampling Date
Agrico-Saddle Creek	Settling Area-2	1-28-81
AMAX-Big Four	Settling Area BF-1	6-05-81
Beker-Wingate Creek	Pilot Plant Samples	6-05-81
Brewster-Haynsworth	Settling Area-L	1-27-81
CF Mining-Hardee	Settling Area N-1	1-28-81
Estech-Watson	Settling Area 13	4-10-81
Hopewell-Hillsborough	Pilot Plant Samples	3-04-81
IMC-Noralyn	Settling Area N-14	2-23-81
Mobil-Nichols	Settling Area N-3	1-28-81
Occidental-Suwannee River	Settling Area-8	2-02-81
USSAC-Rockland	Settling Area-6	1-28-81
WR Grace-Four Corners	Pilot Plant Samples	9-11-81



SOURCE: ADAPTED FROM LAMONT, ET AL. "CHARACTERIZATION STUDIES OF FLORIDA PHOSPHATE SLIMES." U.S. BUREAU OF MINES, REPORT OF INVESTIGATIONS 8089, 1975.

SETTLED SOLIDS CONTENT VS. TIME FOR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3.7%

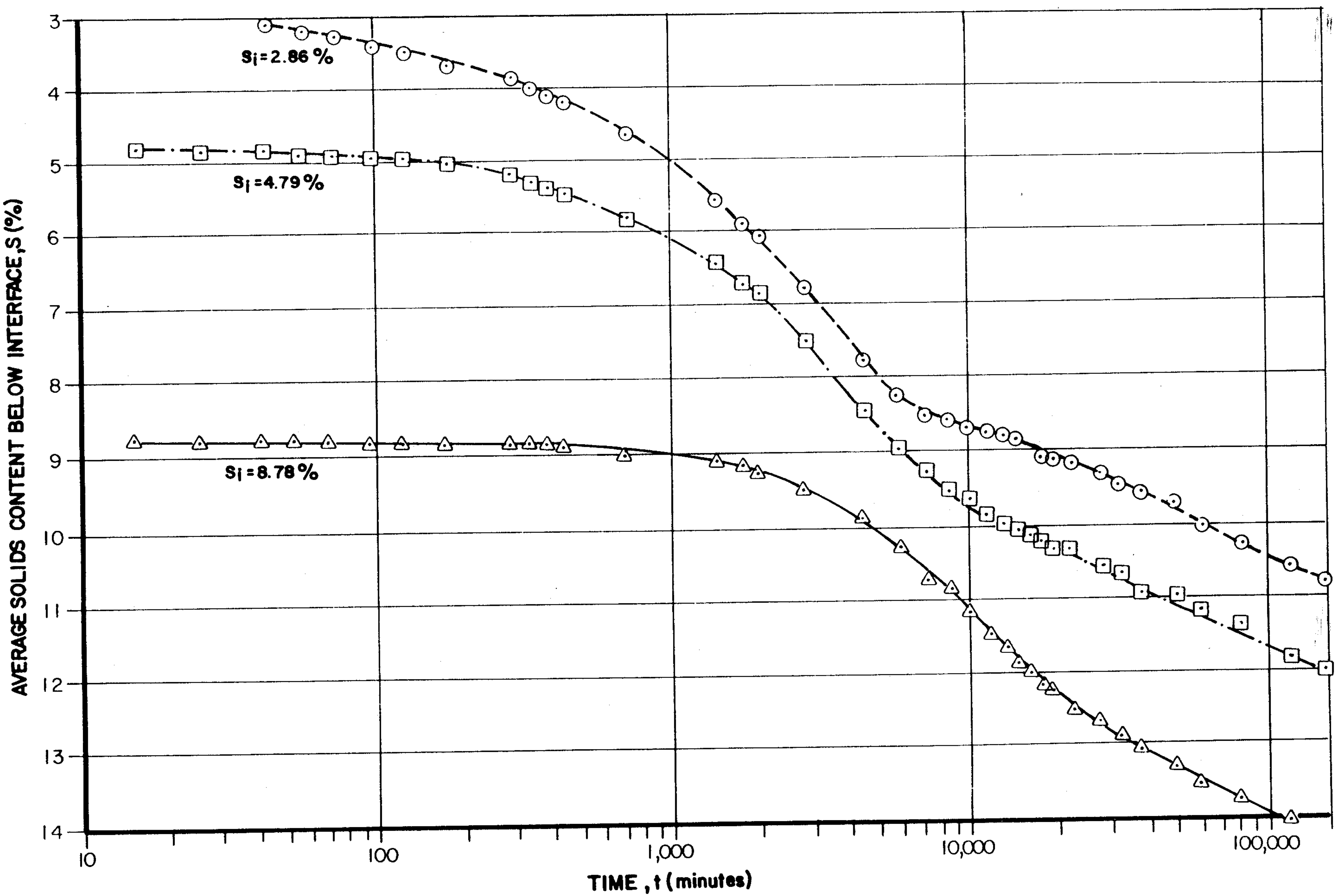
FIGURE 1-1



SOURCE: ADAPTED FROM LAMONT, ET AL. "CHARACTERIZATION STUDIES OF FLORIDA PHOSPHATE SLIMES." U.S. BUREAU OF MINES, REPORT OF INVESTIGATIONS 8089, 1975.

FINAL SETTLED SOLIDS CONTENT VS. SETTLING RATE

FIGURE 1-2

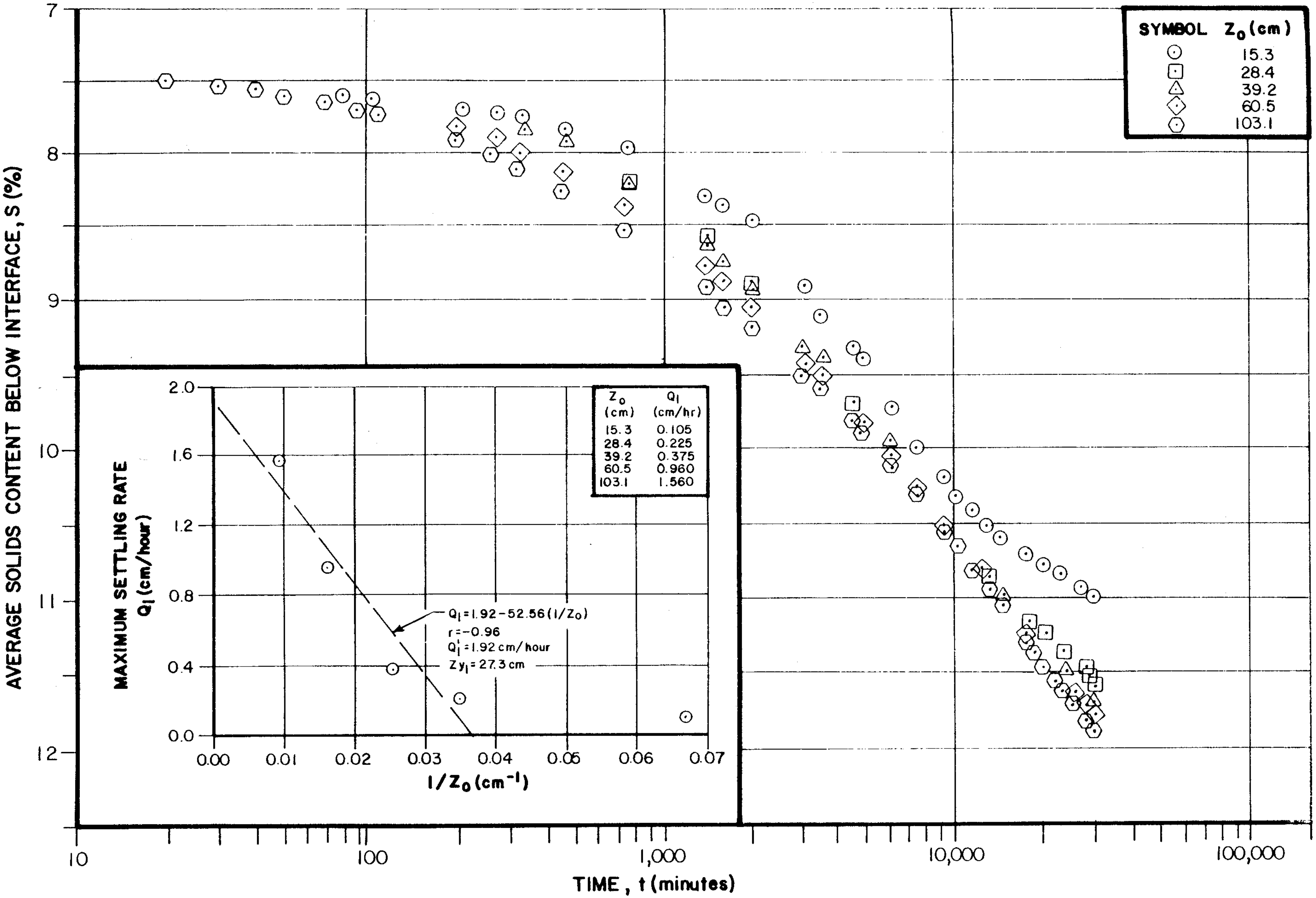


SOURCE: ADAPTED FROM ROMA, J.R. (1976). "GEOTECHNICAL PROPERTIES OF PHOSPHATIC CLAYS," M.S. THESIS, DEPARTMENT OF CIVIL ENGINEERING, M.I.T., CAMBRIDGE, MASSACHUSETTS.

FIGURE 1-3

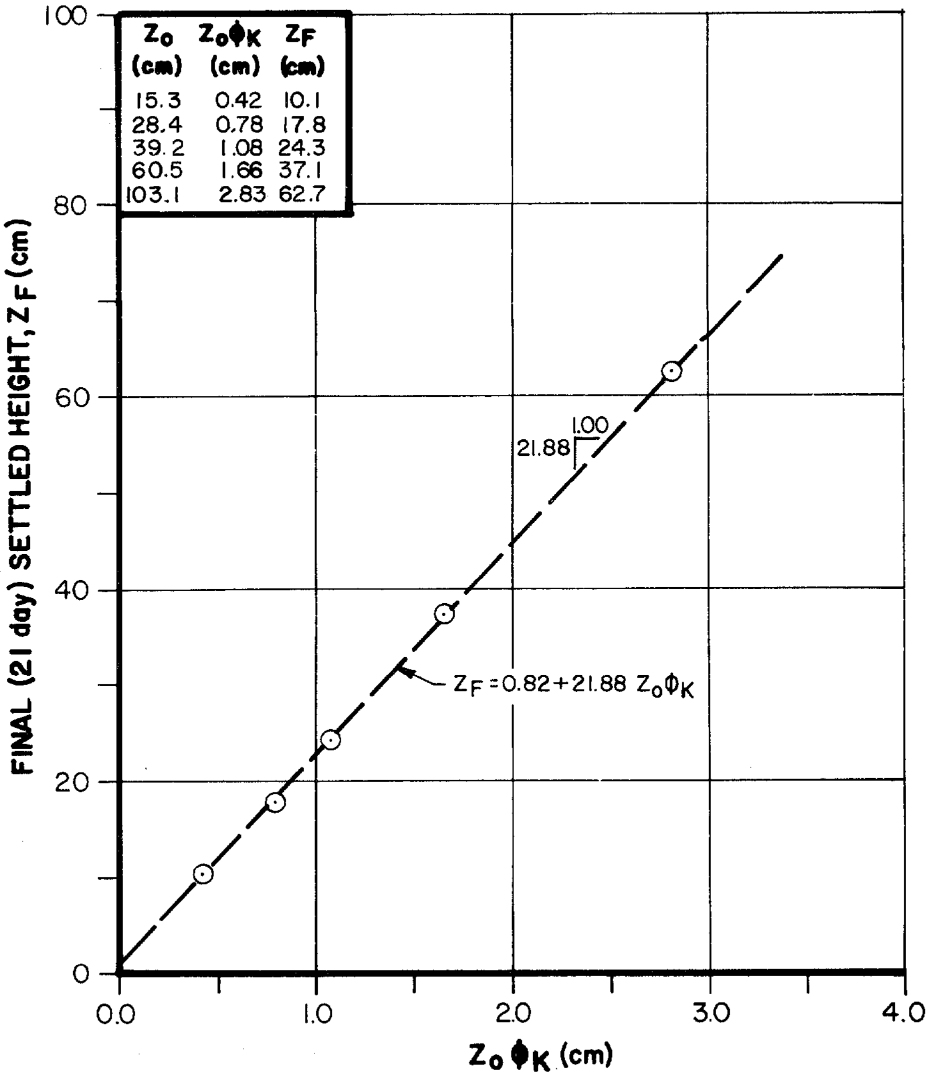
SOLIDS CONTENT VS. LOG TIME FOR MOBIL PHOSPHATIC CLAY WITH VARIOUS INITIAL SOLIDS CONTENTS

FIGURE 1-4



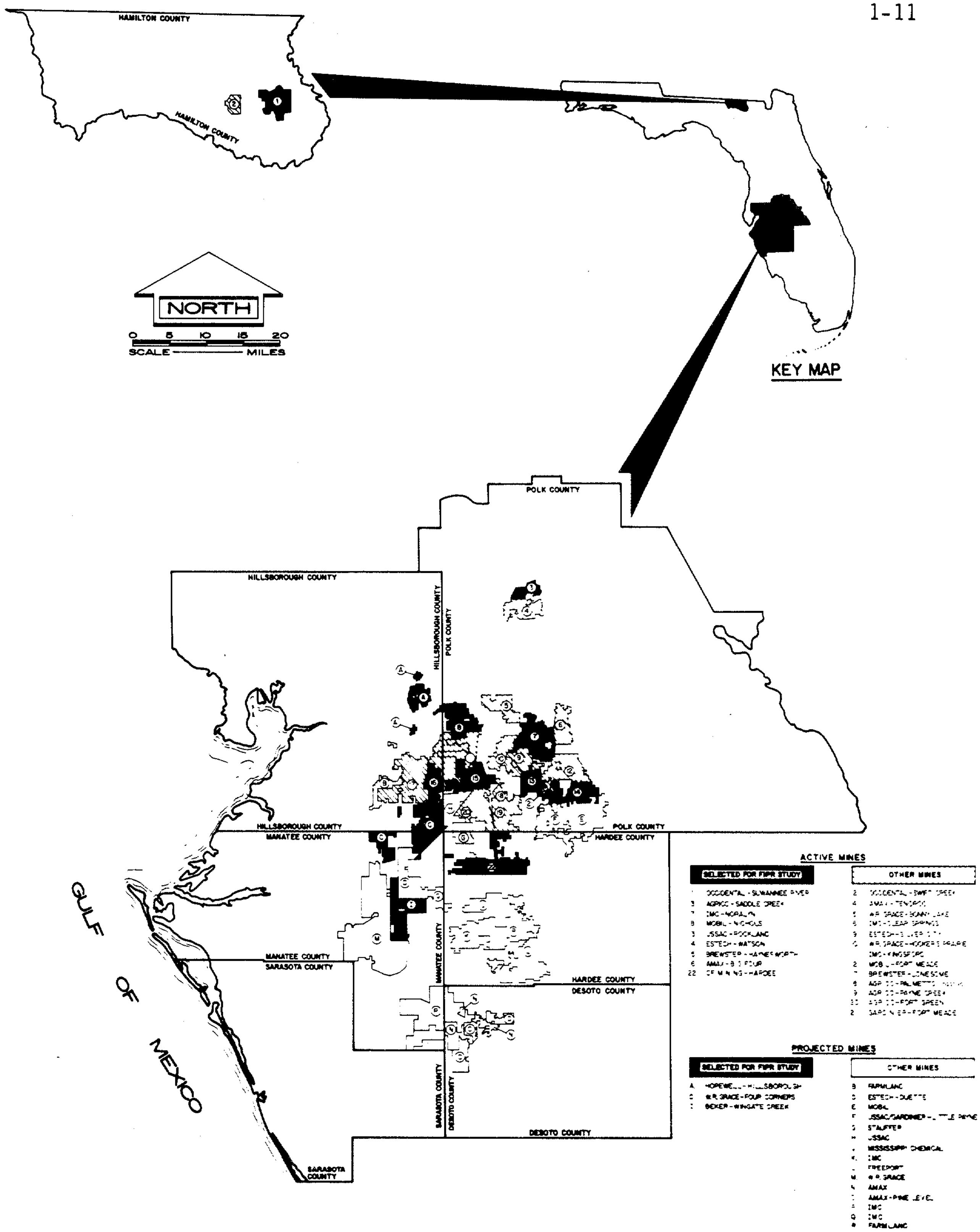
SOURCE: ADAPTED FROM ROMA, J.R. (1976). "GEOTECHNICAL PROPERTIES OF PHOSPHATIC CLAYS," M.S. THESIS, DEPARTMENT OF CIVIL ENGINEERING, M.I.T., CAMBRIDGE, MASSACHUSETTS.

SOLIDS CONTENT VS. LOG TIME FOR USSAC PHOSPHATIC CLAY WITH VARIOUS INITIAL SAMPLE HEIGHTS AND INITIAL SOLIDS CONTENT OF 7.46%



SOURCE: ADAPTED FROM ROMA, J.R. (1976). "GEOTECHNICAL PROPERTIES OF PHOSPHATIC CLAYS," M.S. THESIS, DEPARTMENT OF CIVIL ENGINEERING, M.I.T., CAMBRIDGE, MASSACHUSETTS.

FINAL SETTLED HEIGHT FOR USSAC PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 7.46%



MINE SITES SELECTED FOR INVESTIGATION

FIGURE 1-6

Section 2

EXPERIMENTAL SCHEME, TESTING METHODS AND QUANTITATIVE INTERPRETATION METHODOLOGY

2.1 Introduction

The sedimentation behavior of clays determined from laboratory settling tests is dependent on the procedures used to determine that behavior. The initial solids content, initial sample height and sample diameter used for laboratory tests influence the settled solids content and settling velocity of laboratory samples. Extrapolation of laboratory settling tests from a limited size container to the field situation of an "infinite size container", therefore, must be performed with a methodology considering these effects.

The sedimentation behavior of twelve phosphatic clays were investigated with over 100 laboratory settling tests. The sedimentation behavior of sand-clay mixes were investigated for three of the twelve phosphatic clays with 22 additional laboratory settling tests. The procedures used to perform these tests and criteria used to evaluate the results are presented in this section.

2.2 Experimental Scheme

Three series of laboratory settling tests were performed to evaluate the sedimentation behavior of phosphatic clays and sand-clay mixes (Figure 2-1):

- Constant initial height settling tests
- Variable initial height settling tests
- Sand-clay mix settling tests

Constant initial height settling tests were performed on twelve phosphatic clays at three different initial solids contents. These tests were performed from an initial height, Z_o, of 24 cm in 10.4 cm diameter settling columns. Initial solids contents, S_i of 1.0, 3.0 and 8.0% were used in this test series. Results from the constant initial height settling tests were used to: determine the range in settling behavior of phosphatic clays; and allow selection of clays which display the range in settling characteristics of phosphatic clays for further detailed conventional settling and sand-clay mix settling tests.

Based on results from the constant initial height settling tests, eight phosphatic clays were selected for variable initial height settling tests*. The eight clays were chosen to represent the range in settling behavior and index properties of phosphatic clays.** These tests were performed at initial solids contents of 3.0

*Phosphatic clay from the AMAX, Agrico, Beker, CF, IMC, Mobil, Oxy and USSAC mines were selected.

**Refer to Volume I for presentation of the index properties of the twelve phosphatic clays.

and 8.0%. Initial heights of 6, 12, 18 and 24 cm were used, corresponding to 25, 50, 75 and 100%, respectively, of the total slurry weight used in the 24 cm high samples. Results from these tests were used to: establish the void ratio (or solids content) versus effective stress compressibility curve at low stresses $\bar{\sigma}_{vc}$= 0.10 to 1.0 lb/ft) as detailed in Section 3.4; and to obtain parameters describing the settling characteristics of flocculated clay suspensions (see Section 2.4.2).

Sand-clay mix settling tests were performed on three selected phosphatic clays*. The tests were performed from an initial height of 24 cm and two initial clay solids contents, S_{ic}, dependent on the specific clay. The final solids content measured on the constant initial height settling tests with S_i = 3.0% were used as a guide in selecting the initial clay solids contents for the sand-clay mix settling tests. Sand-clay ratios, SCR, of 1:1, 2:1 and 3:1 based on dry weights of solids were used for each initial clay solids content. Sand tailings from corresponding mines were used in preparing the sand-clay mixes.

2.3 Testing Methods

Laboratory settling tests were performed in Plexiglas graduated settling “columns" 10.4 cm in diameter and 30.5 cm high. A total of 30 columns were used in this investigation allowing the performance of 30 settling tests simultaneously. A photograph of the settling columns is shown in Figure 2-2.

After preparing a sample to a desired initial solids content, the clay slurry was poured into the settling column to a desired initial sample height. The clay was thoroughly mixed after placement within the column with a hand-held stirrer to provide a homogeneous sample, and remove any segregation of particles which occurred during placement of the clay in the column. The columns were securely covered with clear plastic wrap to prevent evaporation of supernatent during the test period. The tests were performed in a fluorescent lighted room and were not exposed to direct sunlight.

Performance of the settling tests consisted of visually monitoring the height of clay slurry-supernatant interface versus time. Depending on the behavior of the clay, initial readings were obtained of height versus time in the range of one reading every 1 to 10 minutes. Subsequent readings were obtained at increasing time intervals. The tests were continued for a period of 30 to 40 days, until the height remained relatively constant.

After completion of the test, the solids content of the settled clay was measured for comparison to the calculated value based on final height and initial solids content. The supernatant pH and specific conductance at the end of the test was measured to determine if a significant change in supernatant chemistry occurred over the test period. For sand-clay mix settling tests, the percent soil fraction by dry weight passing a U.S. Standard No. 200 sieve (74 µm sieve size) was determined for the top and bottom half of the sample to check if segregation of clay and sand occurred during the test.

*Phosphatic clays from the Agrico, CF and USSAC mines were selected.

2.3.1 Presentation of Test Results

Plots of the height of interface versus time and average solids content below the interface versus time are presented for each series of settling tests, The initial sample height, final sample height, initial solids content, final solids content and final supernatant pH and specific conductance are also included on the figures.

The height of interface versus time readings were manually input into data files on a HP 9845B mini computer. The average solids content below the interface versus time and incremental settling rate between readings was then calculated for all readings and the results plotted on a HP 9872B plotter. The average solids content below the interface, S_k, for any height Of interface, Z_k, at time k was calculated from the relation:

$$S_k \quad = \quad \rho/(\rho+(Z_k/Z_s)-1) \qquad (1)$$

where: ρ is the specific gravity of solids and Z_s is the height of clay solids determined from the relation:

$$Z_s \quad = \quad Z_o/(1-\rho+(\rho/S_i)) \qquad (2)$$

where: Z_o is the initial height and Si is the initial solids content. The incremental settling rate was calculated as the ratio of the change in height to the elapsed time between two successive observations.

2.4 Interpretation Methodology

Michaels and Bolger (1962) provide a comprehensive methodology for interpreting the results of settling tests and extrapolating data obtained in the laboratory from a limited size container to the field situation of an “infinite size container”.* Their model is based on the premise that the settling rate is not directly dependent on primary clay particle sizes, but rather on flocs consisting of clusters of particles. The flocs possess a small but finite strength that allows them to remain intact under the mild surface shear forces experienced in gravity settling. At slow shear rates (as occur in settling tests), the flocs in turn group into clusters designated as “aggregates" that give the suspension its settling characteristics.

The settling behavior of dilute suspensions differs from that of more concentrated suspensions as depicted in Figure 2-3. The settling rate is defined as the rate of settling of the interfacial plane between the clay slurry and the supernatant. The

*The Michaels and Bolger methodology was developed from studies of the sedimentation behavior of kaolinite. Kaolinite was selected for investigation because the characteristics of kaolinite are generally well understood, therefore, allowing interpretation of settling behavior in terms of particle to particle interactions. The use of kaolinite to develop the model does not limit its application to other non-kaolinitic clays.

settling rate of dilute suspensions over much of the settling range is constant with time and independent of the size of container used. This settling behavior is characteristic for solids contents generally less than 1% and is, therefore, of little practical interest.*

At intermediate slurry concentrations (i.e., greater than a solids content of l%), the clusters of flocs or aggregates settle as a coherent network. The initial settling rate, Q, is very low, but increases with time, reaching a maximum value, Q_1, at time t_1 when free-fall settling ends and consolidation presumably begins. Distinguishing sedimentation, the increase in "particle" concentration due to gravity settling "without particle-to-particle contact" (i.e., at zero effective stress), completely from consolidation, the increase in solids content as a result of the applied self-weight effective stress, is an almost impossible task since both phenomena undoubtedly proceed simultaneously particularly in the mid-stages of settling.

Michaels and Bolger (1662) base their theory for intermediate slurry concentrations on the experimental fact that during the early free-fall settling period, there exists a region extending from the interface a certain distance downward whose density is constant and equal to the density of the original suspension. This equal density zone, "plug" or control volume varies in length during the test. Its weight is supported by buoyancy, fluid friction due to upward flow, the aggregate network (i.e., shear forces at the walls of the container), and the compressive strength of the underlying compressed zone of material.

By establishing equilibrium of forces on the control volume, Michaels and Bolger obtain the general settling equation for flocculated suspensions:

$$Q = Q'\left(1 - (D_y/D_o) - (Z_y/Z_o)\right) \qquad (3)$$

where:

- Q' = field settling rate in an infinitely large container (Q' varies with time)
- Q = laboratory settling rate in a container having a diameter, D_o, and an initial height, Z_o (Q varies with time)
- D_y = yield diameter
- Z_y = yield height (Z_y varies with time)

*Phosphatic clay from primary launders is typically deposited in settling areas at an initial solids content of 3-4%, and hence is not characterized as a dilute suspension. Phosphatic clay from the secondary launder, however, is typically at a solids content of 1.0% and may exhibit settling behavior similar to a dilute suspension.

The significance of the yield diameter and yield height is that if $D_o \leq D_y$ or if $Z_o \leq Z_y$ then Q is zero, which means that the slurry will not undergo free-fall settling. It will, however, exhibit consolidation or compression settling which the Michaels and Bolger theory does not model. For a given clay volume concentration, ϕ_K*, D_y is dependent on the yield shear stress between the container wall and the settling slurry plug, and Z_y is dependent amongst other things on the compressive yield strength of the aggregate network. The above equation indicates that if D_o and Z_o are sufficiently large, the settling rate in the laboratory is equal to the settling rate in the field. D_y/D_o can be taken equal to zero if a large diameter container is used since D_y for solids contents up to 8% is generally smaller than 0.3 cm**.

Note that the effects of container height and diameter in the settling equation are uncoupled since the settling rate depends on the ratios D_y/D_o and Z_y/Z_o. This is obviously not true for compression and consolidation settling where the ratio of height of clay sample to container diameter influences the friction force experienced at the container walls.

Michaels and Bolger derive equations that can be used to determine the following parameters that influence settling behavior:

Q_1 = maximum laboratory settling rate
Q'_1 = maximum field settling rate
Z_{y1} = yield height at maximum settling rate
ϕ_F = floc volume concentration
ϕ_A = aggregate volume concentration
d_p = average pore diameter

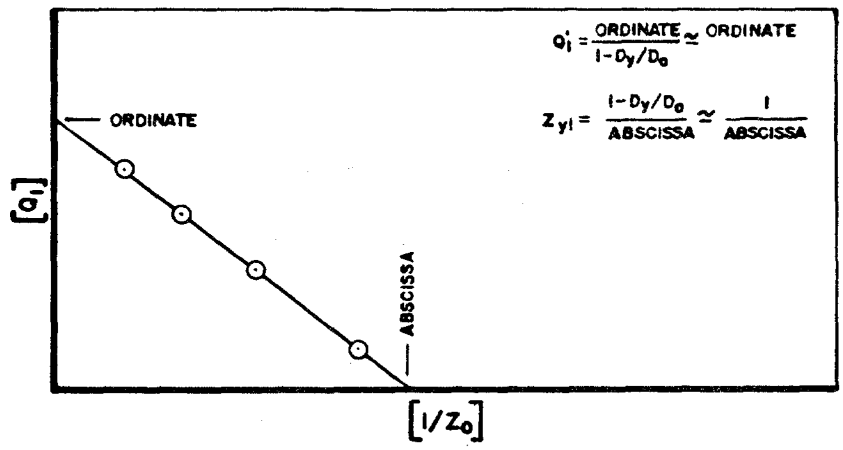
These parameters can be determined from graphical solutions as subsequently illustrated.

2.4.1 Height Effect and Field Settling Rate

For a given initial solids content and corresponding clay volume concentration, extrapolation of laboratory settling rates in a given size container to field settling rates can be determined from tests with varying initial heights. As shown below, the maximum field settling rate, Q'_1, is determined from the maximum laboratory settling rate, Q_1, from tests with varying initial heights, Z_o, by constructing a plot of $1/Z_o$ versus Q_1. For intermediate concentrations, this plot ideally yields a linear relationship.

*$\phi_K = S/[S + (1 - S)\rho]$; where: S = solids content; and ρ = specific gravity of solids. Physically, ϕ_K is the ratio of the clay solids volume to the total volume of the clay suspension.

**For kaolinite at an initial solids content of 8% (ϕ_K = 0.032), Michaels and Bolger (1962) report a yield diameter, D_y, of 0.24 cm.



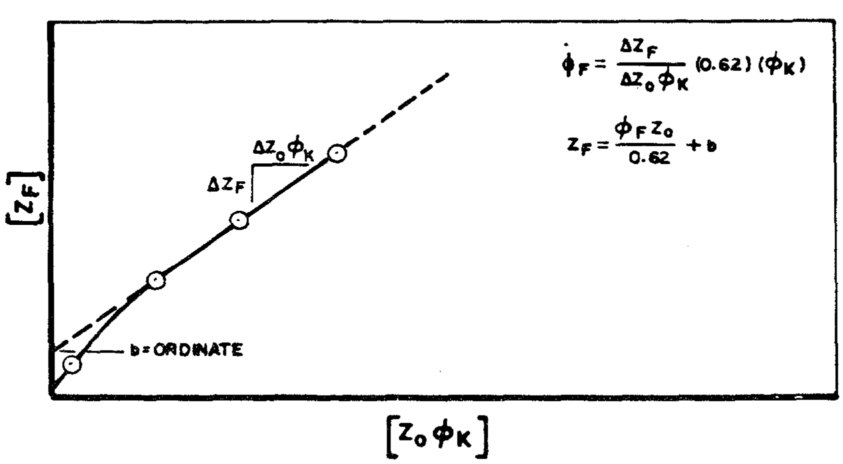
The ordinate intercept on this plot is the maximum field settling rate, Q'_1, corresponding to an infinitely high sample (i.e., $1/Z_0 = 1/\infty = 0$). The inverse of the abscissa intercept is the yield height at the maximum settling rate, Z_{yl}.

Similar plots may be prepared at different times, say $t\alpha$ instead of t_l, to determine $Z_y\alpha$ and $Q'\alpha$. Using this approach for several values of to allows extrapolation of the field settling rate, $Q'\alpha$, at any time to from laboratory settling rates at the same time.

2.4.2 Floc Volume Concentration and Final Height

Physically, the floc volume concentration , ϕ_F is the ratio of the volume of the flocs to the total volume of the clay suspension. Flocs consist of small clusters of clay particles. The floc volume concentration depends on the type of clay minerals and the initial solids content or clay volume concentration. For a given clay, the size of the flocs increases with increasing initial solids content.

For a given initial solids content or clay volume concentration, the corresponding floc volume concentration can be determined from tests with varying initial heights. As shown below, the floc volume concentration is determined from the slope of the linear portion of the curve obtained by constructing a plot of $Z_0\phi_K$ versus final height, Z_F.



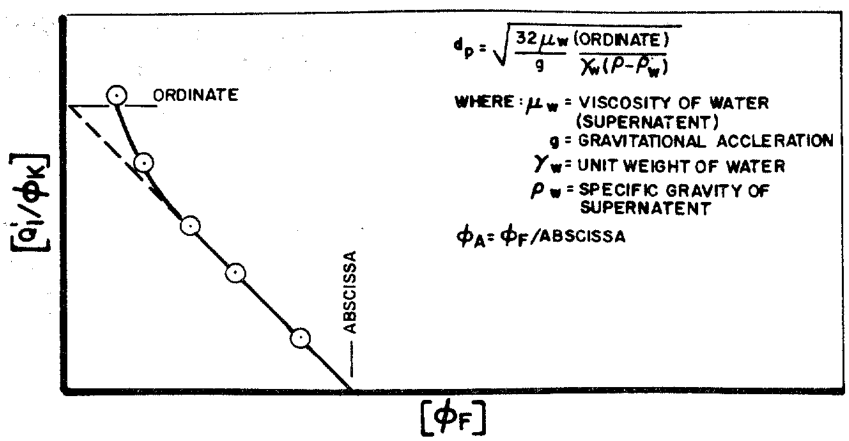
Physically, $Z_o \phi_K$ is the height of clay solids. Hence, for a given clay and initial solids content the final height, Z_F, must increase as the initial height, Z_o, increases. Assuming that the clay flocs form a final structure that can be modeled as a random, closely-packed array of uniform spheres, where the solid volume fraction is 0.62*, the final settled height of a suspension with initial height Z_o, is:

$$Z_F = (Z_o \phi_F / 0.62) + b \tag{4}$$

where b is a constant additional height resulting from the presence of an upper low density settled zone where the flocs are not as closely packed.

2.4.3 Aggregate Volume Concentration and Pore Diameter

At the slow shear rates which occur in settling tests, the flocs of clay particles group into clusters designated as aggregates. From settling tests with varying initial clay volume concentrations, Michaels and Bolger (1962) show that the aggregate volume concentration and pore diameter can be determined from a linear plot of ϕ_F versus Q'_1/ϕ_K. A series of tests on a clay is necessary with varying initial solids content or ϕ_K, with Q'_1 and ϕ_F determined as described in Sections 2.4.1 and 2.4.2, respectively. From these data a plot of ϕ_F versus Q'_1/ϕ_K is obtained for a given clay as shown below.



Physically, the aggregate volume concentration, ϕ_A is the ratio of the volume of the aggregates to the total volume of the clay suspension. An aggregate is composed of flocs with entrained inter-floc water. The total volume of the clay

*Physically, a solid volume fraction of 0.62 implies that the ratio (Z_{flocs}/Z_F) = 0.62, where Z_{flocs} is the height of flocs.

suspension, therefore, is composed of aggregates with entrained inter-floc water and inter-aggregate "free" water. When aggregates comprise the entire volume of the suspension, no free-fall gravity settling occurs and Q'_1 is zero. The intercept of the linear relation between Q'_1/ϕ_K and ϕ_F, therefore, corresponds to a ϕ_A value of 1.0. For other values of Q'_1/ϕ_K and corresponding value of ϕ_F, the value of ϕ_A is determined from the ratio of ϕ_F to the abscissa intercept.

The pore diameter, d_p, is the average diameter of the drainage paths between aggregates. According to Michaels and Bolger, given enough time in a container of infinite size, the drainage paths between aggregates tend to approach the configuration of smooth vertical tubes rising through the aggregate network, at which time the settling rate increases to the maximum value, Q'_1. At this point, the maximum settling rate is:

$$Q'_1 = \left[(g\gamma_w(\rho-\rho_w)\phi_K dp^2) \;/32\,\mu_w\right]\left[1 - C_{AF}\phi_F\right] \qquad (5)$$

where g is gravitional acceleration, γ_w is the unit weight of water, ρ is the specific gravity of clay solids, ρ_w is the supernatant specific gravity, μ_w is the absolute viscosity of water, and C_{AF} is the ratio ϕ_A/ϕ_F. From this relationship, when $\phi_F = 0$ the ordinate intercept of Q'_1/ϕ_K is $g\gamma_w(\rho-\rho_w)\, dp^2/32\,\mu_w$ and the value of d_p can be determined. Conversely, when $Q'_1 = 0$, the abscissa intercept of ϕ_F is $1/C_{AF}$ from which ϕA can be determined for any ϕ_F. .

Note that the floc and aggregate volume concentrations, ϕ_F and ϕA, respectively, are not only dependent on clay minerals but also on the initial solids content or clay volume concentrations, ϕ_K.

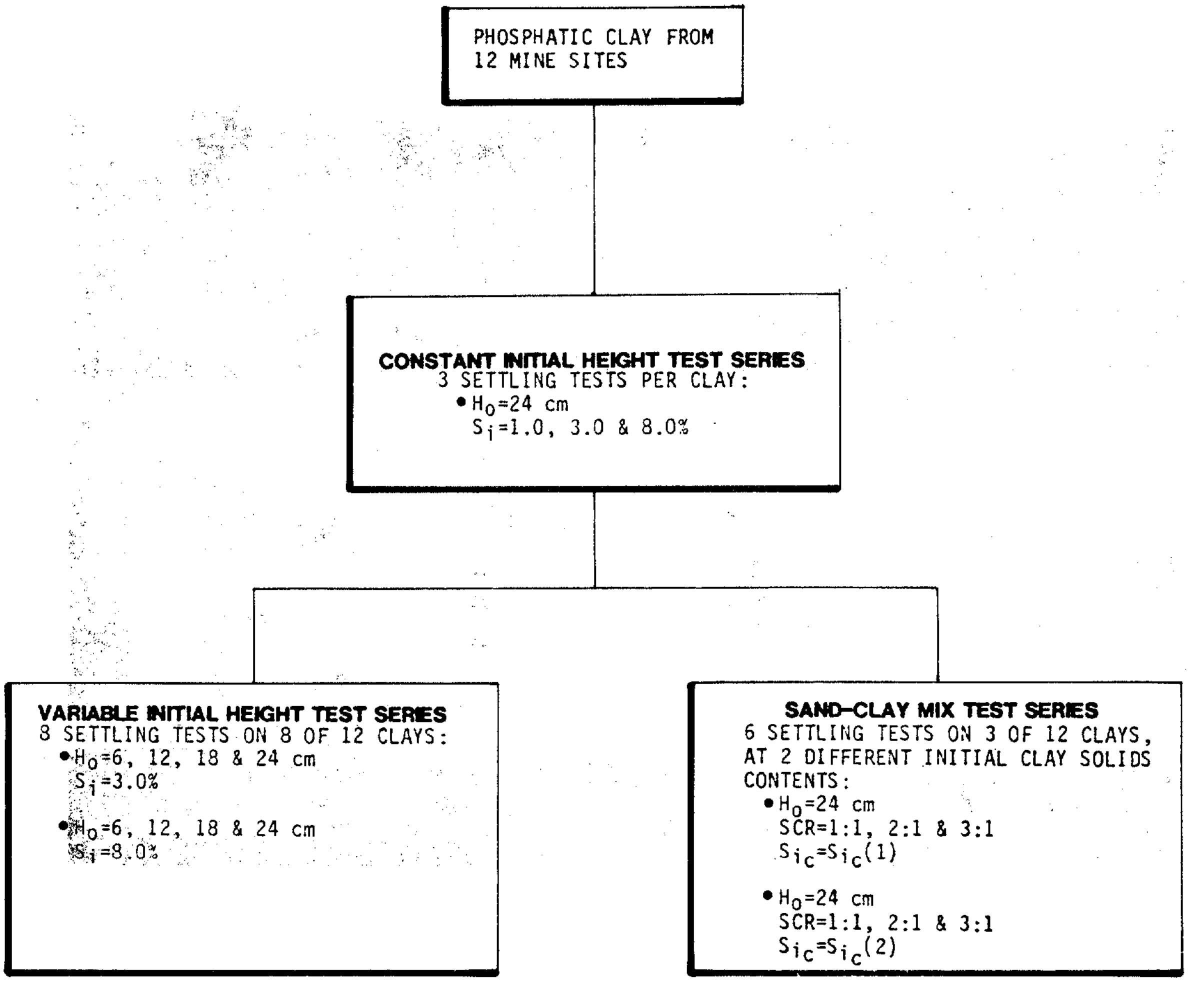
2.4.4 Diameter Effect

If the diameter of the laboratory settling test container, D_o, is not greater than the yield diameter, D_y, of the clay suspension, there is no gravity settling or accelerated settling rate period. Michaels and Bolger show that the yield diameter can be determined from the equation:

$$D_y = 4(\tau_y/g) \;/\; \gamma_w(\rho-\rho_w)\phi_K \qquad (6)$$

where τ_y is the yield stress of the clay suspension.

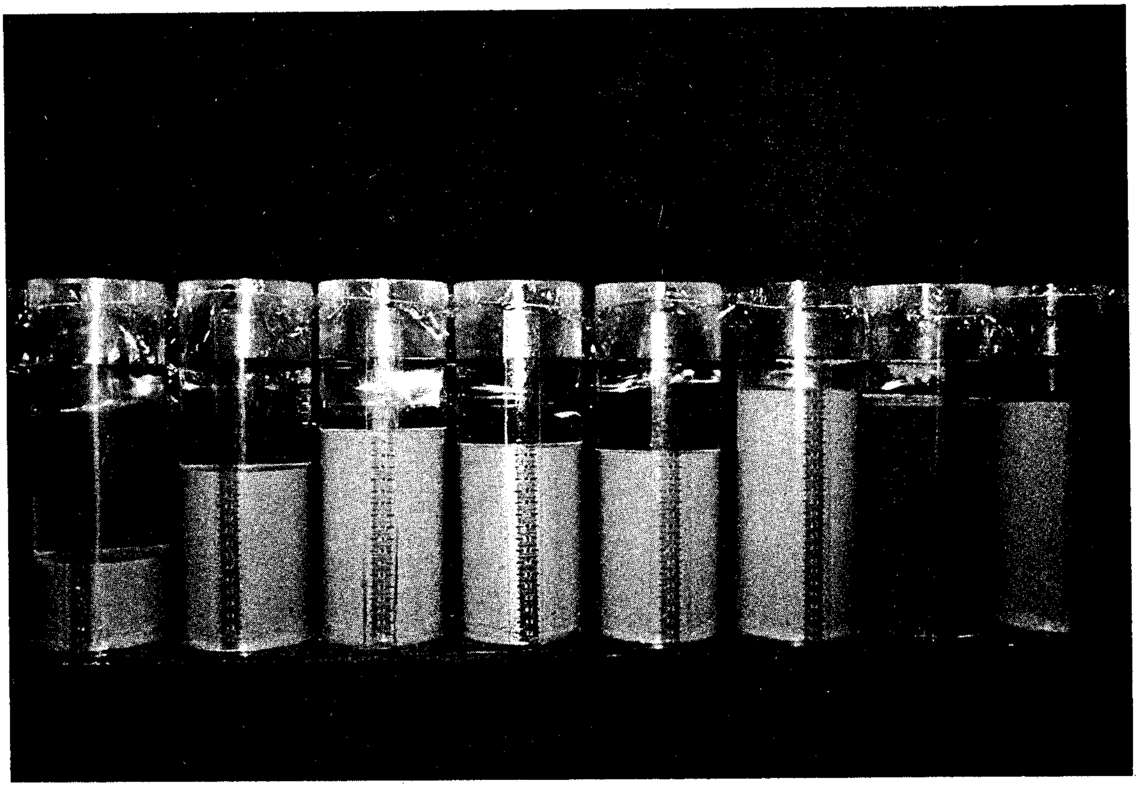
For kaolinite at an initial solids content of 8.0% ($\phi_K = 0.032$), Michaels and Bolger report a yield stress of 3 dynes/cm^2 and a yield diameter of 0.24 cm. Hence, for many clays and for initial solids contents less than 8.0%, the yield diameter is small. For the container diameter of 10.4 cm used during this investigation the ratio D_y/D_o would be 0.023 for kaolinite at an initial solids content of 8.0%. Therefore, Equation 3 predicts that settling rates in a 10.4 cm diameter container would be only 2.3% less than in a container of infinite diameter. For most applications the diameter effect is, therefore, negligible unless consolidation takes place subsequent to settling.



NOTATION: H_0=INITIAL SAMPLE HEIGHT; S_i=INITIAL SOLIDS CONTENT; SCR=SAND-CLAY RATIO; S_{ic}=INITIAL CLAY SOLIDS CONTENT; AND $S_{ic}(1)$ AND $S_{ic}(2)$=VARIABLE INITIAL CLAY SOLIDS CONTENT DEPENDENT OF SPECIFIC CLAY SAMPLE.

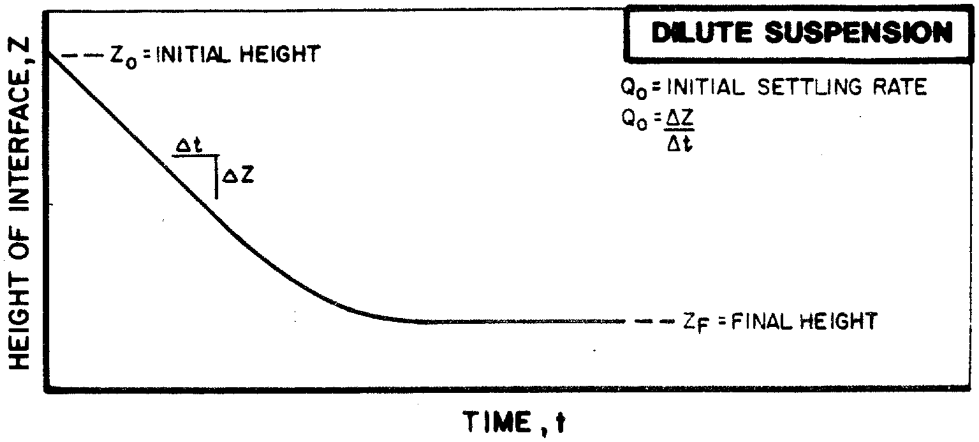
EXPERIMENTAL SCHEME FOR EVALUATION OF SEDIMENTATION BEHAVIOR

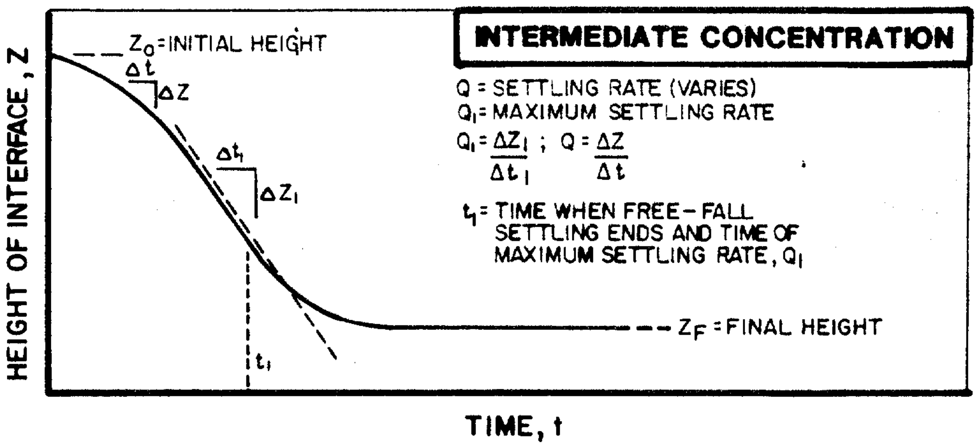
FIGURE 2-1



SETTLING "COLUMNS"

FIGURE 2-2





SOURCE: MICHAELS, A.S. AND BOLGER, J.C. (1962). "SETTLING RATES AND SEDIMENT VOLUMES OF FLOCCULATED KAOLIN SUSPENSIONS." IND. ENG. CHEMICAL FUNDAMENTALS, VOL. I, NO. 1.

TYPICAL HEIGHT VS. TIME CURVES FOR DILUTE AND INTERMEDIATE CONCENTRATION FLOCCUATED CLAY SUSPENSIONS

FIGURE 2-3

Section 3

SEDIMENTATION BEHAVIOR OF PHOSPHATIC CLAYS

3.1 Introduction

The objective of the present investigation of the sedimentation behavior of phosphatic clays is to determine the range of settling behavior and final solids contents of phosphatic clays after deposition and gravity settling within an impoundment, and to attempt to determine the physical parameters governing the settling behavior of phosphatic clays. To achieve this objective over 100 laboratory settling tests on twelve phosphatic clays were performed with various initial solids contents and sample heights.

All settling tests performed on the phosphatic clays are presented and evaluated in this section. The results from constant initial height settling tests with initial solids contents of 1.0, 3.0 and 8.0% are first reported. The results from variable initial height settling tests are then presented for eight of the twelve clays with interpretations of physical parameters according to the Michaels and Bolger (1962) methodology. Finally, the void ratio (or solids content) versus effective stress compressibility curves at low stresses inferred from the settling tests are described.

3.2 Constant Initial Height Settling Test Series

Constant initial height settling tests were performed on each of the twelve phosphatic clays. An initial height, Z_o, of 24 cm was used for the test series. Initial solids contents, S_i, of 1.0, 3.0 and 8.0% were selected to provide settling characteristics for the range of initial solids contents likely to result for clay slurry from a primary launder and to provide samples exhibiting dilute suspension settling behavior (S_i = 1.0%), intermediate concentration settling behavior (S_i = 3.0 to 8.0%)* and compression settling behavior (S_i = 8.0%) as defined by Michaels and Bolger (1962).

The constant height settling tests were evaluated to determine solids content versus time, settling rate versus time, and the final solids content achieved after 30 to 40 days when settling was assumed to be complete as no significant additional settling was observed.

3.2.1 Final Solids Content

Results from constant initial height settling tests graphically summarized as solids content versus time are presented in Figures 3-1, 3-2 and 3-3 for initial solids

*It was anticipated that some clays with an initial solids content of 8.0% would exhibit intermediate concentration settling behavior while others would exhibit compression settling behavior.

contents of 1.0, 3.0 and 8.0%, respectively. The final solids contents selected for each clay are listed in Table 3-1 and are also shown on the figures. Height of interface versus time, height of interface versus the log of time, and average solids content versus time plots for each of the settling tests are presented in Appendix B, Figures B-1 through B-36. Appendix A, Tables A-1 through A-12 summarize relevant test data.

As shown in Figures 3-1, 3-2 and 3-3, the test results clearly indicate that significant variability exists between the settling behavior of phosphatic clays at each initial solids content. Some phosphatic clays exhibit little gravitational settling increse in solids content, while others exhibit significant increases in solids content. For an initial solids content of 3.0%, the increase in solids content due to gravitational settling varies from a low of 2.4% (i.e., from 3.0 to 5.4%) to a high of 14.8% (i.e., from 3.0 to 17.8%). The settling behavior of the twelve clays generally occurs in three groups as shown in Figure 3-4. For all initial solids contents the, lowest solids content versus time relationship occurs for the Agrico-Saddle Creek samples, and the highest solids content versus time relationship occurs for the AMAX-Big Four and/or CF Mining-Hardee samples. The remaining nine clay samples yield a range of solids content versus time relationships intermediate between these extremes. Figure 3-5 illustrates the typical behavior of the lowest (Agrico), average (USSAC), and high (CF) solids content versus time relationship.

The minimum, maximum and average final solids contents measured on the twelve clays are summarized in Table 3-1 for each initial solids content. The average final solids contents for initial solids contents of 1.0, 3.0 and 8.0% are 9.7, 10.9 and 12.9%, respectively. The variability from these averages are significant as indicated by coefficients of variation (C.V.) of 22.0.to 43.5%. For an initial solids content of 3.0%, the Agrico clay yields the minimum final solids content of 5.4%, 5.5% below the average, and the CF clay yields the maximum final solids content of 17.8%, 6.9% above the average. The range of settling behavior measured on the twelve clays is consistent with settling behavior observed on other phosphatic clays (Table 3-1). The results from an initial solids content of 3.0% agree with the range of 5.7 to 15.9% and average of 10.9% reported by Lamont et al. (1975) for 15 phosphatic clays tested with a somewhat similar initial solids content of 3.7% (Figure 1-1).

The settling test results generally indicate that for a given clay, a slurry prepared at an initially lower solids content will not obtain as high a settled solids content with time as a slurry prepared at an initially higher solids content. This behavior was also noted by Roma (1976) from settling tests performed on Mobil-Fort Meade phosphatic clay (Figure 1-3). For example, for the USSAC-Rockland clay shown in Figure 3-6, a slurry with an initial solids content of 1.0% settles to a final solids content of 7.7%, whereas a slurry with an initial solids content of 3.0% settles to a final solids content of 9.3%.

The percent settling completed versus log time for the Agrico, CF, Mobil and USSAC phosphatic clays from an initial solids content of 3% is presented in Figure 3-7. As shown, the clays which settle to the lowest final solids content also require a greater time to complete the same percentage of settling. The poor settling clays, therefore, are characterized by both a relatively lower final settled solids content and relatively slower rate of "settling" than the good settling clays.

Measurements of supernatant pH and specific conductivity obtained at the end of the settling tests were consistent with values determined prior to testing. No significant changes or trends on supernatant pH or specific conductivity were observed during the 36 day settling test period.

3.2.2 Laboratory Settling Rate

The maximum laboratory settling rates, Q_1, measured for each clay at initial solids contents of 1%, 3% and 9% are summarized in Table 3-2 and Figure 3-8. The maximum settling rates consistently decrease with increasing initial solids content. For a given initial solids content, however, the maximum settling rate varies considerably between phosphatic clays. Samples from Agrico-Saddle Creek and CF Mining-Hardee consistently yield the slowest and fastest maximum settling rates, respectively.

For a given initial solids content, the maximum laboratory settling rate increases as the final settled solids content increases. As shown in Figure 3-9, for clays with an initial solids content of 3% the maximum laboratory settling rate increases from 0.2-0.4 cm/hour for final settled solids contents of 6 to 10% to 8.4 cm/hour for a final settled solids content of 17.8%, A trend of increasing settling rate with increasing final settled solids content was also observed by Lamont et al. (1975).

The maximum laboratory settling rate is an instantaneous settling rate that occurs relatively early in the settling test in comparison to the time required to reach the final settled solids content. Figures 3-10, 3-11 and 3-12 illustrate the time at which the maximum settling rate occurs, t_1, and the solids content at this time, S_{t1}, for Agrico, CF and USSAC phosphatic clays at initial solids contents of 1.0, 3.0 and 8.0%, respectively.* As shown, the time required to reach the maximum settling rate increases for clays with slower settling rates and lower final settled solids contents. For each initial solids content, however, the clays have a relatively similar solids content at the time of the maximum settling rate. For initial solids contents of 1.0, 3.0 and 8.0%, the average solids contents at the time the maximum settling rate occurs are 1.2, 3.5 and 8.2%, respectively.

While the maximum laboratory settling rate is of interest to characterize the settling behavior of phosphatic clays, the average settling rate from the initial to final solids content is more appropriately represented by the average secant settling rate, Q_s. The average secant settling rate is the slope of the line between the initial and final height of interface versus time. For determining the average secant settling rate the final height and time were defined at the intersection of

*These clays are representative of clays with low, high and average final settled solids contents, respectively.

the linear portion of the tail end of the height of interface versus time curve with the initial. curved portion of the settling curve (Figures B-13 through B-24). Table 3-3 presents the average secant settling rates determined for an initial solids content of 3%. As shown, the average secant settling rate ranges from 0.026 to 0.073 cm/hour and averages 0.054 cm/hour.

3.2.3 Comparison With Settling Tests on Primary and Secondary Launder Clay Samples

The results from settling tests on primary and secondary launder clay samples are summarized in Table 3-4. Height of interface versus time and versus log time plots are presented in Appendix B, Figures B-13 through B-36. The initial solids contents for these tests were similar to the solids contents determined for the primary and secondary launders.*

As shown in Table 3-4, the measured final solids contents for the primary and secondary launder samples, $S_F(m)$, agreed in general with the predicted solids contents, $S_F(p)$ based on the constant initial height settling tests for corresponding settling area phosphatic clay with initial solids contents of 1, 3 and 8%. The basis for each predicted solids content is shown in Table 3-4. For primary launder samples with initial solids contents of 2.8 to 6.4%, the predicted final solids contents are, on the average, 15% greater than measured. For secondary launder samples with initial solids contents of 0.5 to 1.1%, the predicted final solids contents are, on the, average, 10% less than measured. The differences between measured and predicted values are generally small, especially if one considers that the clay samples are not likely to be identical. Settling tests performed on settling area samples diluted to 1% are believed representative of the sedimentation behavior of secondary launder clays, and settling tests performed on settling area samples diluted to 3-8% are representative of the sedimentation behavior of primary launder clays.

3.3 Variable Initial Height Settling Test Series

Variable initial height settling tests were performed on eight phosphatic clays. The eight selected included the Agrico, AMAX, Beker, CF, IMC, Mobil, Occidental and USSAC phosphatic clays.** Initial solids contents of 3 and 8% were selected and initial heights of 6, 12, 18 and 24 cm were used. The variable initial height settling tests were evaluated in detail with the Michaels and Bolger (1962) methodology to determine parameters describing the settling characteristics of flocculated clay suspensions. Void ratio versus effective stress relationships at low stresses were also determined from the variable initial height settling tests.

*Refer to Volume 1, Section 2, Table 2-2 for the solids contents measured on samples from the primary and secondary launders.

**The Estech phosphatic clay was also tested with variable initial heights for an initial solids content of 3%.

Solids content versus time and height of interface versus time plots for each settling test are presented in Appendix C, Figures C-1 through C-34.

3.3.1 Field Settling Rate

For a given initial solids content, S_i, or clay volume concentration, ϕ_K, and several settling tests with varying initial sample heights, the maximum field settling rate can be extrapolated from maximum laboratory settling rates using the Michaels and Bolger (1962) methodology. Comparison of the extrapolated field settling rate and the measured laboratory settling rate shows the effect of limited sample height or container diameter relative to what is expected to occur in the field for an "infinite size container".

The maximum field settling rate is determined from the relationship between the maximum laboratory settling rate, Q_1, for various initial heights, Z_o. The maximum field settling rate, Q'_1 , corresponds to Q_1 for a $1/Z_o$ value 0 i.e., infinite container height). Graphical plots of Q_1 versus $1/Z_o$ for each clay at initial solids contents of 3 and 8% are shown in Appendix D, Figures D-1 through D-17. The height of interface versus time and time at which the maximum settling rate occurs for each initial height are also shown on these figures.

Typical plots of Q_1 versus $1/Z_o$ are presented in Figure 3-13 for selected clays at an initial solids content of 3%. The extrapolated maximum field settling rates are shown at $1/Z_o = 0$ or the ordinate intercept. For most phosphatic clays, the maximum laboratory settling rate measured for an initial sample height of 6 cm ($1/Z_o$ = 0.167 cm^{-1}) was beyond the linear portion of the Q_1 versus $1/Z_0$ curve used to determine the maximum field settling rate.* Hence, only 2 or 3 data points were available to extrapolate the data to the maximum field settling rate.

Table 3-5 presents the maximum field settling rates determined for each phosphatic clay at initial solids contents of 3 and 8% using the procedure illustrated in Figure 3-13. A comparison of maximum field and laboratory settling rates** as a function of final settled solids content is shown in Figure 3-14 for an initial solids content of 3%. Least squares linear regression analyses of maximum laboratory and maximum field settling rates versus final settled solids contents are also shown. The regressions indicate that field settling rates are greater than laboratory settling rates measured on samples with initial heights of 24 cm. For a final settled solids content of 8% the field settling rate is faster by a factor of 2.4 and for a final settled solids content of 18% they differ by a factor of 1.3. Similar differences also result for clays at an initial solids content of 8%.

3.3.2 Yield Height

The significance of the yield height, Z_y, for a given initial solids content is that if the initial sample height, Z_O, is less than Z_y, there is no gravity settling or

*Except for the AMAX and Beker phosphatic clay samples (Figures D-2 and D-3).
**Maximum laboratory settling rates from initial sample heights of 24 cm.

accelerated settling rate period. Instead, the interface of the suspension subsides at a continuously decreasing rate. For gravity settling to occur, therefore, the initial sample height must be greater than the yield height.

Using the graphical methodology of Michaels and Bolger (1962), the yield height at the time of the maximum settling rate, Z_{y1}, was determined for initial solids contents of 3 and 8%. Generally, for a given clay mineralogy, initial solids content and pore fluid chemistry, the value of Z_{y1} is constant. During a settling test Z_y will vary, but will approach the value of Z_{y1} as t approaches t_1. The Q_1 versus $1/Z_o$ curves presented in Appendix D, Figures D-1 through D-17 were used to determine Z_{y1}. On these figures the abscissa intercept of the initial linear portion of the curve, corresponding to $Q_1 = 0$, is the inverse of the yield height. Figure 3-13 illustrates the determination of the yield height at the time of the maximum settling rate for several clays.

Table 3-5 presents the yield height at the time of the maximum settling rate determined for each phosphatic clay at initial solids contents of 3 and 8%. The yield heights are in the range of 2.4 to 14.2 cm and 2.1 to 17.1 cm for initial solids contents of 3 and 8%, respectively. These yield heights are greater than the initial heights of some of the test samples indicating that "free-fall" gravity settling did not occur where the yield height was greater than the initial height. Theoretically, the yield height for an initial solids content of 8% should be greater than for an initial solids content of 3%. For three clays (AMAX, IMC and Mobil), however, the reverse relationship was found due to difficulties in accurately extrapolating the test data.

To predict settling rates which occur in the field from laboratory sized settling experiments the effect of the initial sample height can be determined for the case of the maximum settling rate from the equation:

$$Q_1 = Q'_1\{1 - (Z_{y1}/Z_o)\} \qquad (1)$$

Where:
Q_1 = maximum laboratory settling rate
Q'_1 = maximum field settling rate
Z_o = initial sample height
Z_{y1} = yield height at maximum settling rate

For a range in yield heights, Z_{y1}, of 3 to 10 cm, which probably includes the yield heights for most phosphatic clays, the value of Z_{y1}/Z_o for initial sample heights of 24.0 cm varies from 0.125 to 0.417. The maximum field settling rate, therefore, is generally on the order of 14 to 72% greater than measured in the laboratory on 24.0 cm high samples. This result is useful to correct laboratory settling rates measured on clay samples where numerous tests are not performed to quantitatively determine the effect of sample height as done in Section 3.3.1 above.

3.3.3 Yield Diameter

If the diameter of the settling test container, D_o, is not greater than the yield diameter, D_y, of the clay slurry, there is no gravity settling or accelerated settling rate period. Michaels and Bolger (1962) show that the yield diameter can be determined from the equation:

$$D_y = 4(\tau_y/g) \;/\; \gamma_w(\rho - \rho_w)\phi_K \qquad (2)$$

Where:

τ_y	=	yield stress of clay slurry
ρ	=	clay solids specific gravity
ρ_w	=	supernatant specific gravity (0.997 at 25^oC)
γ_w	=	unit weight of water (1.0 gm/cm^3)
g	=	gravitational acceleration (980 cm^2/sec)
ϕ_K	=	clay volume concentration

The yield diameters determined for the Agrico, CF, Mobil and USSAC phosphatic clays for initial solids contents of 3 and 8% are summarized in Table 3-6. The yield diameters are relatively small and range from 0.11 to 0.51 cm.

The effect of the yield diameter can be evaluated from the equation:

$$Q_1 = Q'_1\{1-(D_y/D_o)\} \qquad (3)$$

Where:

Q_1	=	maximum laboratory settling rate
Q'_1	=	maximum field settling rate
D_o	=	laboratory container diameter
D_y	=	yield diameter

For yield diameters of 0.11 to 0.51 cm and a settling test container diameter of 10.4 cm, the ratio D_y/D_o varies from 0.011 to 0.05. The maximum field settling rate, therefore, is only 1 to 5% greater than measured in the laboratory in a 10.4 cm diameter container.

3.3.4 Floc Volume Concentration

The Michaels and Bolger (1962) methodology is based on the premise that the settling rate is not directly dependent on individual clay particle sizes, but rather on flocs consisting of clusters of particles.The floc volume concentration, ϕ_F, depends on the type of clay minerals and the initial solids content or clay volume concentration. The size of the flocs increases with increasing initial solids content. Further, for a given initial solids content the greater the floc volume concentration, the lower the final settled solids content.

The floc volume concentration is determined by the slope of the linear portion of the curve obtained by constructing a plot of $Z_o\phi_K$ versus the final settled height, Z_F. These plots are presented in Appendix E, Figures E-1 through E-17 for each phosphatic clay for initial solids contents of 3 and 8%. The least squares linear regression equations for the fitted lines are also shown on the figures and summarized in Table 3-7.

The determination of the floc volume concentration is based on the assumption that the clay flocs form a final structure of random, closely-packed array of spheres having a solid volume fraction of 0.62. The final settled height of a suspension, therefore, can be written as:

$$Z_F = b + (H_F/0.62) \tag{4}$$

Where:

Z_F = final settled height
H_F = height of clay flocs
b = nonuniform surficial low density settled zone where the flocs are not closely packed

By definition, the floc volume concentration, ϕ_F, is the ratio H_F/Z_o. Equation 4, therefore, can be rewritten as:

$$Z_F = b + (Z_o\phi_F/0.62) \tag{5}$$

From Figures E-1 through E-17, the expression for Z_F is of the form:

$$Z_F = b + \alpha Z_o\phi_K \tag{6}$$

Where a and b are least squares estimators for the slope and intercept, respectively. Combining equations 5 and 6 yields the following expression for ϕ_F:

$$\phi_F = 0.62\,\alpha\,\phi_K \tag{7}$$

The floc volume concentrations determined from Equation 7 are presented in Table 3-7 and graphically summarized in Figure 3-15 as a function of the clay volume concentration which is directly related to the initial solids content. As shown, the floc volume concentration varied from 0.092 to 0.313 for an initial solids content of 3% and from 0.229 to 0.525 for an initial solids content of 8%. Agrico phosphatic clay displayed the greatest floc volume concentrations and CF clay generally displayed the lowest floc volume concentrations.

Figure 3-16 illustrates a correlation found between the slope, a, or normalized floc volume concentration at an initial solids content of 3%, $\phi_F/0.62\,\phi_K$, and liquid limit for the nine phosphatic clays investigated on this study and three additional phosphatic clays from the Agrico-Fort Green Mine. As shown, ten of the twelve clays plot along a linear relation between liquid limit and $\phi_F/0.62\,\phi_K$ with a correlation coefficient of 0.984. The Beker and Mobil clays, however, yield behavior not consistent with the other clays, which indicates that the correlation is not applicable to all phosphatic clays. Despite the two outliers, the correlation appears applicable to most clays and shows an increase in floc volume concentration with increasing liquid limit or plasticity.

Physically, the floc volume concentration is the ratio of the volume of the flocs to the total volume of the clay suspension. Flocs are composed of clusters of clay particles plus inter-floc water. For a given initial solids content, the greater the floc volume concentration the greater the amount of inter-floc water, and hence the lower the final settled solids content. For an initial solids content of 3% and corresponding clay volume concentration of 0.011, the floc volume concentrations are 0.092 and 0.313 for the CF and Agrico clays, respectively. Therefore, for the floc volume approximately 3 times larger than the CF sample.

3.3.5 Aggregate Volume Concentration and Pore Diameter

At the slow shear rates which occur in settling tests, the flocs of clay particles group into clusters designated as aggregates. From settling tests with varying initial clay volume concentrations, ϕ_K, Michaels and Bolger (1962) show that the aggregate volume concentration and pore diameter can be determined from a linear plot of ϕ_F versus Q'_1/ϕ_K. Since a sufficient number of settling tests at differing ϕ_K were not performed to accurately define the linear ϕ_F versus Q'_1/ϕ_K relation, it was assumed that the two data points available for each clay from initial solids contents of 3 and 8% were on the linear portion of the curve. This assumption is reasonable since the deviation from linearity occurs near the ordinate intercept (Section 2.4.3). The results obtained with this assumption are presented in Table 3-8 and graphically summarized in Figure 3-17.

Physically, the aggregate volume concentration is the ratio of the volume of the aggregates to the total volume of the clay suspension. For an initial solids content of 3%, ϕ_A varies from 0.33 to 0.59 for the CF Mining and Agrico-Saddle Creek clays, respectively. These values indicate that the aggregates compose 33% and 59%, respectively, of the total volume of the suspension with "free" inter-aggregate water comprising the remaining volume of the suspensions. At an initial solid content of 8%, ϕ_A, varies from 0.90 to 0.99 for all eight clays tested. These values indicate that aggregates comprise almost the entire volume of the suspension. Since there is little or no "free" inter-aggregate water there can be no significant free-fall gravity settling. Instead, the interface slowly subsides due to the squeezing-out of the inter-aggregate water.

As shown in Table 3-8, the ratio of the aggregate volume concentration to the floc volume concentration, C_{AF}, varies from 1.88 to 3.96. For an aggregate volume concentration of 1.0, therefore, the corresponding floc volume concentrations range from 0.53 to 0.25 (i.e., $1/C_{AF}$). Physcially, this means that the aggregates are composed of approximately 50% flocs and 50% water, and 25% flocs and 75% water, respectively. When the aggregate volume concentration is 1.0 no "free-fall" settling occurs. The floc volume concentrations for each clay at which the aggregate volume concentrations equal 1.0 are shown on Figure 3-18. The corresponding clay volume concentrations generally vary from 0.030 to 0.035, indicating that for initial solids contents greater than 8 or 9% no "free-fall" settling occurs.

The pore diameters, d_p, shown in Table 3-8 are constant over the range of aggregate volume concentrations of 0.33 to 1.0 used in the calculations. The pore diameters range from 27×10^{-4} cm for the Agrico clay to 81×10^{-4} cm for the CF clay. The larger pore diameters occur for the faster settling rates. For pure kaolinite, which settles much faster than phosphatic clays, Michaels and Bolger (1962) report a pore diameter of 180×10^{-4} cm for initial solids contents of 4 to 8%.

The settling behavior of phosphatic clays can be explained by the floc volume concentration, ϕ_F, and/or aggregate volume concentration, ϕ_A*. At a given initial clay volume concentration, ϕ_K, or initial solids content, S_i, the clays that exhibit a higher ϕ_F and, hence, higher ϕ_A have a greater amount of trapped inter-floc and inter-aggregate water and, hence, will not settle as much as clays with lower floc and aggregate volume concentrations. Therefore, the higher ϕ_F clays will have a lower final settled solids content, S_F. Moreover, the higher ϕ_F clays at a given S_i which exhibit larger aggregates and more trapped water are characterized by a smaller effective pore diameter and more tortuosity and, hence, a slower rate of settling. For example, referring to Figure 3-18 at an initial solids content of 3% (ϕ_K = 0.011), the CF clay which has a much lower ϕ_F than the Agrico clay is expected to settle faster and to a higher solids content than the Agrico clay.

The same phosphatic clay has a higher floc and aggregate volume concentration at increased initial solids content, S_i (see Figure 3-18). Hence, the higher S_i or ϕ_K clay sample will not settle as much. Nevertheless, the higher S_i sample will settle to a higher final settled solids content S_F as was illustrated in Figure 3-6. At an initial solids content, S_i, of 1% and 8%, the USSAC clay settled to final solids contents, S_F, of 7.7% and 11.4%, respectively. Note that the settled solids content of 7.7% for an S_i of 1% is approximately equal to the starting condition at an initial solids content of 8%. However, when the higher S_i sample is mixed in preparation for settling, the aggregate network that would have been formed in the settled sample (S_F = 7.7%) is broken up and some entrapped water is released until a new more extensive aggregate network is reformed due to the larger quantity of clay in the higher S_i sample at the same initial slurry height. The partial release of entrapped water is sufficient to result in an increase in S_F. (This finding is consistent with the theory of consolidation which would indicate that the higher S_i clay would be subject to a higher effective stress and, hence, additional consolidation resulting in a higher S_F.) Moreover, the higher S_i clay has a higher floc and aggregate volume concentrations and hence a longer more tortuous pore water path. It is, therefore, expected to settle at a slower rate.

As shown in Table 3-8 and Figure 3-18, the phosphatic clays are naturally flocculated to varying degrees. Had this not been the case, the above conclusions would not have been valid since colloidal particles would have remained in suspension precluding the formation of a clear supernatent/settled clay interface.

3.3.6 "Final" Settled Height and Field Solids Content

Using the equations that were presented in Figures E-1 through E-17 and summarized in Table 3-7, the "final" settled height for any initial height at initial solids contents of 3 and 8% can be obtained. As shown in Figure 3-19 for phosphatic clays at an initial solids content of 3%, the final settled height varied considerably between clays with the same initial sample height. Agrico phosphatic clay consistently yielded the greatest final settled heights, and CF phosphatic clay yielded the lowest final settled heights.

*As shown in Table 3-8, an increased ϕ_F corresponds to an increased ϕ_A.

Based on Equation 6 presented above, it can be shown that the final average solids content, S_F, for a given initial height can be calculated from the following:

$$S_F = \rho_c / \{ \rho_c - 1 + \alpha(b + Z_o \phi_K)/Z_o \phi_K) \} \qquad (8)$$

Where:

ρ_c	=	specific gravity of clay solids
α	=	slope of Z_F versus $Z_o\phi_K$ curve
b	=	ordinate intercept of Z_F versus $Z_o\phi_K$ curve

For relatively small values of initial height in comparison to the b value, the average final solids content increases slightly with increasing initial sample height. For large values of initial height in comparison to the b value, the average final solids content remains essentially independent of initial height.

3.4 **Void Ratio Versus Effective Stress**

The final settling test heights and solids contents were used to estimate the solids content (or void ratio) versus effective stress compressibility curves at the very low effective stresses that result from limited self-weight consolidation.* Although results from settling tests have been used to establish compressibility curves at low effective stresses (Carrier and Keshian, 1979), the simplifying assumptions involved (constant solids content with depth, linear effective stress distribution with depth, and no significant change in effective stress across the layer) render such a relationship somewhat questionable unless additional testing is performed and an iterative procedure used to render the relationship more accurate. In this study, the effective consolidation stress $\bar{\sigma}_{vc}$, and void ratio, e, were determined from settling tests on the same clay with initial heights of 6.0, 12.0, 18.0 and 24.0 cm. The effective stress vs. void ratio relationship was developed for the lowermost initial 6.0 cm clay zone for each test. This was accomplished by first determining Z_F, $\bar{\sigma}_{vc}$ and e for the 6.0 cm high test sample. The final height, Z_F, of the 6.0 cm high sample was then subtracted from the final height of the 12.0 cm high sample to determine the Z_F and e of the lower 6.0 cm zone of the 12.0 cm high sample. This iterative approach was continued for the 18.0 and 24.0 cm high samples. The advantage of this approach over the simpler technique of taking one average $\bar{\sigma}_{vc}$ and e for each test is that it accounts for variations in solids content with depth.

The void ratio versus effective stress relationship developed for each clay from the variable height settling tests using this approach and from the constant height settling tests using the simpler average approach are shown in Appendix F, Figures F-1 through F-9. Tables F-1 through F-9 summarize relevant data used to determine the void ratio versus effective stress relationships. Least squares

*Solids content, S, and void ratio, e, are related by the expression: $e = (\rho(1-S)/S)$, where ρ is the specific gravity of clay solids.

power function linear regressions of the form $e_f = \alpha \bar{\sigma}_{vc}^{\beta}$ are shown on Figures F-1 through F-9 for seven of the clays where the data were sufficiently consistent to yield meaningful regressions.* Table 3-9 summarizes the power function coefficients α and β. Selected uncharacteristic data points were not included in some of the regressions.** The power function relation between void ratio and effective stress was generally found to yield the highest correlation coefficient from several forms of relationships (i.e., linear, exponential, power function, hyperbola, inverse linear and inverse hyperbola).

Figure 3-21 compares the void ratio versus effective stress relationships at low effective stress determined for five phosphatic clays. As shown, the clays exhibit a wide range of compressibility behavior. The Agrico phosphatic clay exhibits the highest void ratio at low effective stresses with a range in void ratio of 70 to 24 for effective stresses of 0.10 to 2.0 lb/ft^2 . In contrast, the CF phopshatic clay exhibits the lowest void ratio, with a range in void ratio of 15 to 11 for the same stresses.

The power function coefficients α and β seem to be governed by the plasticity of the clay. The α coefficient tends to increase with increasing plasticity index, PI, as shown in Figure 3-22. Similarly, the β coefficient increases with increasing plasticity index. Physically, these trends indicate that the higher the plasticity of the clay: (i) the higher the void ratio at a given stress; and (ii) the greater the compressibility of the clay. Although the trends in the data are clear, linear regression analyses performed on α and β as a function of the plasticity index indicated relatively low correlation coefficients of 0.78 and 0.73, respectively.

3.5 Variability in Sedimentation Behavior at a Given Mine Site

The settling test results clearly indicate that significant variability exists between the sedimentation behavior of phosphatic clays from different mine sites. A comparison of settling tests from Lamont et al. (1975) and Roma (1976) with current tests from the same mine sites, however, also reveals relatively large differences. The final settled solids contents at approximately 30 days from the three series of settling tests are summarized in Table 3-10.

Although the final settled solids contents from the Lamont et al. (1975) series of tests should be slightly higher due to the higher initial solids content, the difference between the series of tests are occasionally much larger than can be explained by this factor. As shown in Figure 3-4, the maximum expected increase in final settled soids content by increasing the initial solids content from 3.0 to 3.7% is on the order of 1.0%. The most significant difference in sedimentation behavior is observed for the Agrico-Saddle Creek phosphatic clay. In this study the Agrico clay displayed the lowest final settled solids content, whereas in the

*Regressions were not performed on the AMAX and Estech test data.
**The data omitted from regression analyses are indicated by a question mark on Figures F-1 through F-9,

Lamont et al. (1975) study the Agrico clay displayed the greatest final settled solids content. These results clearly indicate that large differences in the sedimentation behavior of phosphatic clays occur at a given mine site, and that the difference can be as large as occurs for clays from all Florida mine sites.

3.6 Correlations Between Index Properties and Sedimentation Behavior

Correlations between index properties and sedimentation behavior are useful to allow prediction of the sedimentation behavior of phosphatic clays without performing numerous relatively time consuming laboratory settling tests at least for preliminary evaluations. Correlations can also be used to screen numerous clay samples from a given site to allow selection of representative samples for further laboratory testing. Finally, correlations between index properties and sedimentation behavior provide a basis for comparison of phosphatic clays from numerous sources.

3.6.1 Methodology

Correlations between index properties and sedimentation behavior were evaluated statistically to yield predictive relationships and indicate the degree of correlation between variables. Statistical analyses were performed with the General Electric Information Service Statistical Analysis System II Program STATII* routine CURV. Regression analyses of bivariate data were performed with the curve-fitting routine CURV, which fits six curve types to the data: straight line; exponential; power function; hyperbola; reciprocal of straight line; and reciprocal of hyperbola.

3.6.2 "Final" Settled Solids Content

The only practical correlation found for sedimentation behavior was between liquid limit and final settled solids content for a specific initial solids content. The final settled solids content for an initial solids content of 3% and corresponding liquid limit for the twelve phosphatic clays studied in this investigation and seven additional clays are presented in Table 3-11. As shown in Figure 3-23, there is some variability in the data, but a reasonable correlation was found indicating decreasing final settled solids content with increasing liquid limit. The correlation coefficient, r, of 0.784 indicates tht 61% of the variability in final settled solids content is explained by variations in liquid limit. The standard deviation of the estimated final solids content is 2.3%, indicating that 67% of the measured solids content values fall within ±2.3% of the estimated values based on the established correlations.

Figure 3-24 illustrates a comparison of predicted versus measured final solids contents based on the liquid limit correlation. As shown, 9 (47%) of the predicted values are within ±10% deviation from the measured values, 14 (74%) of the predicted values are within ±20% deviation from the measured values, and 5 (26%) of the predicted values are beyond ±20% deviation from the measured values.

Attempts to improve the accuracy of the correlation were made using final settled void ratio instead of final settled solids content. The final void ratio and final settled solids content are related by the expression $e_f = \rho(1-S_F)/S_F$, where ρ is the specific gravity of clay solids. The calculated values of the final void ratio are presented in Table 3-11. As shown in Figure 3-24, a linear correlation was found between the liquid limit and final settled void ratio. The correlation coefficient of 0.803, however, is only slightly improved from the value of 0.784 found for the liquid limit versus final solids content correlation. Either regression, therefore, is equally satisfactory for predicting the settling behavior of phosphatic clays.

3.7 Summary and Practical Implications

Settling tests performed on twelve phosphatic clays indicated a wide range of settling characteristics. The sedimentation behavior of the phosphatic clays were evaluated in detail to determine the solids contents of phosphatic clays just after deposition within an impoundment, the time required to reach a given solids content due to gravity settling, the final self-weight consolidation void ratio versus effective stress relation, and the applicability of the Michaels and Bolger (1962) methodology relating to the settling characteristics of flocculated clay suspensions for evaluating the settling characteristics of phosphatic clays. The significant practical findings obtained are summarized below.

Based on settling tests with an initial height of 24 cm and initial solids contents of 1, 3 and 8%, the following behavioral characteristics were observed:

- For an initial solids content of 3%, which is similar to the solids content of clay from primary launders, the final 30-day settled solids content varies from 5.4 to 17.8% with an average of 10.9%.

- The lowest settled solids content versus time relationship occurs for the Agrico-Saddle Creek clay tested and the greatest settled clays content versus time relationship occurs for the CF Mining-Hardee clay. The settling behavior of these two clays brackets the range of settling behavior encountered for phosphatic clays tested in this investigation and that reported for other clays. Hence, the sedimentation behavior of the specific Agrico and CF clays sampled for this investigation reflect the range likely to be encountered for Florida phosphatic clays.

- For a given clay, a slurry prepared at an initially lower solids content will not achieve as high a final settled solids content with time as a slurry prepared at an initially higher solids content. This expected behavior was also noted by Roma (1976).

- The time required to achieve a given percent of the final settled solids content varies considerably between phosphatic clays. Clays which settle to a relatively low final solids content settle slower and require a longer time than clays which settle to a relatively high final solids content.

Settling tests with initial sample heights of 6, 12, 18 and 24 cm were performed with initial solids contents of 3 and 8% to evaluate the parameters describing the settling characteristics of flocculated suspensions according to the methodology of Michaels and Bolger (1962). Based upon results from variable initial height settling tests on eight selected phosphatic clays, an evaluation of the various parameters that influence settling behavior indicate:

- The settling behavior of phosphatic clays is consistent with the Michaels and Bolgers (1962) theory. Their methodology, therefore, is applicable for interpretating results from settling tests on phosphatic clays.

- For an initial solids content of 3%, which is of most practical importance since primary launder slurry concentrations are typically in the range of 3-4%, the maximum field settling rate is greater than measured in the laboratory on 24.6 cm high samples by factors of 2.4 to 1.3 for final settled solids contents of 8 to 18%, respectively. Laboratory settling rates, therefore, should be increased when predicting field settling rates to account for the effects of limited container height.

- The yield height and yield diameter for phosphatic clays with initial solids contents of 3 and 8% where found to vary from 2.4 to 17.1 cm and 0.11 to 0.51 cm, respectively. In general, therefore, an initial sample height greater than 18 cm should be used for laboratory settling tests on phosphatic clays to achieve "free-fall" gravity settling. For yield diameters of 9.11 to 0.51 cm, a container diameter of 10 cm will reduce the settling velocity by only 1 to 5% from what is expected in the field.

- Phosphatic clays are naturally flocculated to varying degrees. For an initial solids content of 3%, the floc volume concentration of phosphatic clays ranged from 0.092 to 6.313. Physically, the floc volume concentration is the ratio of the volume of the flocs to the total volume of the clay suspension, where flocs are composed of clusters of clay particles and inter-floc water. Therefore, for the same initial solids content, some phosphatic clays form flocs approximately 3 times larger than other clays. The higher the floc volume concentration, the lower the final settled solids content.

- For an initial solids content of 3%, the aggregate volume concentration of phosphatic clays ranged from 6.332 to 0.598. Physically, the aggregate volume concentration is the ratio of the volume of the aggregates to the total volume of the clay suspension, where aggregates are composed of clay flocs and inter-aggregate water. These values indicate that clay slurries starting at 3% initial solids content are composed of 33% to 59% clay aggregates and 66% to 41% “free” inter-aggregate water. At initial solids contents of 8 to 9% the aggregate volume concentrations are approximately 1.0, indicating that no "free" inter-aggregate water exists. Hence, at these solids content free-fall settling does not occur.

Void ratio versus effective stress compressibility curves were determined for the phosphatic clays from the final settling test heights and solids contents. The phosphatic clays exhibited a wide range of compressibility behavior. The Agrico phosphatic clay displayed the highest void ratio at a given stress, with a range in void ratio of 70 to 24 for effective stresses of 0.10 to 2.0 lb/ft^2. Conversely, the CF phosphatic clay displayed the lowest void ratio, with a range in void ratio of 15 to 11 for the same stresses. The relationship between void ratio , e, and effective stress, $\bar{\sigma}_{vc}$, was best modeled by a power function of the form $e = \alpha \bar{\sigma}_{vc}^{\beta}$. The coefficients α and β generally increased with increasing plasticity index over ranges of 17.6 to 30.8 and -0.15 to -0.36, respectively.

A comparison of final settled solids contents for phosphatic clays sampled at different times from the same mine was made using data reported in the literature. The comparison indicated that the variability in final settled solids content of phosphatic clays produced at a given mine over time may be as large as occurs for clays from all Florida mine sites.

The only practical correlation found between index properties and sedimentation behavior was between the liquid limit and final settled solids content. Although considerable variation exists in the data, the correlation is satisfactory for predicting final settled solids contents when laboratory settling tests are not available.

Table 3-1

FINAL SOLIDS CONTENT FOR PHOSPHATIC CLAYS WITH INITIAL SOLIDS CONTENTS OF 1.0, 3.0 AND 8.0%

Sample	S_F for S_i = 1% (%)	S_F for S_i = 3% (%)	S_F for S_i = 8% (%)
• FIPR Phosphatic Clays			
Agrico-Saddle Creek	3.5	5.4	9.0
AMAX-Big Four	17.8	16.4	19.7
Beker-Wingate Creek	8.6	10.5	12.8
Brewster-Haynsworth	7.4	8.9	11.2
CF Mining-Hardee	17.2	17.8	16.2
Estech-Watson	11.7	11.6	14.0
Hopewell-Hillsborough	6.4	8.7	11.7
IMC-Noralyn	10.5	10.2	11.2
Mobil-Nichols	9.8	12.3	14.0
Occidental-Suwannee River	8.3	9.6	10.8
USSAC-Rockland	7.7	9.3	11.4
W R Grace-Four Corners	7.2	9.5	12.9
• Statistics for FIPR Phosphatic Clays			
Minimum	3.5	5.4	9.0
Maximum	17.8	17.8	19.7
Average	9.7	10.9	12.9
C.V. (%)	43.5	31.2	22.0
• Other Phosphatic Clays			
Agrico-Fort Green	6.3	7.6	10.4
Agrico-Fort Green	11.2	12.9	14.5
Agrico-Fort Green	9.8	10.5	12.4
IMC-Kingsford	—	11.3	—
IMC-Kingsford	—	8.2	—
Brewster-Lonesome	—	8.2	10.7
Mobil-Fort Meade (Roma, 1976)	—	10.8*	14.0**
USSAC-Rockland (Roma, 1976)	—	—	11.8***
• Statistics for All Phosphatic Clays			
Minimum	3.5	5.4	9.0
Maximum	17.8	17.8	19.7
Average	9.6	10.5	12.7
C.V.(%)	40.3	28.6	20.5

*S_i = 2.86%
**S_i = 8.78%
***S_i = 7.46%

Table 3-2

MAXIMUM LABORATORY SETTLING RATE FOR PHOSPHATIC CLAYS WITH INITIAL SOLIDS CONTENTS OF 1.0, 3.0 AND 8.0%

Sample	Q_1 for S_i = 1% (cm/hour)	Q_1 for S_i = 3% (cm/hour)	Q_1 for S_i = 8% (cm/hour)
• FIPR Phosphatic Clays			
Agrico-Saddle Creek	0.708	0.156	0.031
AMAX-Big Four	—	5.60	2.65
Beker-Wingate Creek	8.00	3.86-4.75	0.084
Brewster-Haynsworth	8.25	0.234	0.056
CF Mining-Hardee	52.50	8.44	1.20-3.34
Estech-Watson	53.00	1.50	0.144
Hopewell-Hillsborough	15.00	2.40	0.060
IMC-Noralyn	21.75	0.618	0.156
Mobil-Nichols	36.00	4.42	0.102
Occidental-Suwannee River	19.50	0.330	0.048
USSAC-Rockland	13.50	0.834	0.174
W R Grace-Four Corners	37.80	0.918	0.234
• Statistics for FIPR Phosphate Clays			
Minimum	0.708	0.156	0.031
Maximum	52.50	8.44	3.34
Average	24.18	2.48	0.501
C.V. (%)	74.6	106.7	183.9
• Other Phosphatic Clays			
Agrico-Fort Green	15.30	0.348	0.040
Agrico-Fort Green	16.20	4.35	0.144
Agrico-Fort Green	19.00	3.46	0.108
IMC-Kingsford	—	5.40	—
IMC-Kingsford	—	0.180	—
Brewster-Lonesome	—	1.47	0.066
• Statistics for All Phosphatic Clays			
Minimum	0.708	0.156	0.031
Maximum	52.50	8.44	3.34
Average	22.61	2.50	0.398
C.V. (%)	71.4	97.5	203.5

Where: Q_1 = Maximum laboratory settling rate; S_i = Initial solids content; and C.V. = coefficient of variation.

Table 3-3

AVERAGE SECANT SETTLING RATE FOR PHOSPHATIC CLAYS WITH INITIAL SOLIDS CONTENTS OF 3%

Sample	Z_F (cm)	t_F (min)	Q_s (cm/hour)
Agrico-Saddle Creek	13.5	24,700	0.026
AMAX-Big Four	4.3	20,200	0.059
Beker-Wingate Creek	6.9	19,100	0.054
Brewster-Haynsworth	8.2	21,700	0.044
CF Mining-Hardee	3.8	18,700	0.065
Estech-Watson	6.3	24,700	0.043
Hopewell-Hillsborough	8.1	13,100	0.073
IMC-Noralyn	7.2	20,300	0.050
Mobil-Nichols	6.0	18,900	0.057
Occidental-Suwannee River	7.9	18,700	0.052
USSAC-Rockland	8.0	17,500	0.055
W R Grace-Four Corners	7.7	14,900	0.066
Statistics			
Average	-	-	0.054
C.V. (%)	-	-	23.1
Minimum	-	-	0.026
Maximum	-	-	0.073

Where Z_F = final settled height at time t_F; and Q_S = average secant settling rate.

Table 3-4

FINAL SETTLED SOLIDS CONTENTS FOR PRIMARY AND SECONDARY LAUNDER CLAY SAMPLES

Sample	S_i (%)	S_F(m) (%)	S_F(p) (%)
• Primary Launder			
Agrico-Saddle Creek	6.4	7.5*	8.2[1]
Brewster-Haynsworth	4.3	9.7*	9.1[1]
CF Mining-Hardee	2.8	12.6*	17.2[2]
Estech-Watson	5.5	12.6**	13.0[1]
IMC-Noralyn	6.0	8.2†	10.1[3]
Mobil-Nichols	3.7	10.2*	12.5[1]
USSAC-Rockland	3.5	7.6*	8.8[1]
• Secondary Launder			
Agrico-Saddle Creek	1.0	4.3*	3.2[2]
CF Mining-Hardee	0.8	13.6*	16.6[2]
Estech-Watson	0.8	14.6**	11.7[1]
IMC-Noralyn	0.5	11.0†	10.0[1]
USSAC-Rockland	1.1	7.9*	7.1[1]

*Final solids content at 14 days
**Final solids content at 47 days
†Final solids content at 11 days

[1]Predicted final solids content based on initial solids content and corresponding settling area clay in Figure 3-4.

[2]Predicted final solids content based on solids content at corresponding time from constant initial height settling test at initial solids content of 1.0% for secondary launder and 3.0% for primary launder.

[3]Predicted final solids content based on initial solids content and Figure 3-4 adjusted by ratio of solids content at time for primary sample (i.e., 11 days) to final solids content measured from constant initial height settling test at 3.0% initial solids content.

Where: S_F(m) = Final solids content measured in settling test; S_F(p) = Final solids content predicted based on constant height settling tests from settling area clays at S_i=1, 3 and 8%, respectively, where S_i = initial solids content.

Table 3-5

MAXIMUM FIELD SETTLING RATES AND YIELD HEIGHTS FOR PHOSPHATIC CLAYS

Sample	$S_i = 3\%$		$S_i = 8\%$	
	Q'_1 (cm/hour)	Z_{y1} (cm)	Q'_1 (cm/hour)	Z_{y1} (cm)
Agrico-Saddle Creek	0.720	9.0	0.063	9.7
AMAX-Big Four	6.15	2.4	2.74	2.1
Beker-Wingate Creek	5.80	5.9	0.120	7.2
CF Mining-Hardee	10.42	4.3	4.15	17.1
Estech-Watson	3.67	14.2	-	-
IMC-Noralyn	0.938	9.2	0.247	7.6
Mobil-Nichols	6.71	10.7	0.444	9.7
Occidental-Suwannee River	0.510	8.5	0.120	14.4
USSAC-Rockland	1.18	8.8	0.297	9.8

Where: S_i = Initial solids content; Q'_1 = Maximum field settling rate; and Z_{y1} = Yield height for maximum settling rate.

Table 3-6

YIELD DIAMETER FOR PHOSPHATIC CLAYS

Sample	S_i (%)	ϕ_K	τ_y* (dynes/cm^2)	D_y (cm)
Agrico-Saddle Creek	3.0	0.0110	0.95	0.20
Agrico-Saddle Creek	8.0	0.0302	6.77	0.51
CF Mining-Hardee	3.0	0.0109	0.62	0.13
CF Mining-Hardee	8.0	0.0300	1.43	0.11
Mobil-Nichols	3.0	0.0106	0.75	0.15
Mobil-Nichols	8.0	0.0292	2.80	0.21
USSAC-Rockland	3.0	0.0109	0.74	0.15
USSAC-Rockland	8.0	0.0300	2.63	0.20

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; τ_y = Yield stress; and D_y = Yield diameter.

*Yield stress determined from correlation presented in Volume 1, Section 4, Figure 4-13.

Table 3-7

FLOC VOLUME CONCENTRATION FOR PHOSPHATIC CLAYS

	$Z_F = b + \alpha(Z_o \phi_K)$					$Z_F = b + \alpha(Z_o \phi_K)$				
Sample	S_i (%)	b	α	r	ϕ_F	S_i (%)	b	α	r	ϕ_F
Agrico-Saddle Creek	3.0	0.90	45.91	0.999	0.313	8.0	0.80	27.98	0.999	0.525
AMAX-Big Four	3.0	0.00	15.69	0.997	0.108	8.0	0.30	12.01	0.999	0.229
Beker-Wingate Creek	3.0	0.45	23.57	0.999	0.162	8.0	0.85	18.49	0.999	0.350
CF Mining-Hardee	3.0	0.12	13.34	0.999	0.092	8.0	0.26	13.33	0.999	0.250
IMC-Noralyn	3.0	0.40	29.84	0.998	0.200	8.0	0.84	22.30	0.999	0.413
Mobil-Nichols	3.0	0.34	20.34	0.999	0.134	8.0	0.86	17.50	0.999	0.317
Occidental-Suwannee River	3.0	0.40	25.68	0.999	0.175	8.0	0.30	23.35	0.999	0.439
USSAC-Rockland	3.0	0.90	30.15	0.999	0.202	8.0	0.94	22.53	1.000	0.418

Where: S_i = Initial solids content; b and α = Least squares estimators for intercept and slope of $Z_o\phi_K$ versus Z_F; r = Correlation coefficient; ϕ_F = Floc volume concentration; ϕ_K = Clay volume concentration; and Z_o and Z_F = Initial and final heights, respectively.

Table 3-8

AGGREGATE VOLUME CONCENTRATION AND PORE DIAMETER OF PHOSPHATIC CLAYS

Sample	S_i (%)	ϕ_K	Q'_1 (cm/hour)	Q'_1/ϕ_K (cm/hour)	ϕ_F	C_{AF}	ϕ_A	$\gamma_w(\rho_K-\rho_w)dp^2/(32\ \mu_w/g)$ (cm/sec)	d_p (10^{-4} cm)
Agrico-Saddle Creek	3.0	0.0110	0.720	65.45	0.313	1.88	0.588	0.0442	26.98
Agrico-Saddle Creek	8.0	0.0303	0.063	2.08	0.525		0.987		
AMAX-Big Four	3.0	0.0111	6.15	554.05	0.106	3.96	0.420	0.265	66.82
AMAX-Big Four	8.0	0.0307	2.74	89.25	0.229		0.907		
Beker-Wingate Creek	3.0	0.0111	5.80	522.52	0.162	2.85	0.461	0.269	67.13
Beker-Wingate Creek	8.0	0.0305	0.120	3.93	0.350		0.996		
CF Mining-Hardee	3.0	0.0110	10.42	947.27	0.092	3.61	0.332	0.394	80.56
CF Mining-Hardee	8.0	0.0302	4.15	137.42	0.250		0.903		
IMC-Noralyn	3.0	0.0108	0.938	86.85	0.203	2.30	0.466	0.0452	27.06
IMC-Noralyn	8.0	0.0299	0.247	8.26	0.413		0.949		
Mobil-Nichols	3.0	0.0106	6.71	633.02	0.134	3.11	0.417	0.302	68.64
Mobil-Nichols	8.0	0.0292	0.444	15.21	0.317		0.985		
Occidental-Suwannee River	3.0	0.0110	0.510	46.36	0.175	2.16	0.377	0.0207	18.52
Occidental-Suwannee River	8.0	0.0303	0.120	3.96	0.439		0.946		
USSAC-Rockland	3.0	0.0108	1.18	109.26	0.202	2.27	0.460	0.0562	30.17
USSAC-Rockland	8.0	0.0299	0.297	9.93	0.418		0.950		

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; Q'_1 = Maximum field settling rate; ϕ_F = Floc volume concentration; C_{AF} = Ratio of ϕ_A/ϕ_F; ϕ_A = Aggregate volume concentration; d_p = Pore diameter; ρ_K = Specific gravity of clay solids; ρ_w = Specific gravity of water; μ_w = Absolute viscosity of water; g = Gravitational acceleration; γ_w = unit weight of water.

Table 3-9

VOID RATIO VERSUS EFFECTIVE STRESS RELATIONS FROM SETTLING TESTS

Sample	$e_f = \alpha \bar{\sigma}_{vc}{}^{\beta}$		
	α	β	r
Agrico-Saddle Creek	30.79	-0.359	0.940
Beker-Wingate Creek	19.16	-0.212	0.930
CF Mining-Hardee	12.22	-0.075	0.940
IMC-Noralyn	23.66	-0.205	0.859
Mobil-Nichols	17.61	-0.178	0.945
Occidental-Suwannee River	22.29	-0.151	0.905
USSAC-Rockland	25.47	-0.244	0.983

Where: e_f = Final void ratio from settling test; $\bar{\sigma}_{vc}$ = Effective stress; α and β = Least squares estimators for power function coefficients; and r = Correlation coefficient.

Table 3-10

VARIABILITY OF FINAL SETTLED SOLIDS CONTENTS AT MINE SITES

Sample	S_F (%)* Lamont et al. (1975)	S_F (%)** Current Study	S_F (%) Roma (1976)
Agrico-Saddle Creek	15.9	5.4	-
Brewster-Haynsworth	10.9	8.9	-
Estech-Watson	6.1	11.6	-
IMC-Noralyn	5.7	8.6	-
Mobil-Fort Meade	12.6	-	9.5†
USSAC-Rockland	13.1	9.3 (11.4)***	11.7††

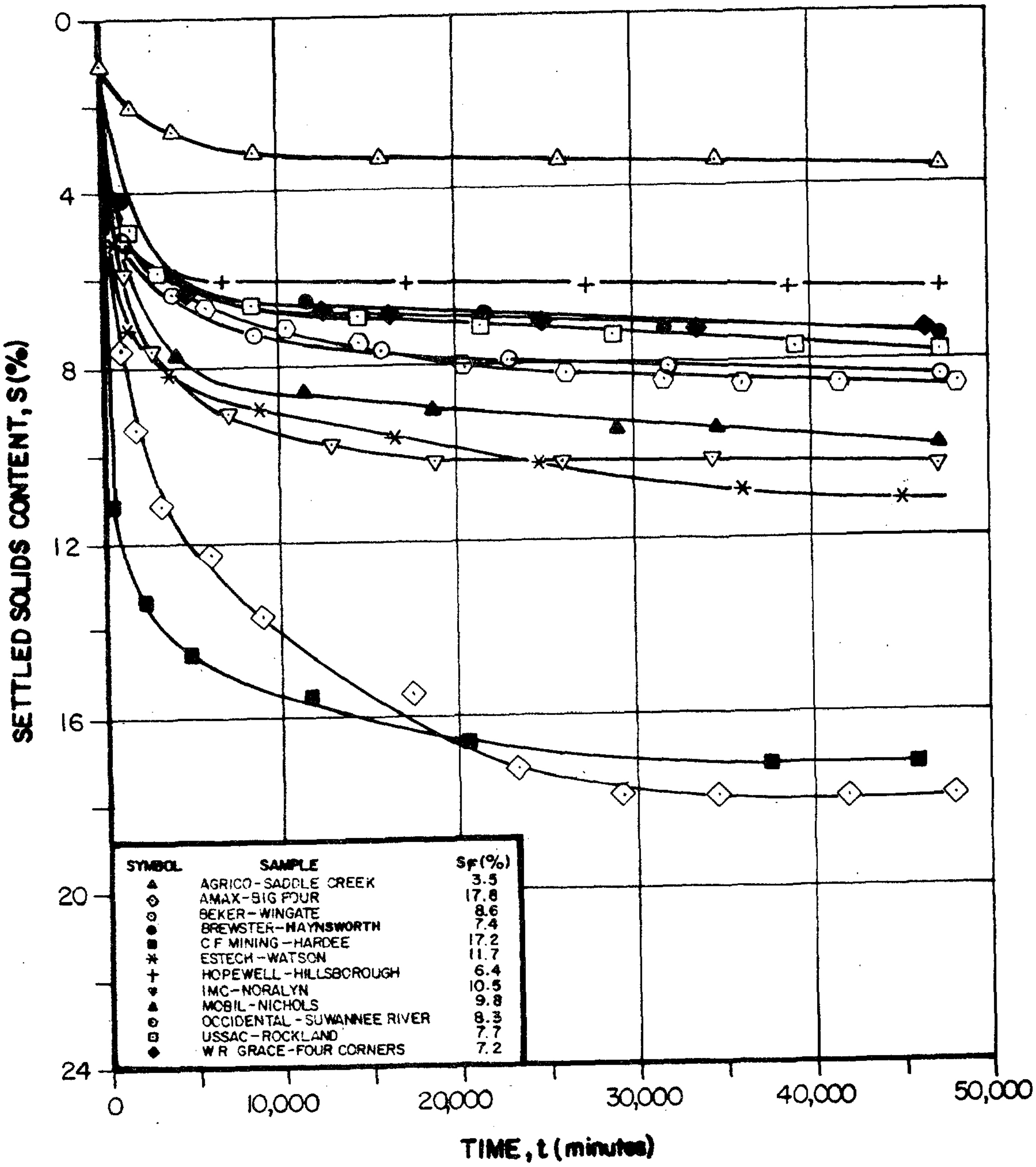
*S_F for S_i = 3.7%
**S_F for S_i = 3.0%
†S_F for S_i = 2.86%
††S_F for S_i = 7.46%
***S_F for S_i = 8.0%

Table 3-11

FINAL SETTLED SOLIDS CONTENT AND LIQUID LIMIT FOR PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT

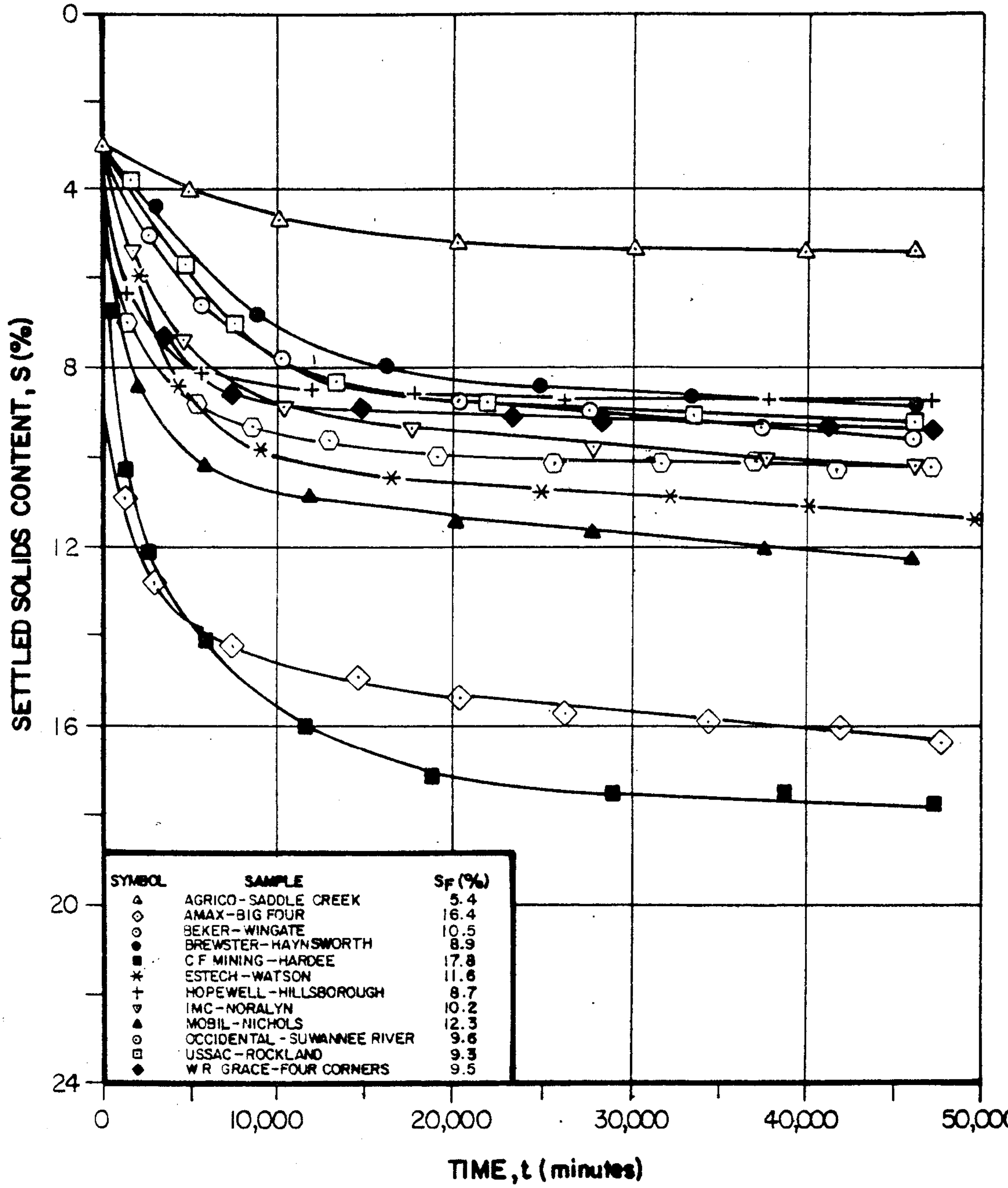
Sample	LL (%)	S_F (%)	e_F
• FIPR Phosphatic Clays			
Agrico-Saddle Creek	268	5.4	48.84
AMAX-Big Four	146	16.4	14.03
Beker-Wingate Creek	127	10.1	24.62
Brewster-Haynsworth	215	8.9	29.33
CF Mining-Hardee	143	17.8	12.96
Estech-Watson	167	11.6	21.99
Hopewell-Hillsborough	170	8.7	29.86
IMC-Noralyn	213	8.6	29.95
Mobil-Nichols	203	12.3	20.62
Occidental-Suwannee River	182	9.6	26.16
USSAC-Rockland	195	8.0	32.34
W R Grace-Four Corners	196	9.5	26.50
• Other Phosphatic Clays			
Agrico-Fort Green	205	7.6	34.53
Agrico-Fort Green	150	12.9	19.18
Agrico-Fort Green	172	10.5	24.04
IMC-Kingsford	209	8.2	31.34
IMC-Kingsford	202	11.3	21.98
Brewster-Lonesome	216	82	30.11
Mobil-Fort Meade (Roma, 1976)	145	10.8	24.28

Where: LL = Liquid limit; S_F = Final settled solids content for 3% initial solids content; and e_f = final settled void ratio; $e_f = \rho(1-S_F)/S_F$, where ρ = Specific gravity of clay solids.



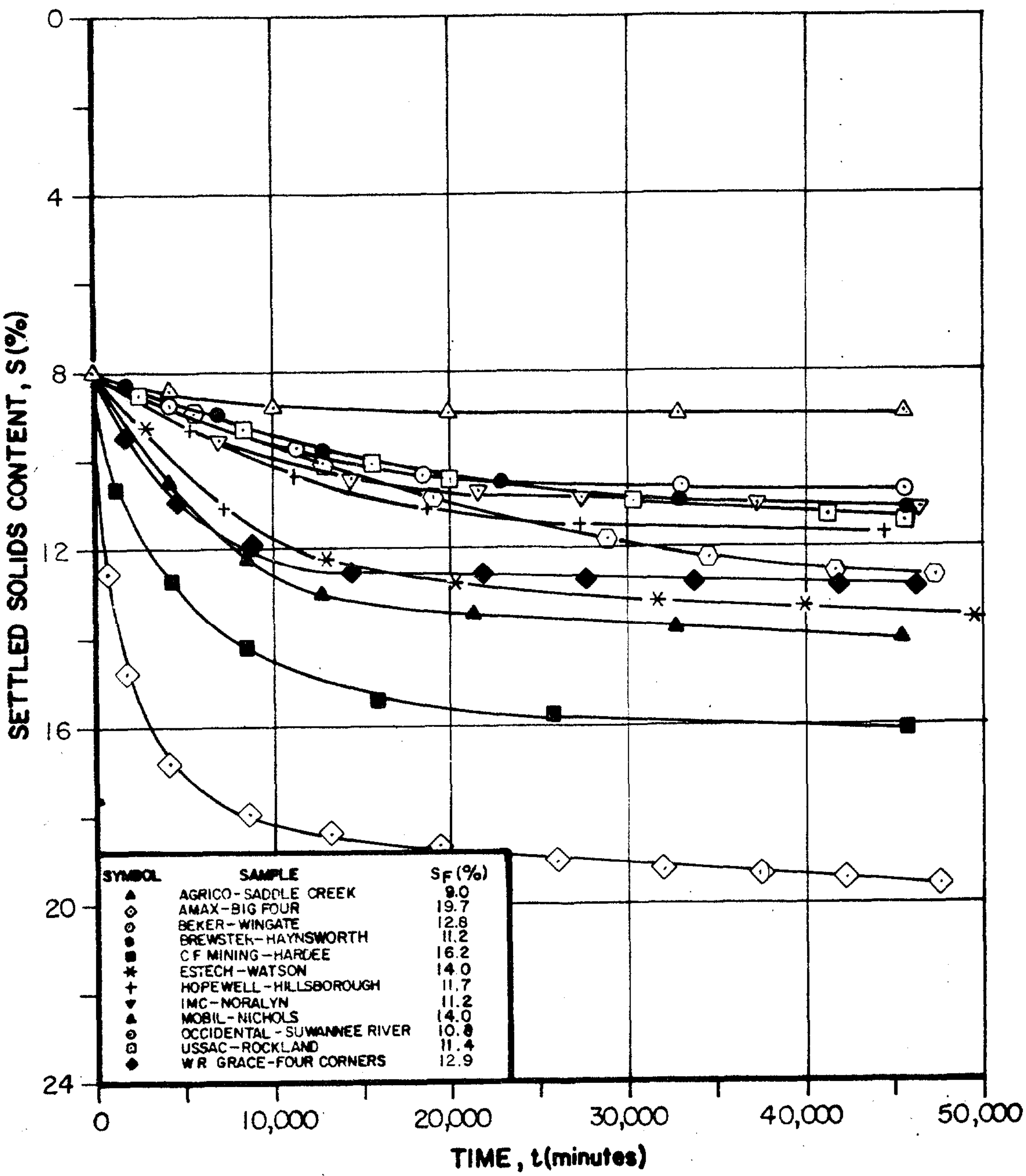
SETTLED SOLIDS CONTENT VS. TIME FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 1%

FIGURE 3-1



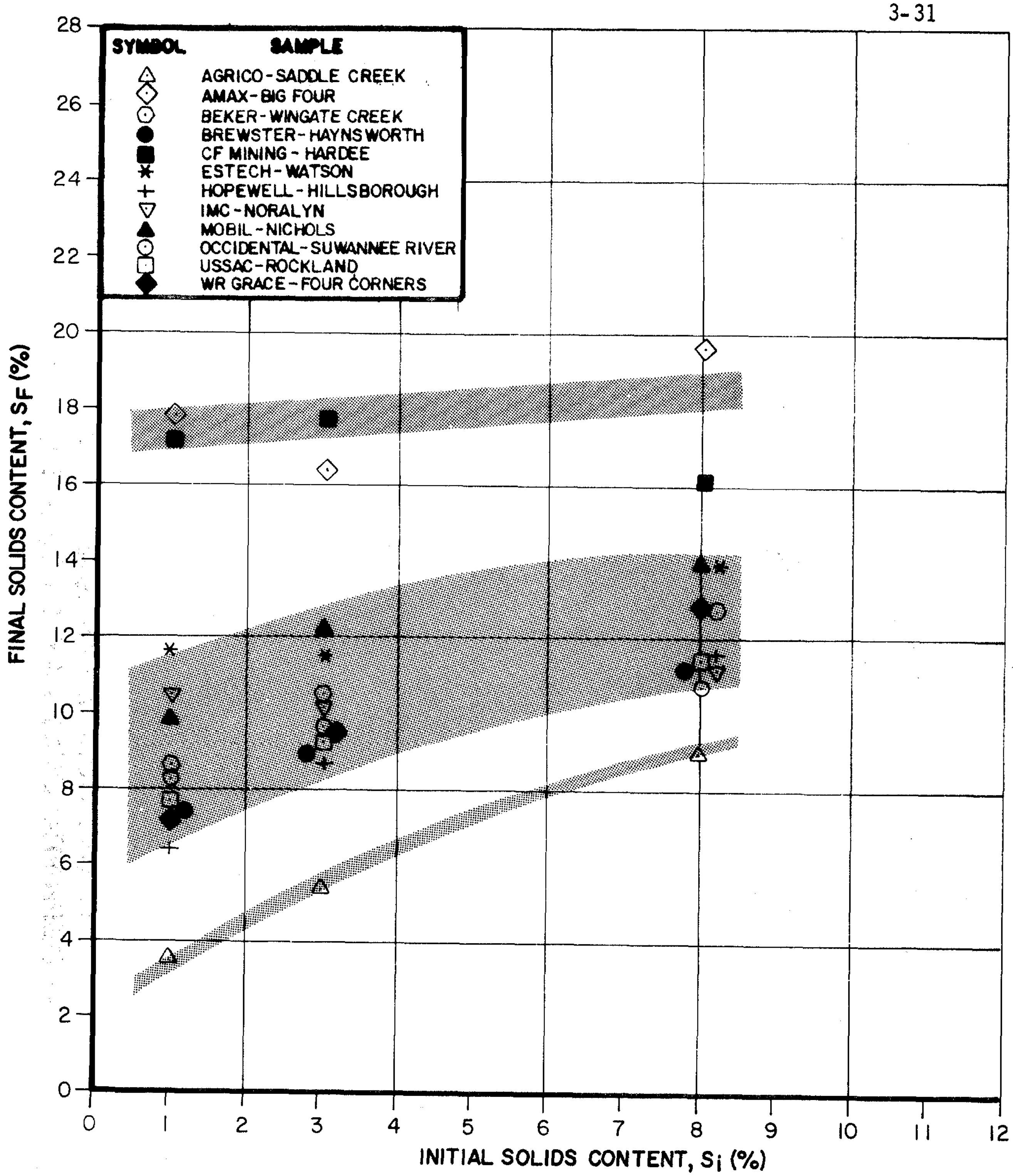
SETTLED SOLIDS CONTENT VS. TIME FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 3%

FIGURE 3-2



SETTLED SOLIDS CONTENT VS. TIME FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 8%

FIGURE 3-3



INITIAL SOLIDS CONTENT VS. FINAL SOLIDS CONTENT FOR PHOSPHATIC CLAYS

FIGURE 3-4

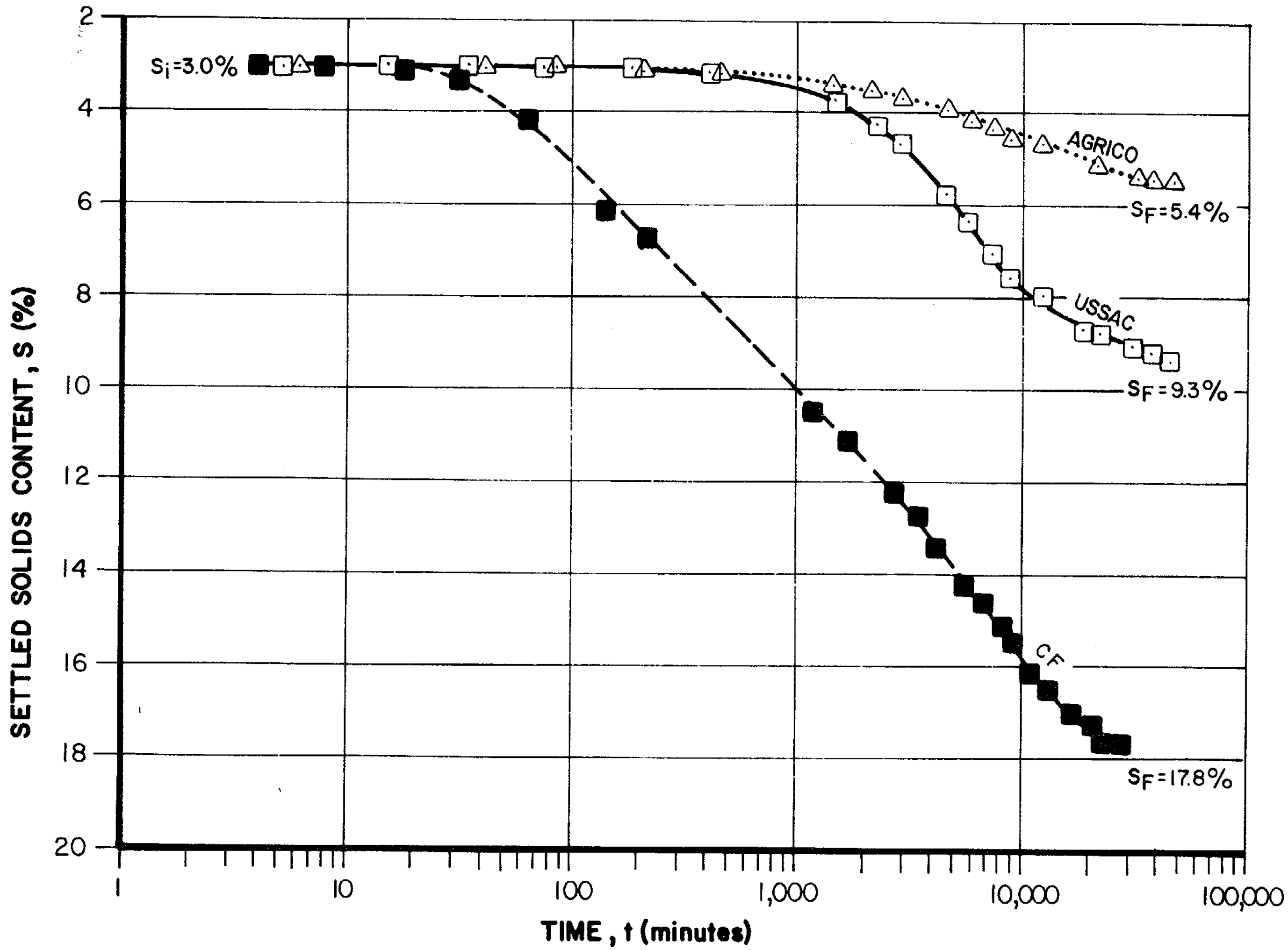
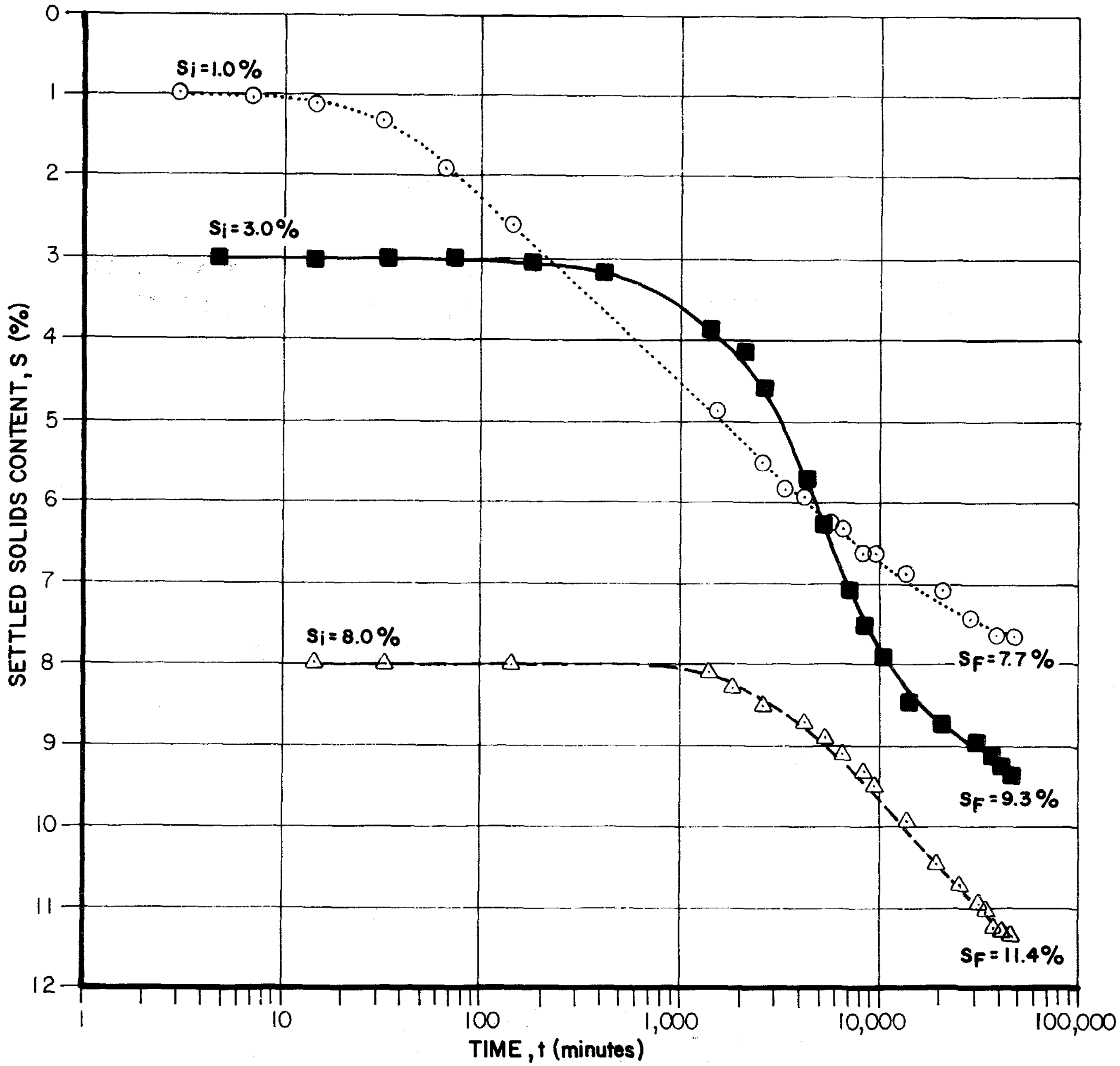


FIGURE 3-5

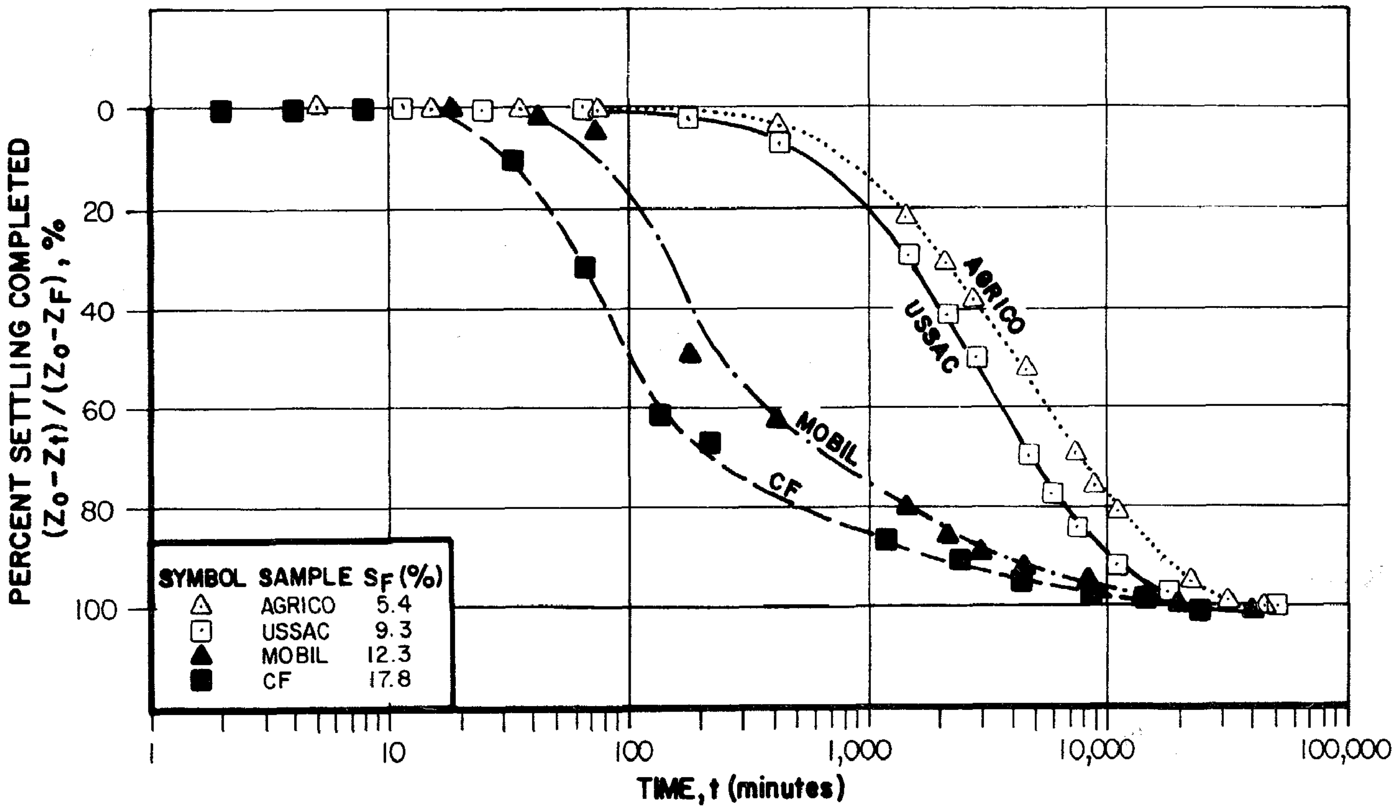
TYPICAL SOLIDS CONTENT VS. LOG TIME FOR PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT

FIGURE 3-6

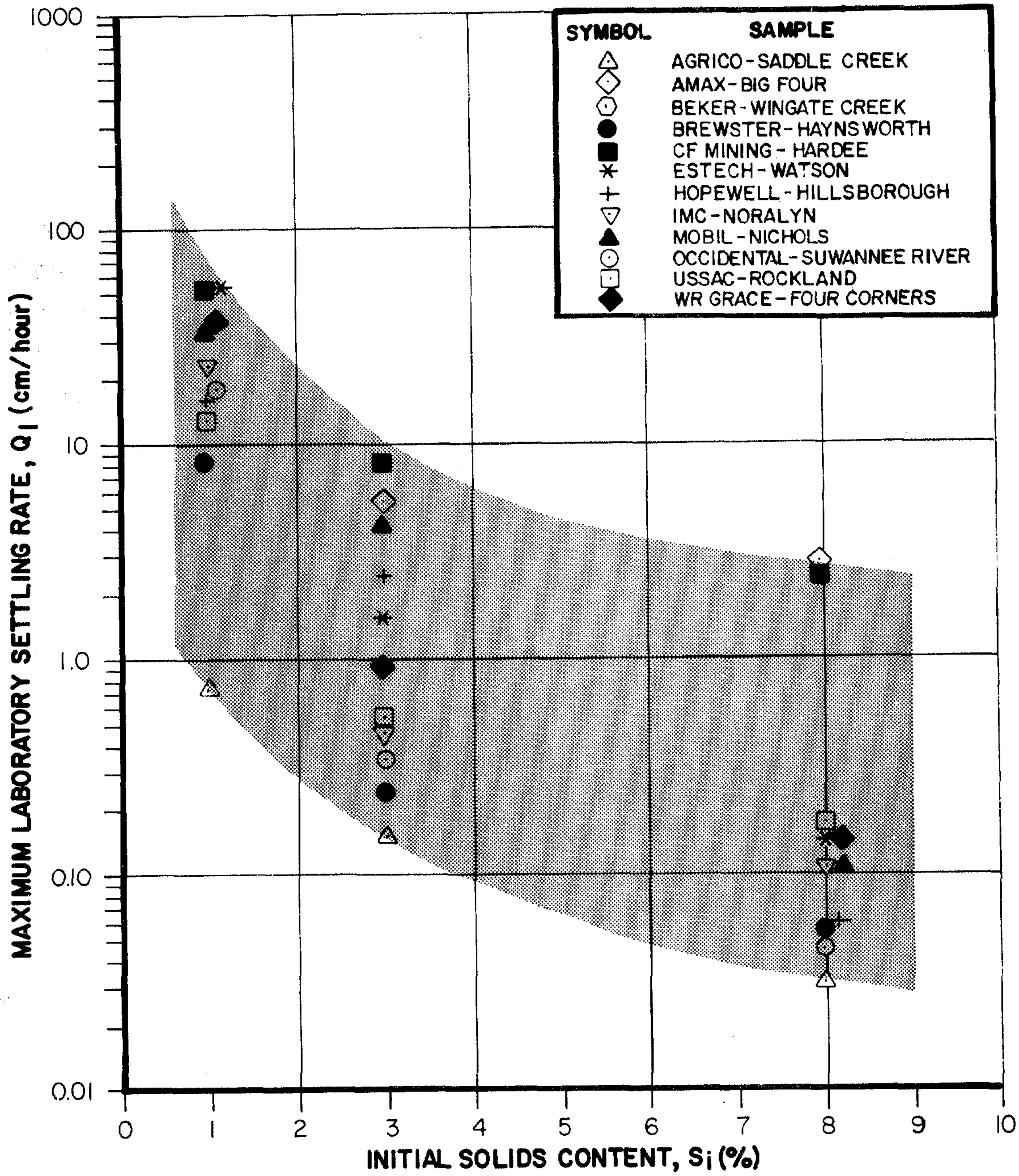


SOLIDS CONTENT VS. LOG TIME FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT VARIOUS INITIAL SOLIDS CONTENT

FIGURE 3-7

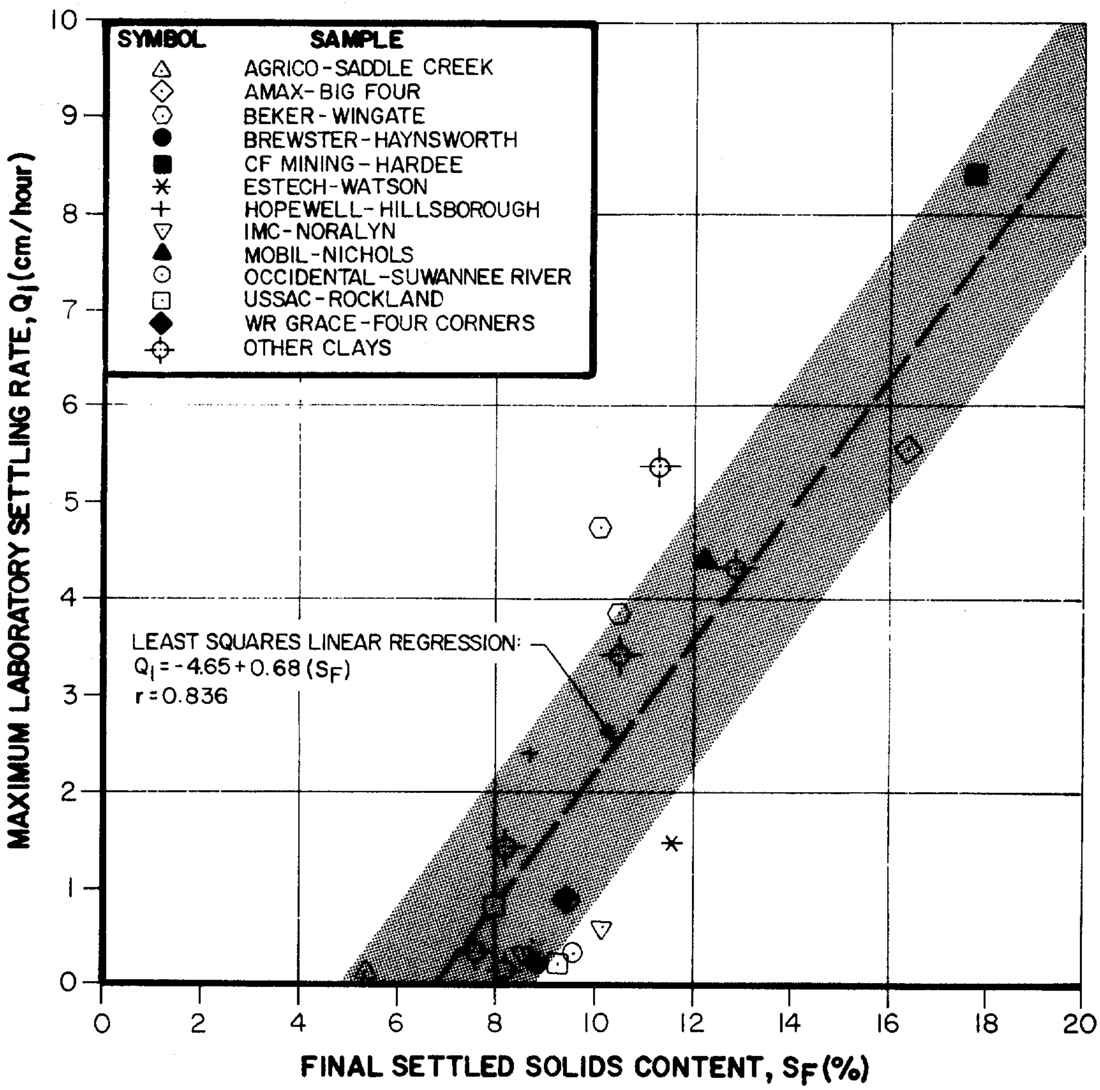


PERCENT SETTLING COMPLETED VS. LOG TIME FOR PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT



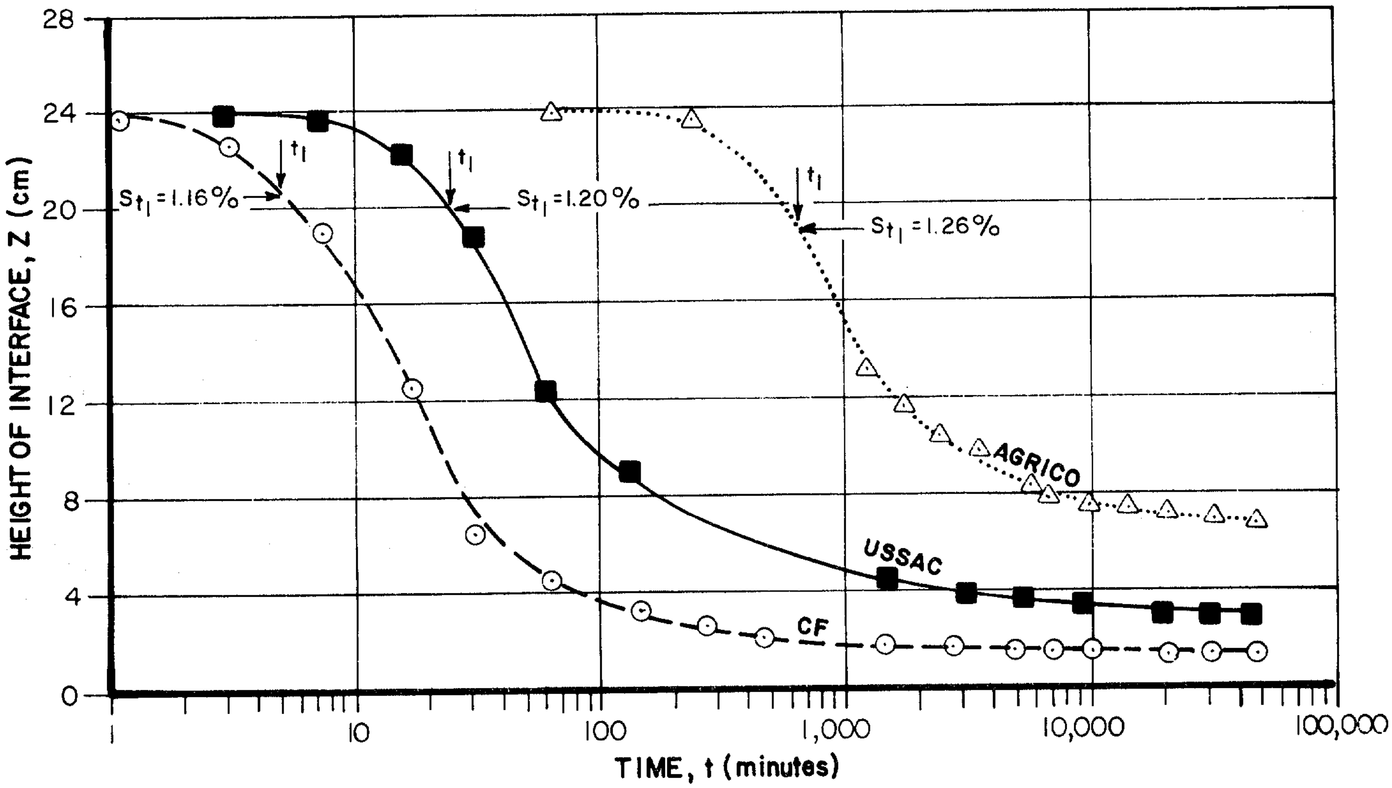
INITIAL SOLIDS CONTENT VS. MAXIMUM LABORATORY SETTLING RATE FOR PHOSPHATIC CLAYS

FIGURE 3-8



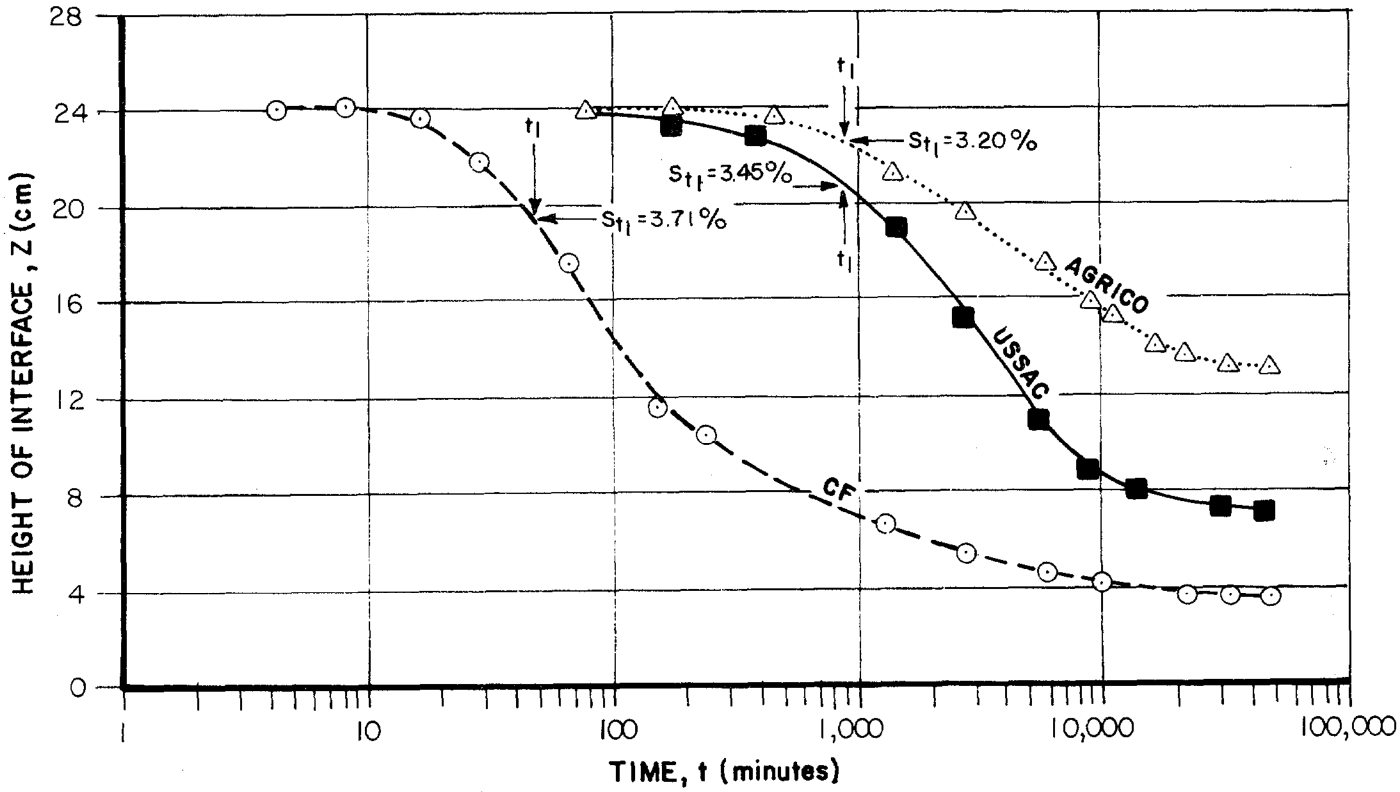
FINAL SETTLED SOLIDS CONTENT VS. MAXIMUM LABORATORY SETTLING RATE FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 3%

FIGURE 3-9



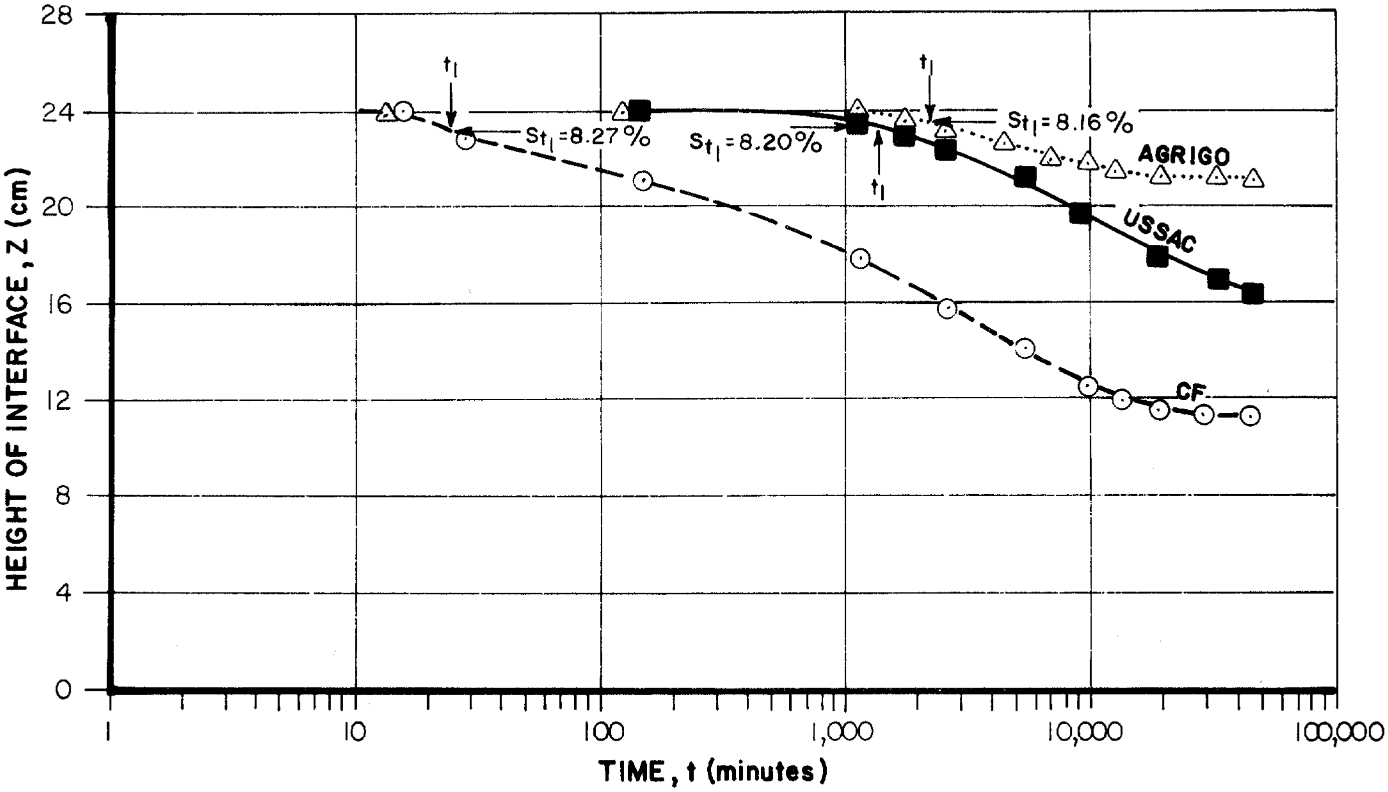
TIME OF MAXIMUM LABORATORY SETTLING RATE FOR AGRICO, CF, AND USSAC PHOSPHATIC CLAYS AT 1% INITIAL SOLIDS CONTENT

FIGURE 3-10



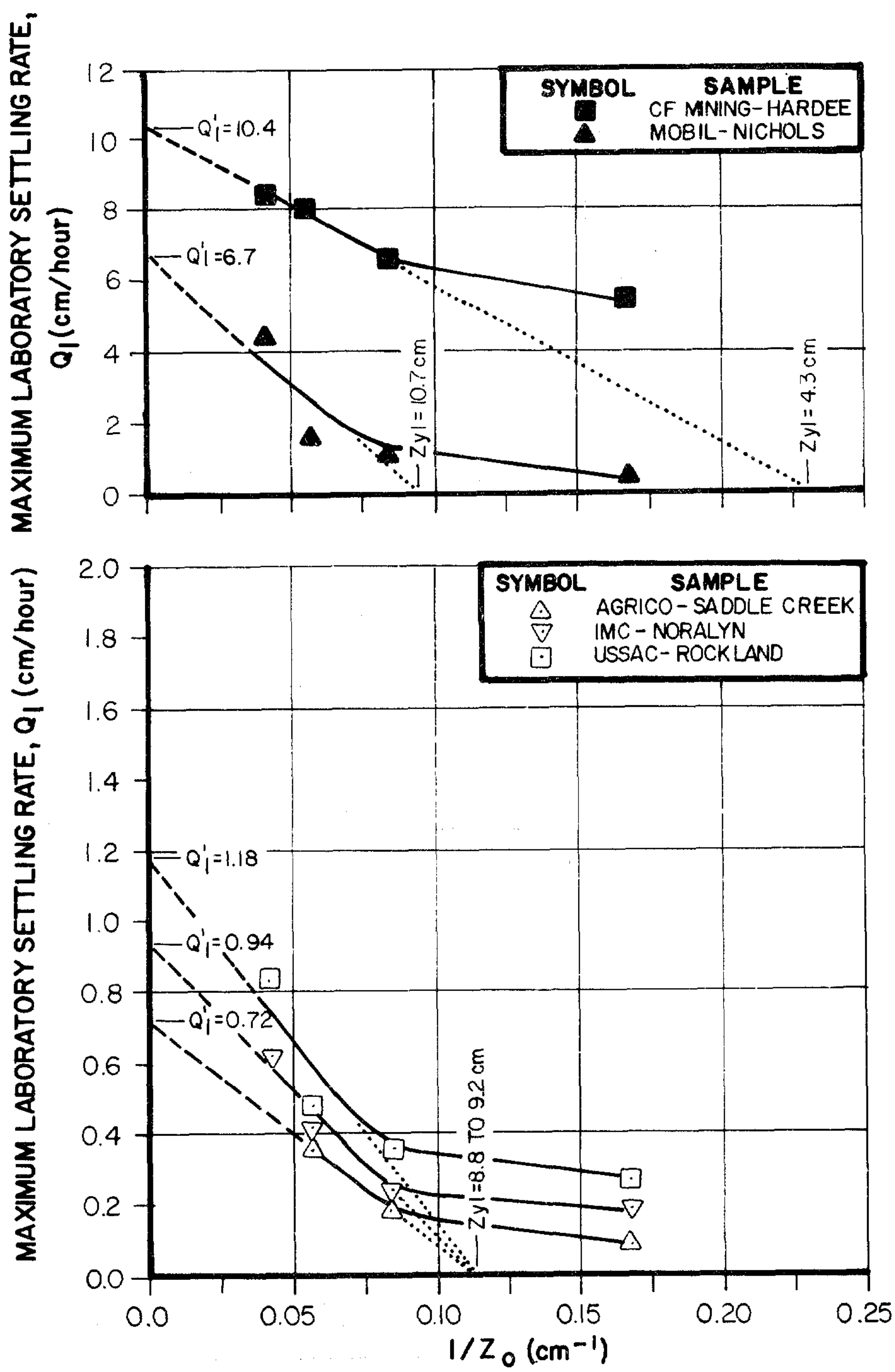
TIME OF MAXIMUM LABORATORY SETTLING RATE FOR AGRICO, CF, AND USSAC PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT

FIGURE 3-11



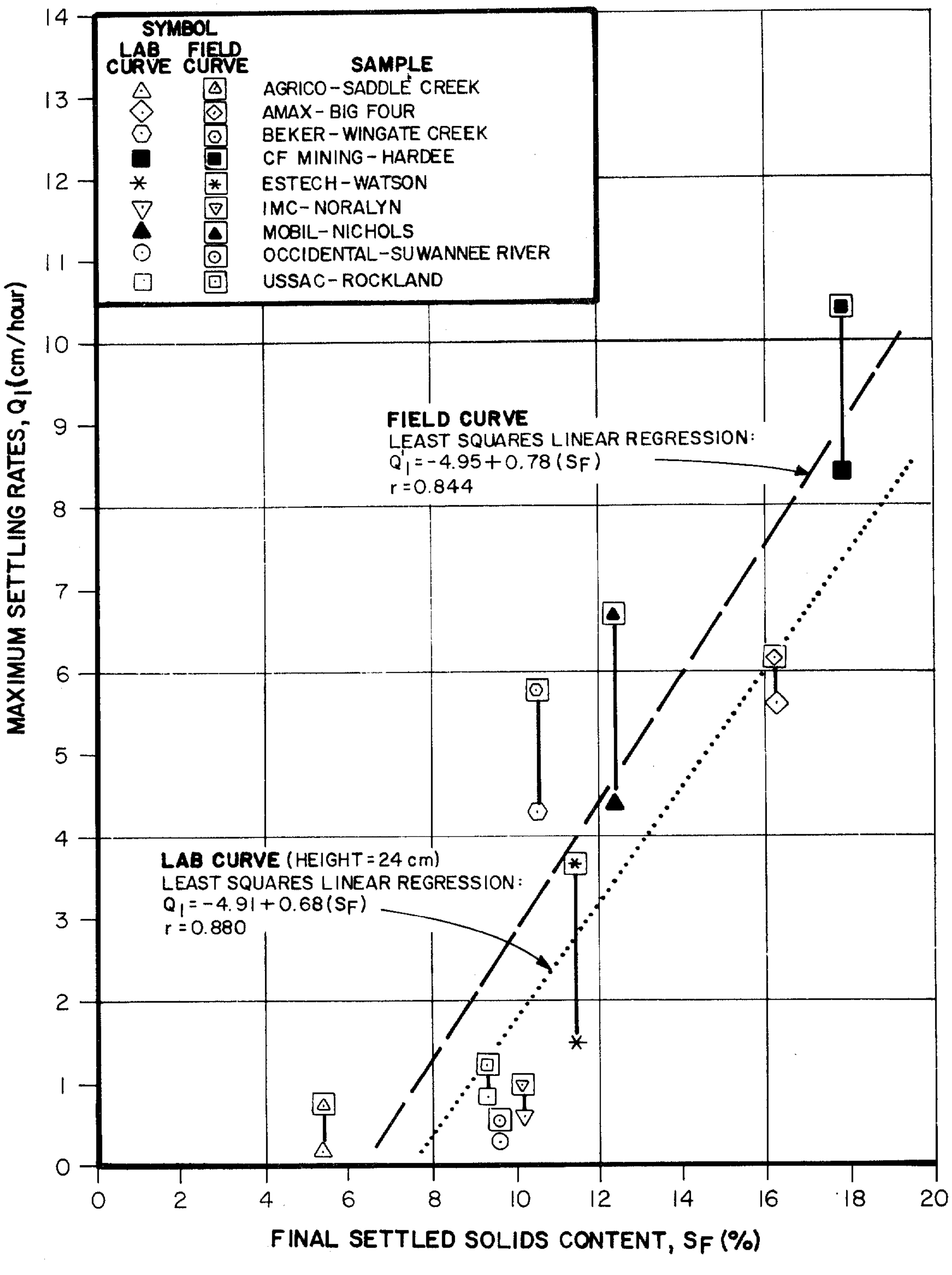
TIME OF MAXIMUM LABORATORY SETTLING RATE FOR AGRICO, CF, AND USSAC PHOSPHATIC CLAYS AT 8% INITIAL SOLIDS CONTENT

FIGURE 3-12



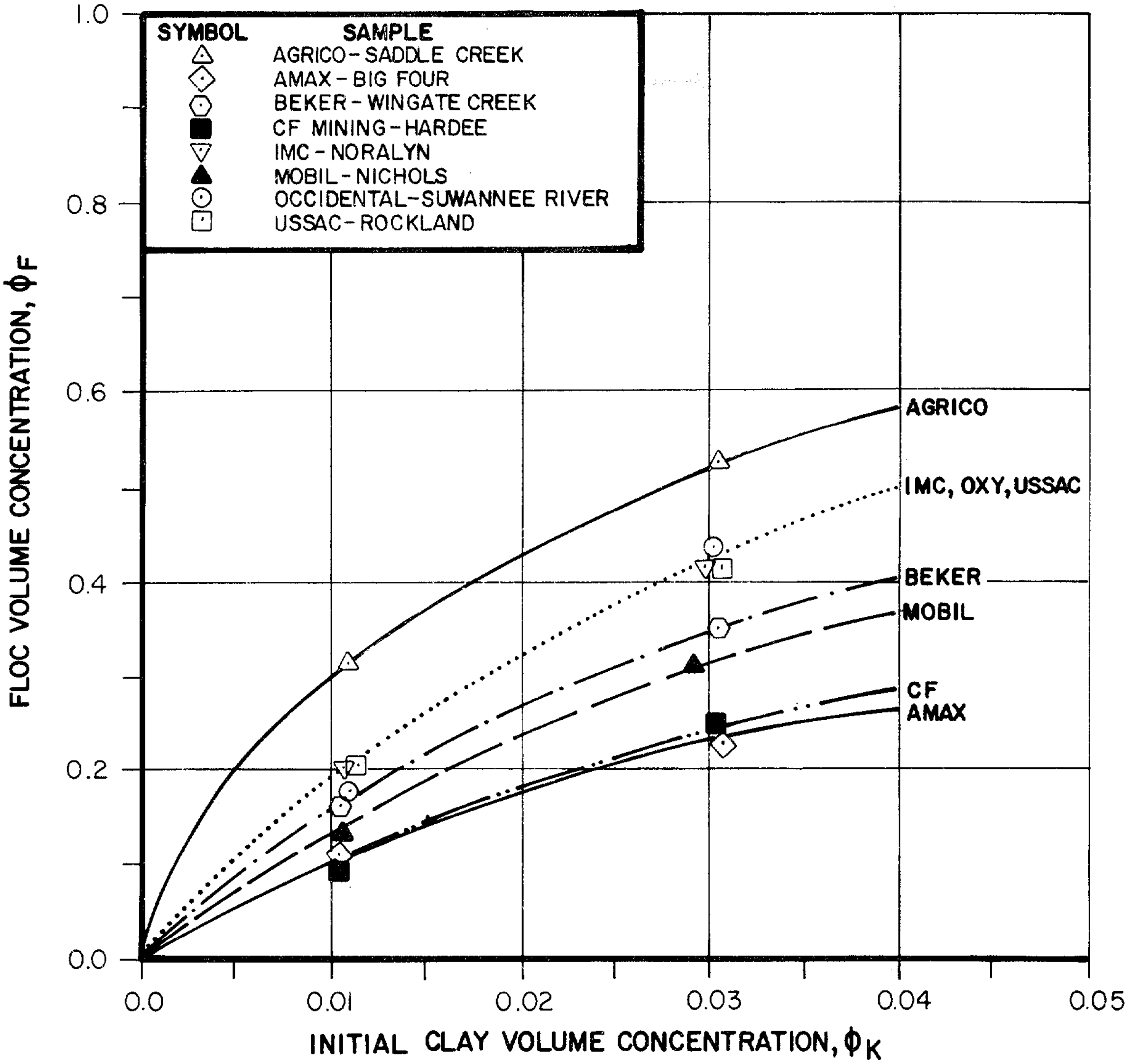
DETERMINATION OF MAXIMUM FIELD SETTLING RATE AND YIELD HEIGHT

FIGURE 3-13



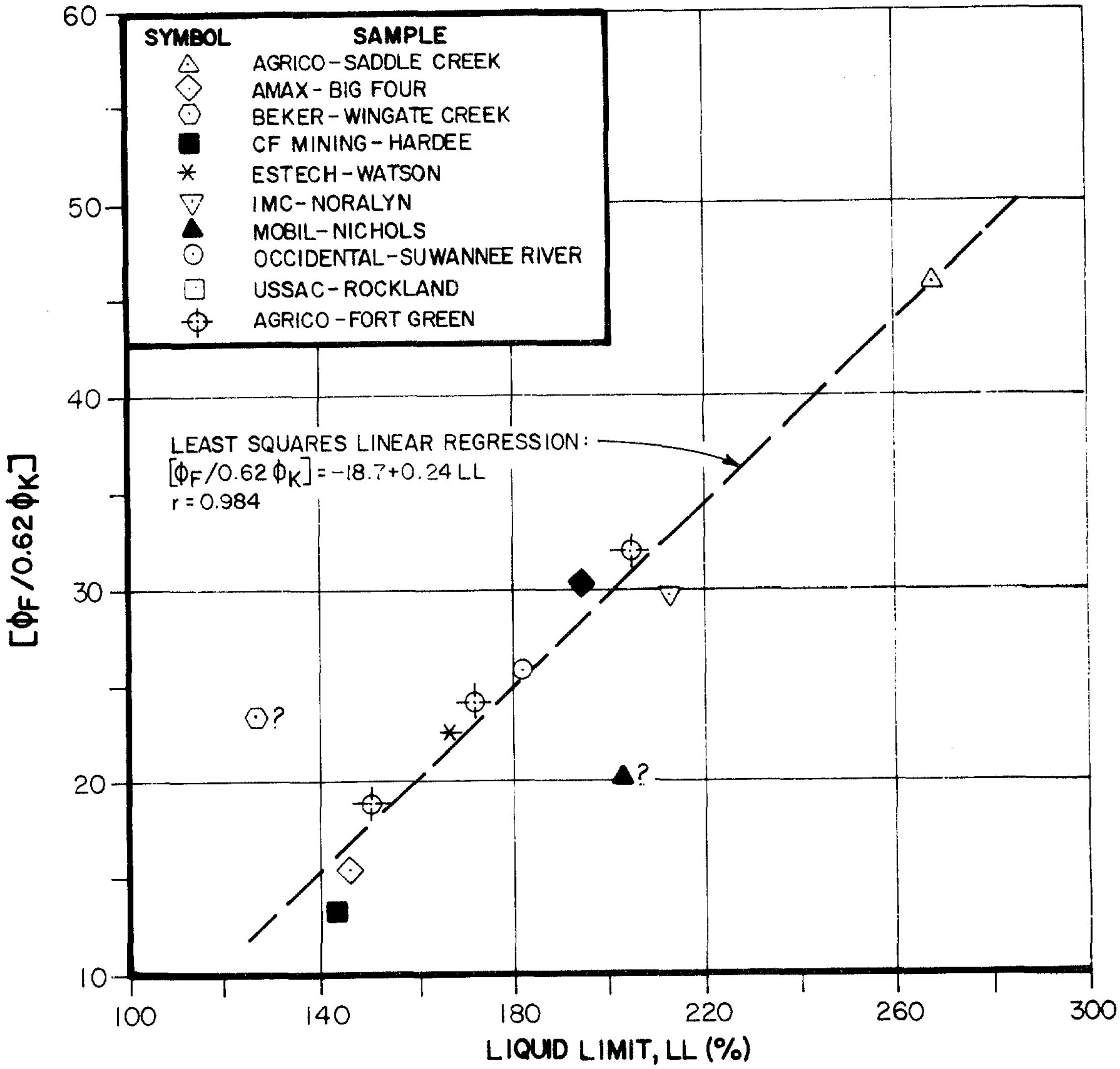
COMPARISON OF FIELD AND LAB MAXIMUM SETTLING RATES FOR INITIAL SOLIDS CONTENT OF 3%

FIGURE 3-14



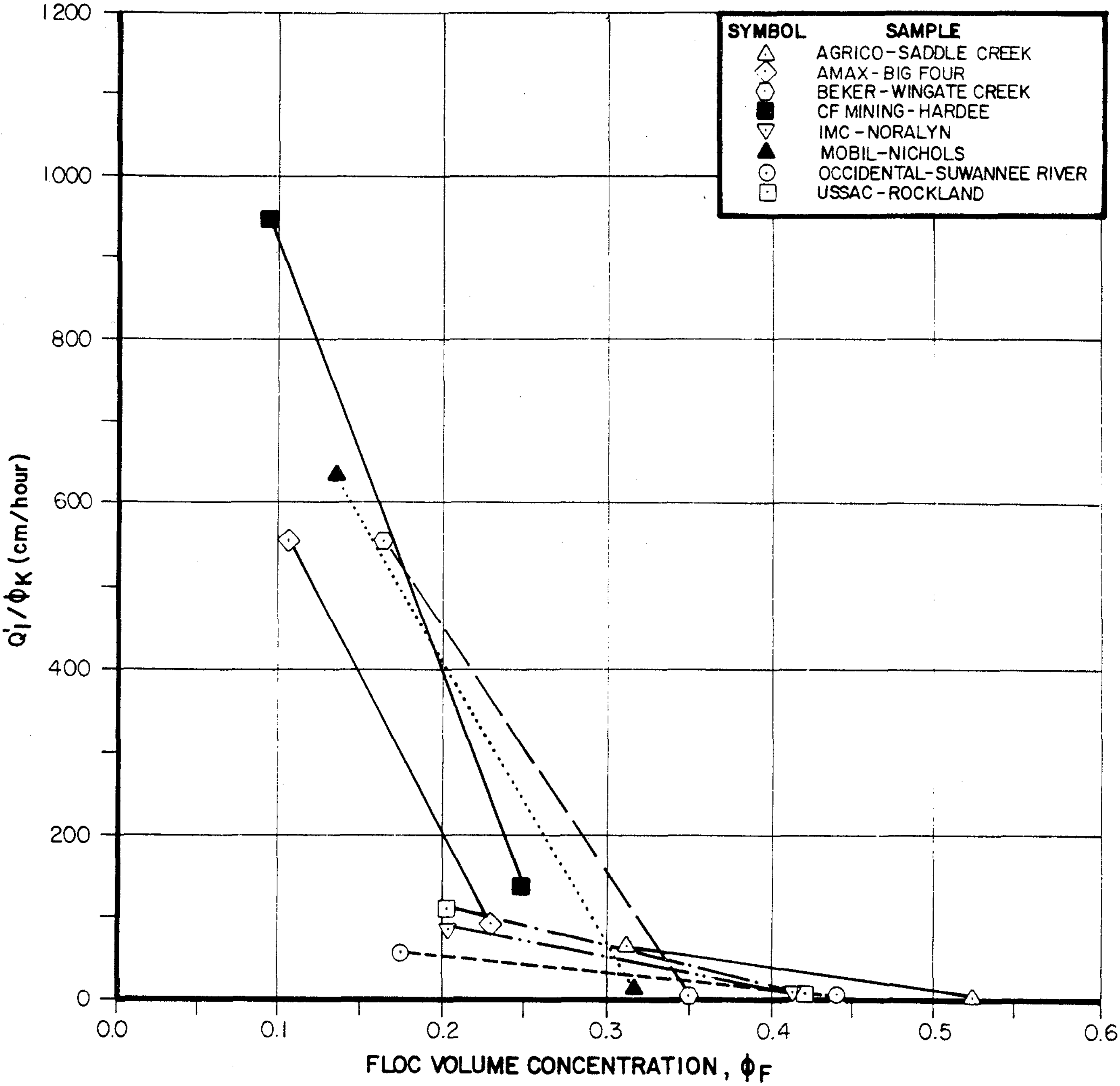
CLAY VOLUME CONCENTRATION VS. FLOC VOLUME CONCENTRATION FOR PHOSPHATIC CLAYS

FIGURE 3-15



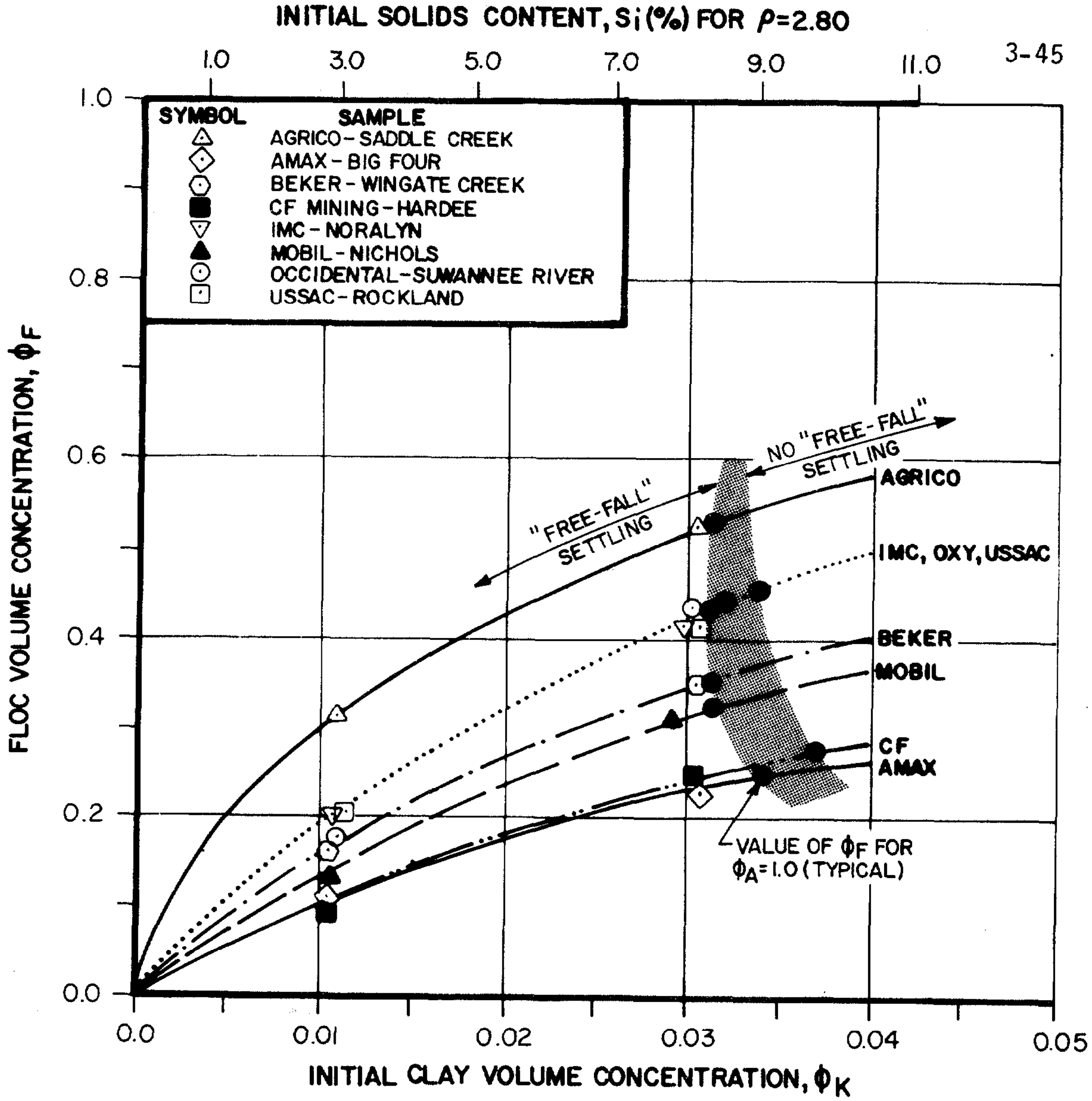
LIQUID LIMIT VS. NORMALIZED FLOC VOLUME CONCENTRATION FOR PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT

FIGURE 3-16



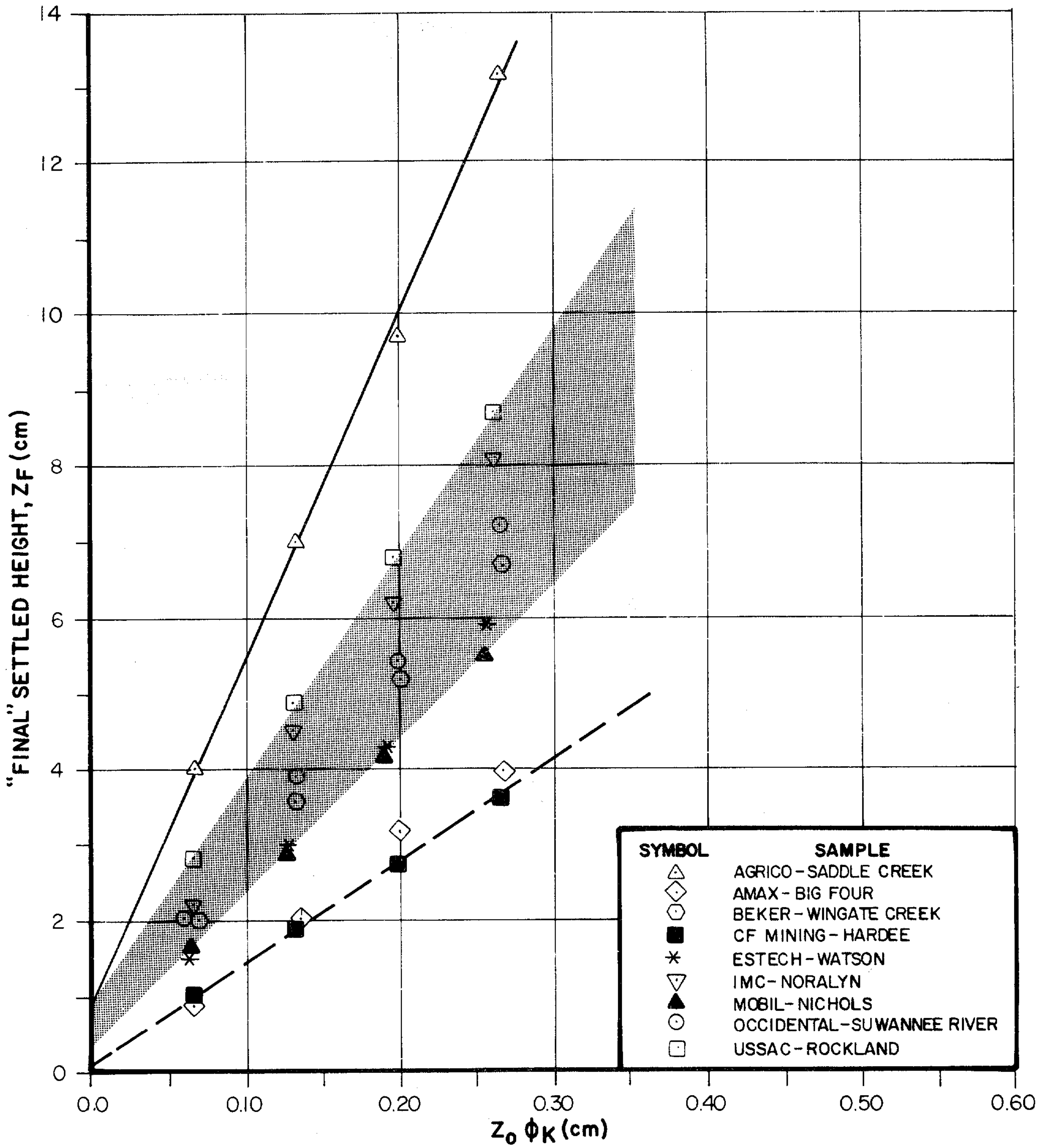
FLOC VOLUME CONCENTRATION VS. Q'_1/ϕ_K FOR PHOSPHATIC CLAYS

FIGURE 3-17



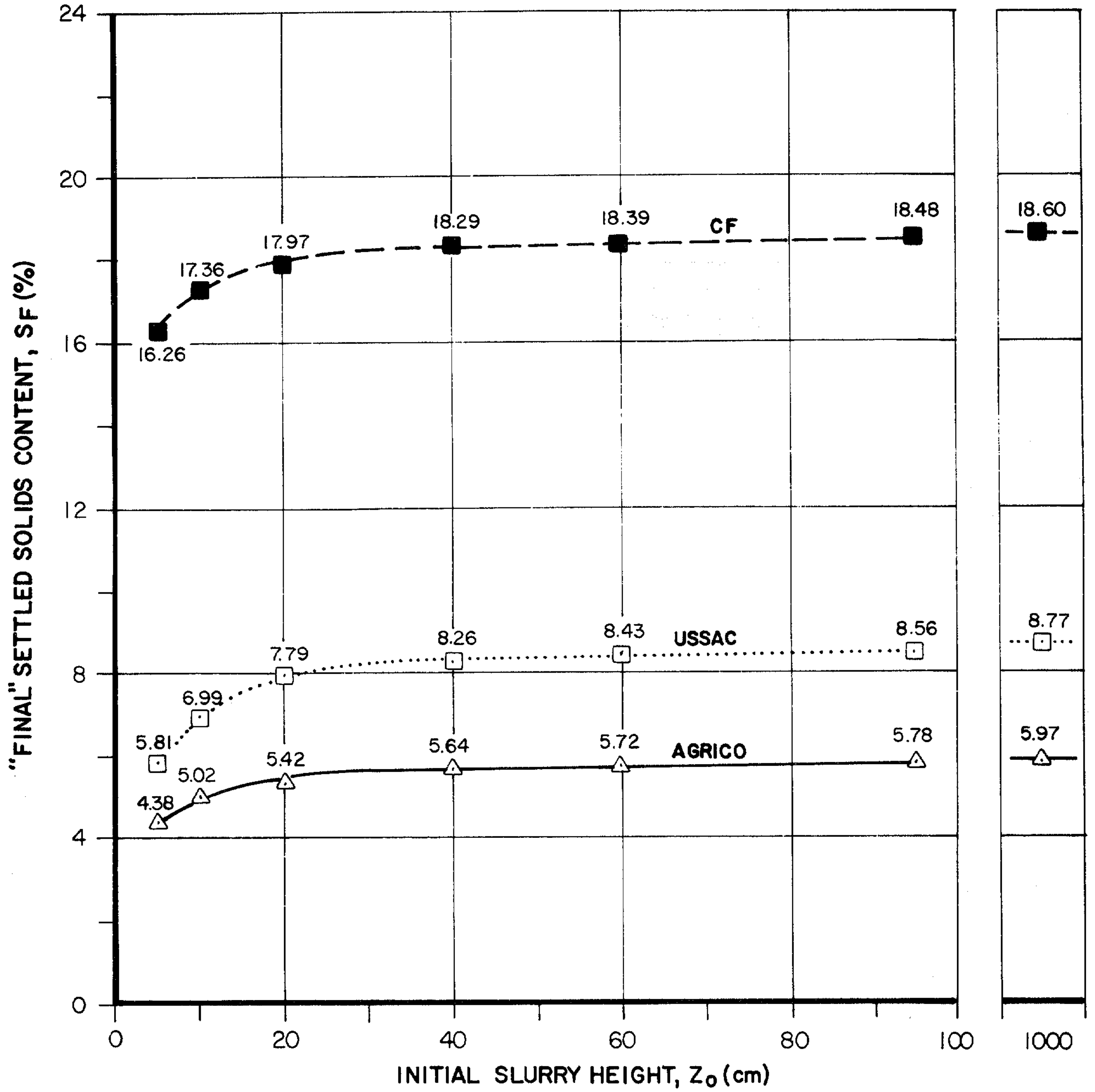
FLOC AND CLAY VOLUME CONCENTRATIONS REQUIRED FOR FREE-FALL SETTLING

FIGURE 3-18



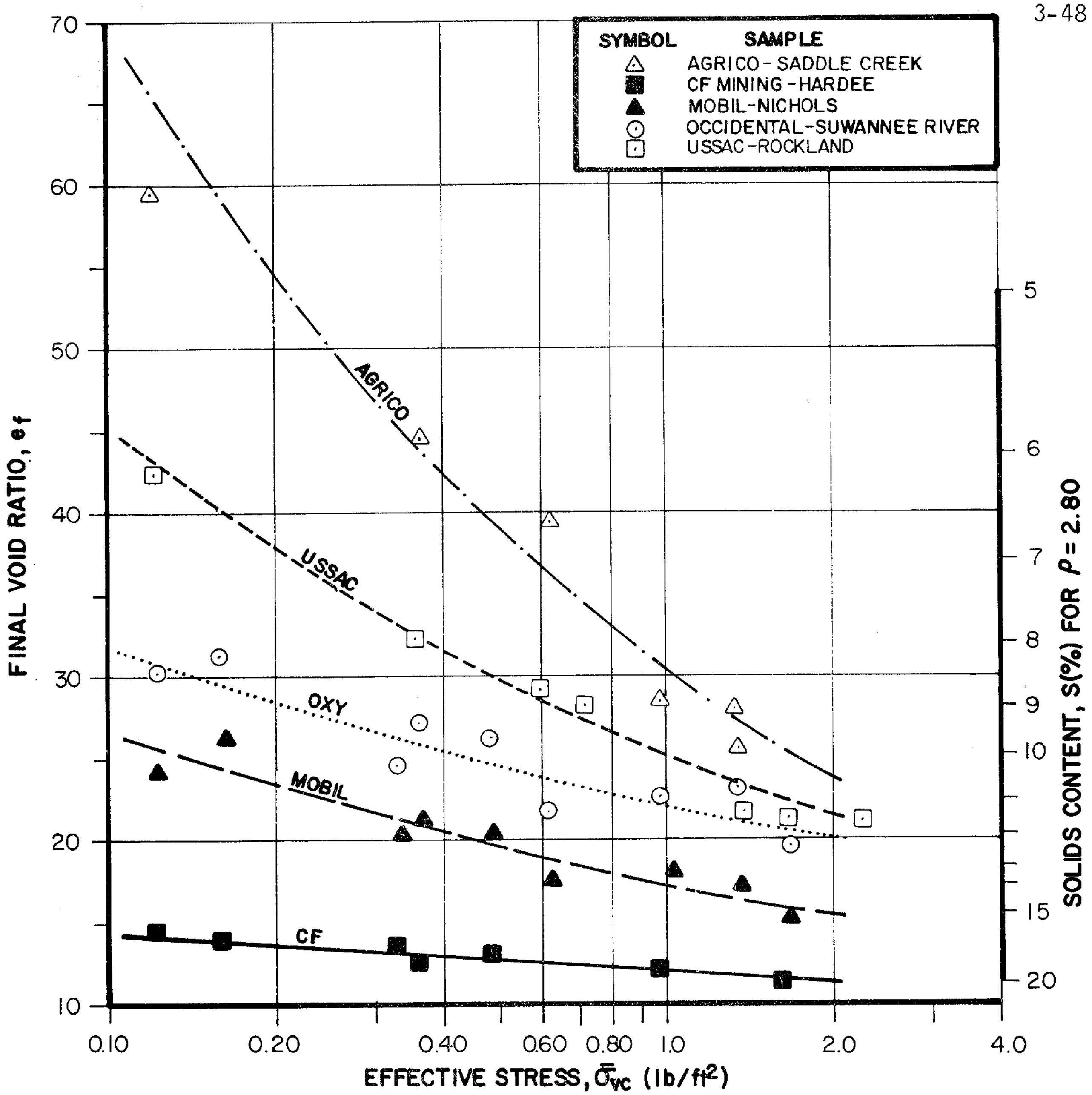
"FINAL" SETTLED HEIGHT VS. $Z_o\phi_K$ FOR PHOSPHATIC CLAYS AT INITIAL SOLIDS CONTENT OF 3%

FIGURE 3-19



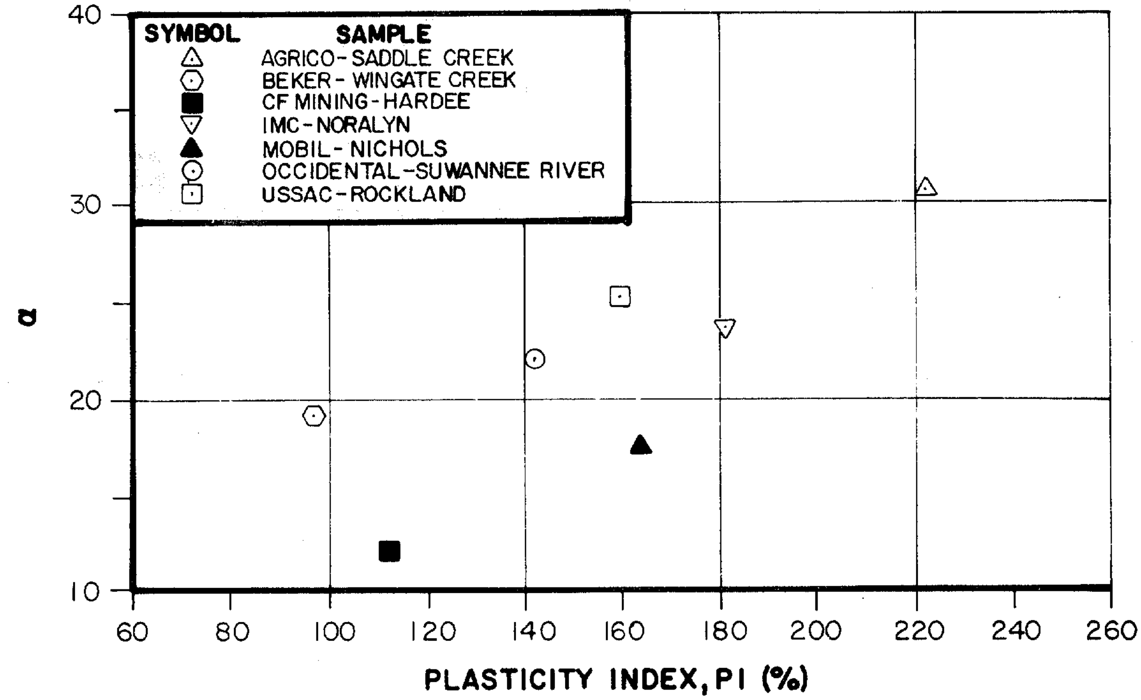
"FINAL" SETTLED SOLIDS CONTENT VS. INITIAL SLURRY HEIGHT

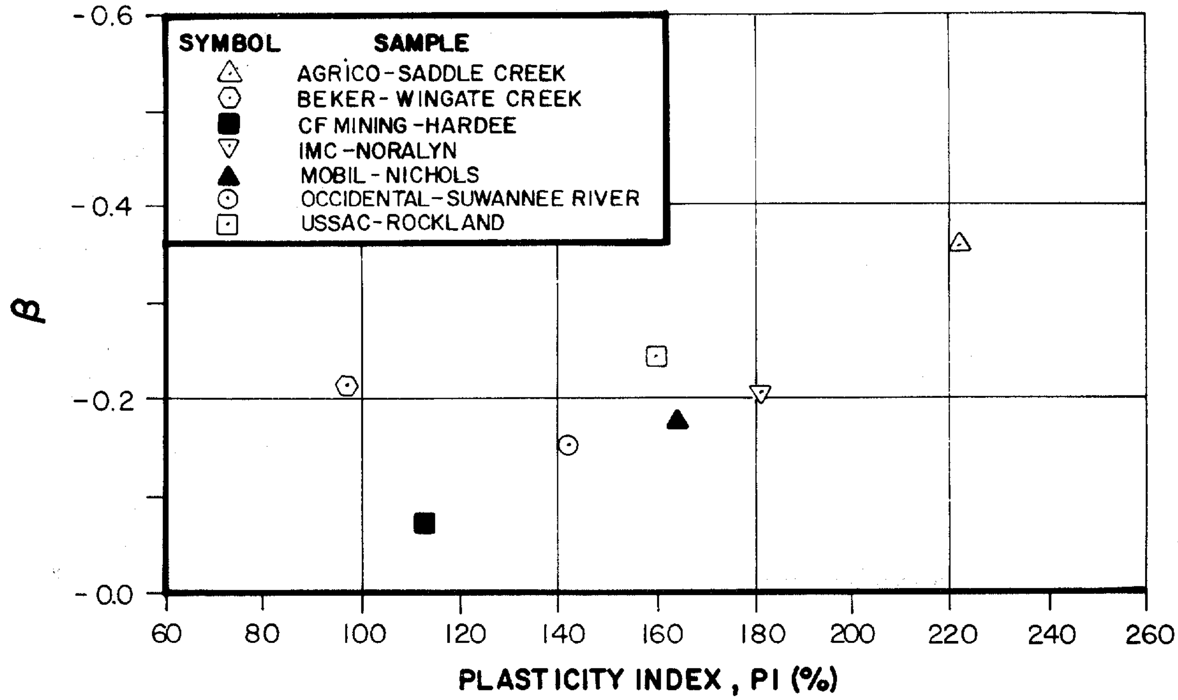
FIGURE 3-20



VOID RATIO VS. EFFECTIVE STRESS FOR PHOSPHATIC CLAYS

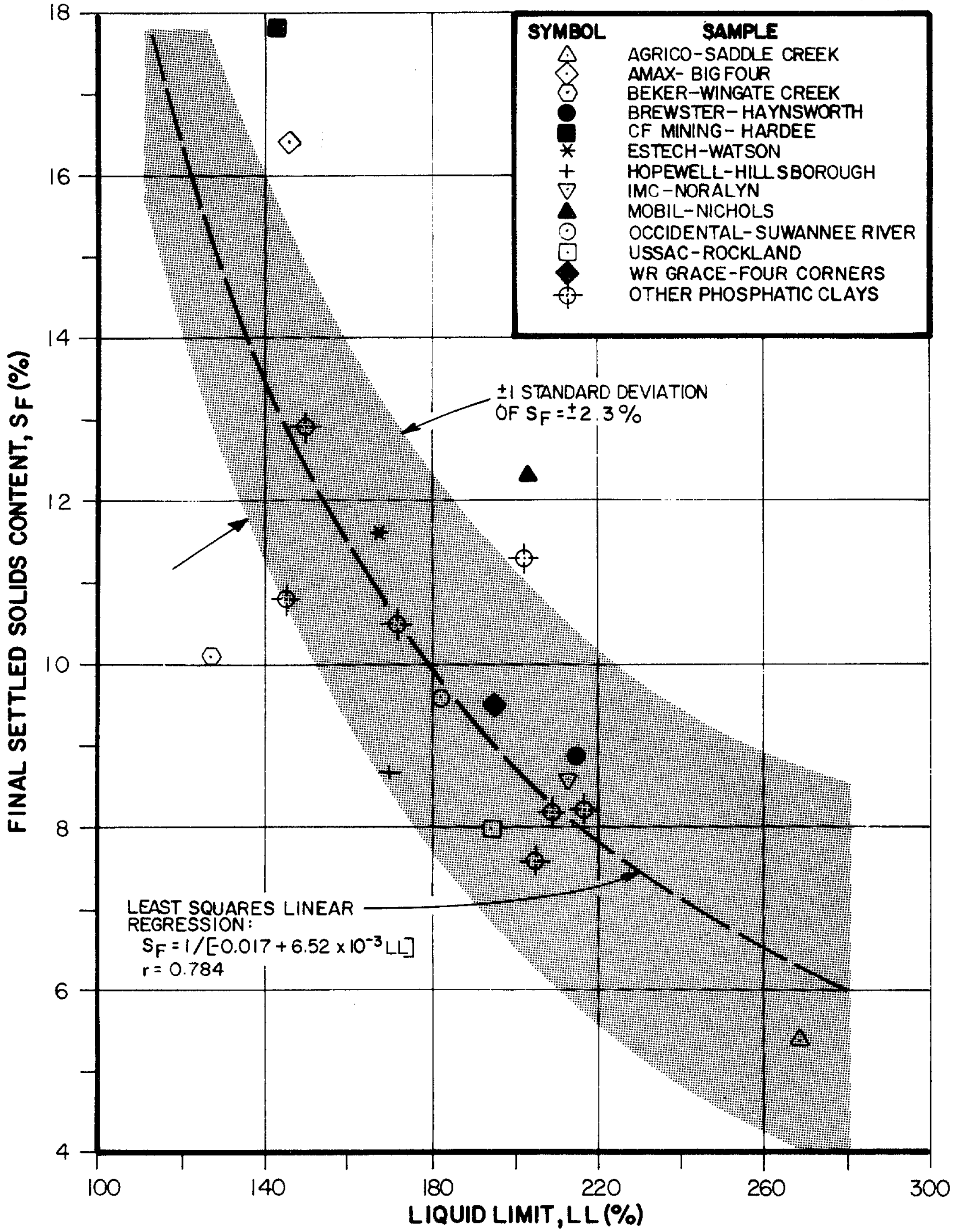
FIGURE 3-21





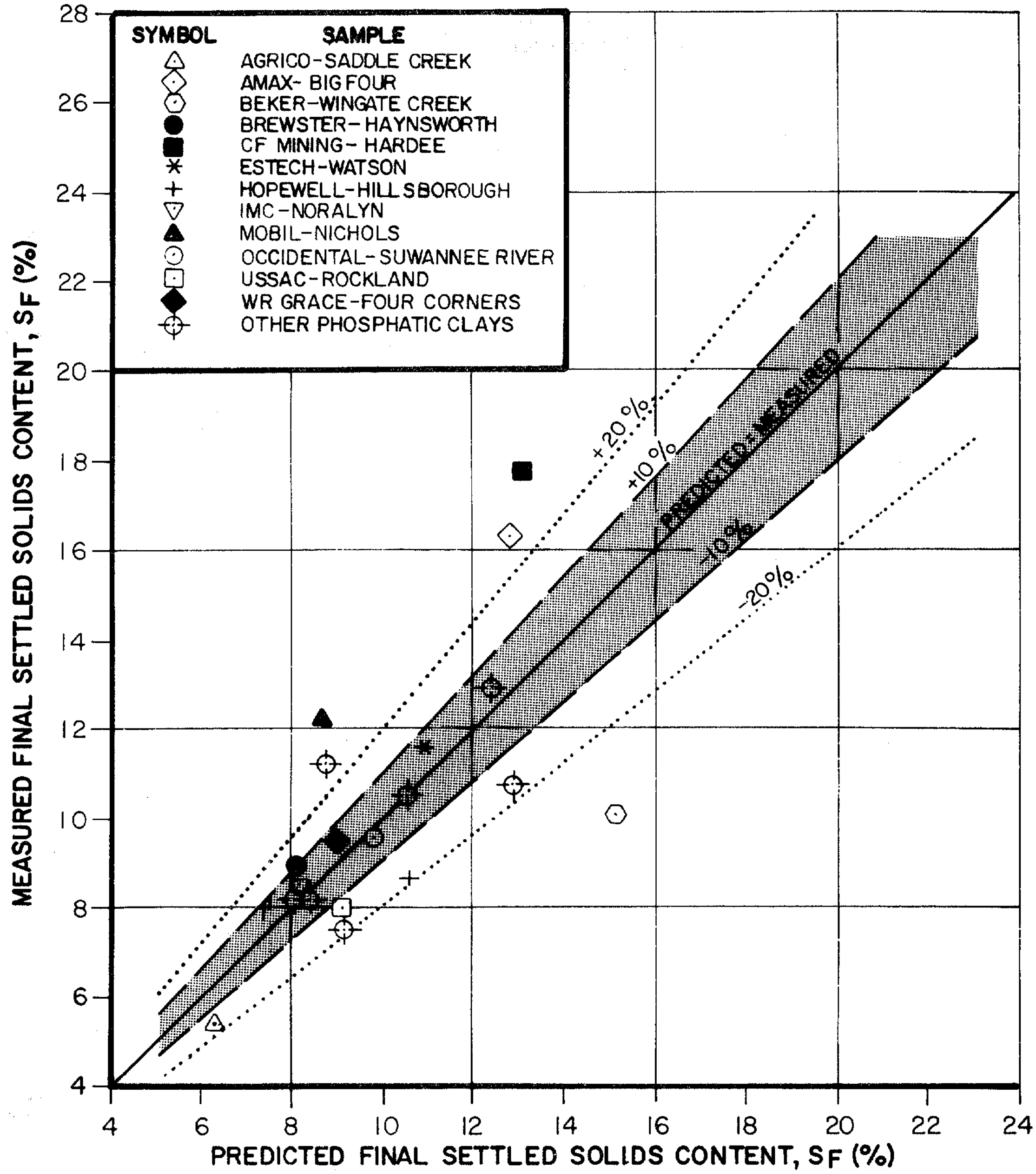
α AND β PARAMETERS FOR SETTLING TEST COMPRESSIBILITY CURVES

FIGURE 3-22



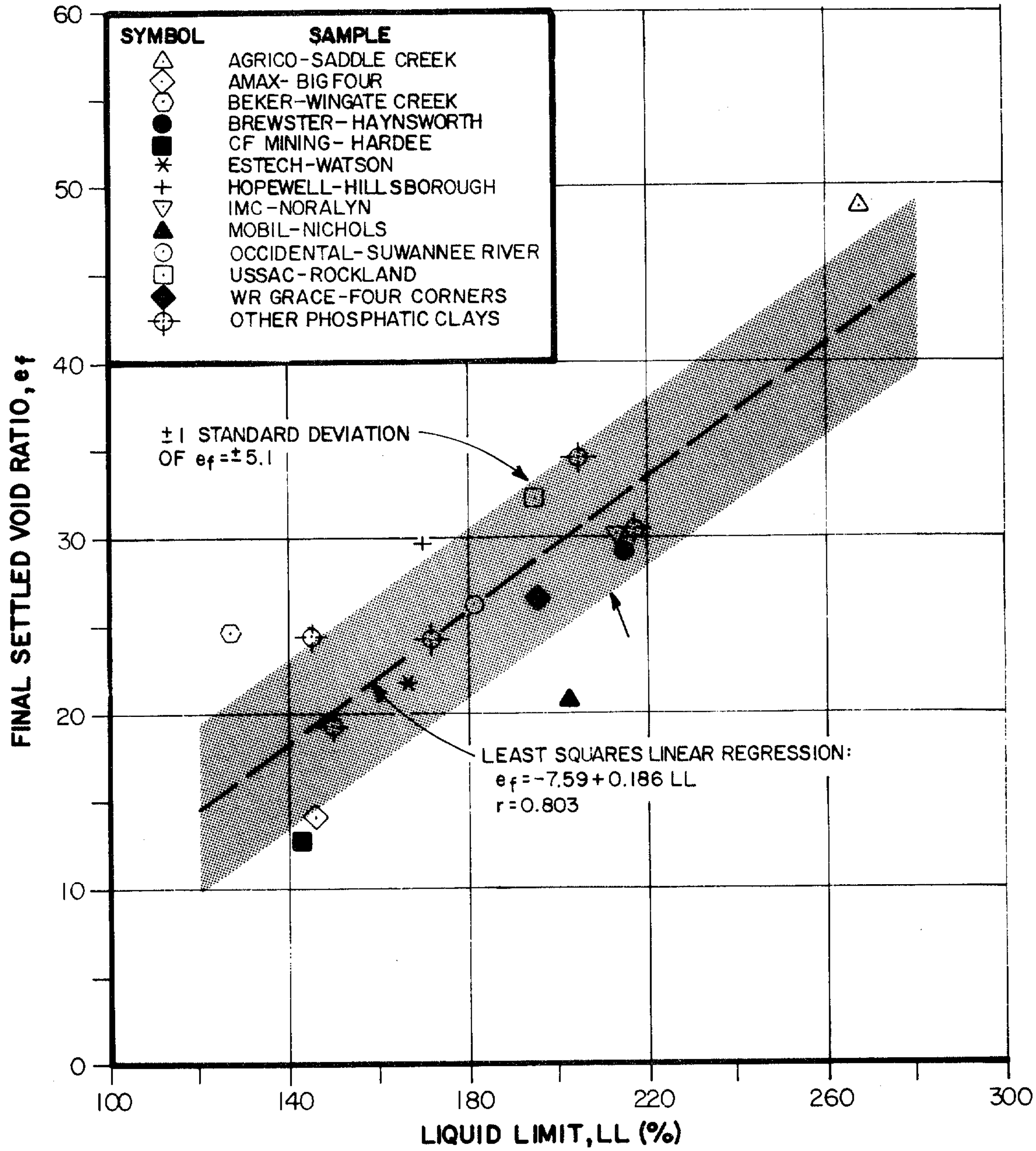
LIQUID LIMIT VS. FINAL SOLIDS CONTENT FOR PHOSPHATIC CLAY AT 3% INITIAL SOLIDS CONTENT

FIGURE 3-23



COMPARISON OF PREDICTED VS. MEASURED FINAL SOLIDS CONTENT FOR LIQUID LIMIT VS. FINAL SOLIDS CONTENT CORRELATION

FIGURE 3-24



LIQUID LIMIT VS. FINAL VOID RATIO FOR PHOSPHATIC CLAYS AT 3% INITIAL SOLIDS CONTENT

FIGURE 3-25

Section 4

SEDIMENTATION BEHAVIOR OF SAND-CLAY MIXES

4.1 Introduction

Little published data exists on the sedimentation behavior of sand-clay mixes. Since the sand-clay mix disposal method is potentially a feasible disposal alternative, at least at some mine sites, the effects of adding sand on the sedimentation characteristics of phosphatic clays are of interest. The objective of the present investigation on the sedimentation behavior of sand-clay mixes, therefore, was to determine the effect of adding sand tailings on settling behavior, and on the final solids contents of phosphatic clays after deposition and gravity settling within an impoundment. To achieve this objective, 22 laboratory settling tests were performed on three phosphatic clays with varying sand-clay ratios.

All settling tests performed on sand-clay mixes are presented and evaluated in this section. Phosphatic clays from the Agrico, CF and USSAC mines were selected for sand-clay mix settling tests. These three clays are representative of relatively poor, good and average settling clays, respectively, and should indicate the effect of sand-clay mix on the range of phosphatic clays likely to occur. Various initial clay solids contents, sand-clay ratios and types of sand tailings were used to determine the effect of these parameters on the settling behavior of sand-clay mixes. Figure 4-1 summarizes the sand-clay mix laboratory settling test program.

4.2 Testing Methods and Nomenclature

Constant initial height settling tests were performed on each sand-clay mix. An initial height, Z_o, of 24 cm was used for this test series. Initial clay solids contents, S_{ic}, of 8 and 12% were used for each phosphatic clay. An additional initial clay solids content of 16% was also used for the CF phosphatic clay. The range of initial clay solids contents was selected to include the final solids contents achieved after settling without sand from an initial solids content of 3 to 8%.

Sand-clay ratios, SCR, of 1:1, 2:1 and 3:1 by dry weight were used with each initial clay solids content. In practice, the SCR is often defined by the ratio of the dry weight of material retained on the 150 sieve (+150) to the dry weight of material passing the 150 sieve (-150). Based on particle size analyses presented in Volume 1*, the sand tailings typically have 96% by dry weight retained on the 150 sieve and 4% by dry weight passing the 150 sieve. Phosphatic clays typically have 96% by dry weight passing the 150 sieve and 4% by dry weight retained on the 150

*Refer to Volume 1, Section 2.6 for the particle size distribution of phosphatic clays and Volume 1, Section 3.2 for the particle size distribution of sand tailings.

sieve. Hence, for these average values a definition of sand-clay ratio by ratio of dry weight of sand to clay or by ratio of +150 to -150 material yields the same result. Depending on the actual particle size distributions of the phosphatic clays and sand tailings being mixed, however, the two definitions may often yield different values, but the differences will likely be small.

4.2.1 Nomenclature

For sand-clay mixes it is useful to define both the solids content of the combined sand and clay, or total solids content, and that of the clay phase alone (assuming all free water is within the clay phase), or clay solids content. The initial total solids content, S_{it}, and initial clay solids content, S_{ic}, are related by the expression:

$$S_{it} = (1 + SCR)/((1/S_{ic}) + SCR) \qquad (1)$$

The final total solids content, S_{Ft}, and final clay solids content, S_{Fc}, are also related by an identical expression. Rearranging terms in Equation 1 for S_{Fc} in terms of S_{Ft} yields the relation:

$$S_{Fc} = 1/[((1 + SCR)/S_{Ft}) - SCR] \qquad (2)$$

The final actual total void ratio, e_{ft}, and final clay phase void ratio, e_{fc}, are also used in evaluating the settling test results. The final total and clay void ratios are defined, respectively, by the following equations:

$$e_{ft} = (\rho(1-S_{Ft})/S_{Ft}) \qquad (3)$$

$$e_{fc} = e_{ft}(1 + (\rho_c SCR/\rho_s)) \qquad (4)$$

Where: ρ is the effective specific gravity of the solids in the sand-clay mix; ρ_C is the specific gravity of clay; and ρ_s, is the specific gravity of sand. The effective specific gravity of the solids in the sand-clay mix is given by the following relation:

$$\rho = \rho_s \rho_c (1 + SCR)/(\rho_c SCR + \rho_s) \qquad (5)$$

The clay solids content, S_c, has been defined as the ratio of weight of clay solids to weight of clay solids and water. This definition neglects the presence of the sand both in terms of weight and volume. If the volume of sand is included as an equivalent water phase (i.e., displaced pore water), then the effective clay solids content, $\bar{S}_c$, is related to S_c by the expression:

$$\bar{S}_c = 1/(SCR/\rho_s + (1/S_c)) \qquad (6)$$

Moreover, if the volume of sand is accounted for as an equivalent displaced water phase, then the effective clay void ratio, $\bar{e}_c$, is related to the clay void ratio, e_c, by the expression:

$$\bar{e}_c = e_c + (\rho_c/\rho_s)SCR \qquad (7)$$

4.3 Sand-Clay Mix Settling Tests

4.3.1 "Final" Solids Contents

Results from constant initial height settling tests on sand-clay mixes graphically summarized as average total solids content versus time and height of interface versus time are presented in Appendix G, Figures G-1 through G-16. Individual test results and relevant data for each clay are also summarized in Appendix G, Tables G-1 through G-3.

The final settled clay solids contents, S_{Fc}, achieved for various sand-clay ratios and initial clay solids contents, S_{ic}, are summarized in Table 4-1. The total initial, S_{it}, and final, S_{Ft} , solids contents are also presented along with the final effective clay solids content, $\overline{S}_{Fc}$. As with the clay settling tests, the sand-clay mix settling tests indicate significant variability in the final clay solids content of various phosphatic clays. For an initial clay solids content of 12% and sand-clay ratio of 2:1, the final clay solids contents range from 12.9 for the Agrico clay, to 15.3% for the USSAC clay, to 19.1% for the CF clay as shown in Figure 4-1. Hence, the variability in settling behavior of sand-clay mixes is as great as the settling behavior of clay alone.

The sand--clay mix settling test results indicate that a clay which settles to a relatively low final clay solids content without sand, also settles to a relatively low final clay solids content with sand. Hence, the addition of sand tailings does little to increase the final clay solids content of a relatively poor settling clay (i.e., Agrico clay) relative to that of a relatively good settling clay (i.e., CF clay).

4.3.2 Effect of Sand-Clay Ratio

The effect of sand-clay ratio on settling behavior and final settled clay solids content, S_{FC}, is illustrated in Figures 4-3 and 4-4. As shown in Figure 4-3 for USSAC sand-clay mixes, the final clay solids content increased with increasing sand-clay ratio from about 11.0% without sand to 13.5% at a SCR of 3:1 Figure 4-4 illustrates that this trend occurred for each clay tested. Least squares linear regression analyses indicate that the trend is significant, since the correlation coefficients, r, were relatively high in the range of 0.95 to 0.98. The correlations indicate that the increases in clay solids content at the end of settling due to sand-clay mixing are not very large. For the four data groups where regression analyses were performed, the increase in clay solids contents at the end of settling above that which occurs for clay alone ranged from 50 to 84% of the sand-clay ratio. Hence, for a sand-clay ratio of 3, the clay solids contents increased by 1.5 to 2.5%. The higher the initial clay solids content, the lower the relative increase with increasing sand-clay ratio.

It should be emphasized that the beneficial effect of sand-clay ratio is not as prominent with regards to the effective clay solids content, $\overline{S}_c$. As shown in Figure 4-3 for USSAC sand-clay mixes, the increase in final effective clay solids content for various sand-clay ratios is less than 1% (see shaded band in Figure 4-3). Hence, the effective clay solids content increased only to a minor degree due to the added weight of the sand. In effect, the main role of the sand during settling is to displace an equivalent volume of pore water.

Figure 4-5 illustrates the trend in final effective clay solids content, $\bar{S}_c$, with increasing sand-clay ratio, SCR, for each clay tested. In general, as the SCR is increased from 1:1 to 3:1, $\bar{S}_{FC}$ remains relatively constant or decreases slightly. This indicates that when the SCR is substantially increased the volume occupied by the sand becomes relatively greater than the volume of water effectively displaced; i.e., the additional sand is not as effective in displacing pore water. For some clays mixed at some initial clay solids content, the final effective clay solids content, $\bar{S}_c$, increases slightly with increased sand-clay ratio up to a SCR of 1:1 (see Figure 4-5).

4.3.3 <u>Effect of Initial Clay Solids Content</u>

The effect of initial clay solids content on the settling behavior of sand-clay mixes is of interest to determine the clay solids content which must be achieved initially by either conventional settling or pre-thickening prior to adding sand tailings for sand-clay mix disposal. Further, the initial clay solids content required to prevent segregation of the clay and sand during settling must also be established.

The sand-clay mix settling tests indicate that for a given clay and sand-clay ratio, a slurry prepared at an initially lower clay solids content will not obtain as high a settled clay solids content with time as a slurry prepared at an initially higher solids content. This behavior is illustrated in Figure 4-5 for USSAC sand-clay mixes with a sand-clay ratio of 2:1 and initial clay solids contents of 8 and 12%. Similar behavior was also observed during clay settling tests (Section 3.2.1).

The effect of initial clay solids content on segregation of sand and clay particles during settling was determined by measuring the percent soil fraction by dry weight passing the U.S. No. 200 sieve (74 µm mesh size) within the top and lower halves of the settled slurries. These results are presented in Table 4-2. The ideal percent soil fraction passing the U.S. No. 200 sieve shown in Table 4-2 is based on the assumption that the clay contains 100% -74 µm size particles and that the sand contains 0% -74 µm size particles.

The results indicate that Agrico and USSAC sand-clay mixes prepared with initial clay solids contents of either 8 or 12% did not segregate during settling. The -74 um size fractions within both the top and lower halves of the settled slurry of these samples were always within 1% of each other and within 1 to 2% of the ideal -74 µm size fraction.

Sand-clay mixes prepared with CF clay at initial clay solids contents of 8 and 12% displayed segregation. The CF sand-clay mix prepared from an initial clay solids content of 8% was unable to retain the sand in suspension, and segregation was visually observed during the settling test.* Segregation was not visually obvious during the settling test for the CF sand-clay mix prepared from an initial clay solids content of 12%. Particle size analyses performed on the top and lower halves of the settled slurry, however, indicated that some segregation occurred as evidenced by -74 μm size fractions 4 to 7% greater in the upper half than in the lower half. As shown in Table 4-2, an initial clay solids content of 16% was required to prevent segregation of the CF sand-clay mix.

Table 4-3 presents a comparison of initial sand-clay mix clay solids contents required to prevent segregation with final settled clay solids contents achieved for clay alone from an initial clay solids content of 3%. As shown, sand-clay mixes prepared with initial clay solids contents approximately equal to or greater than the final settled clay solids content achieved for clay alone from an initial solids content of 3% displayed no segregation. Conversely, sand-clay mixes prepared at an initial clay solids content below the final clay solids content achieved for clay alone from an initial solids content of 3% displayed segregation. The degree of segregation also increased as the initial clay solids content decreased.

Based on this comparison, the initial sand-clay mix clay solids content required to prevent segregation varies significantly for the phosphatic clays. The settling tests performed during this investigation suggest that the final settled clay solids content achieved for clay alone from an initial solids content of 3% is adequate to prevent segregation.

4.3.4 Effect of Type of Sand Tailings

The effects of variations in the type of sand tailings on settling behavior were investigated for Agrico and CF sand-clay mixes. As noted in Volume 1, Section 3, the gradation characteristics of the Agrico, CF and USSAC sand tailings were similar. Hence, no effects from gradation were expected. As outlined in Volume 2, Section 5, however, the mineralogy of the CF and Agrico sand tailings varied considerably. The Agrico sand tailings contained 60% quartz and 40% apatite, whereas two CF sand tailings samples contained 85 and 15% and 94 and 6% quartz and apatite, respectively. The corresponding specific gravities were 2.86 for the Agrico sand tailings, and 2.72 and 2.69 for the two CF sand tailings samples.

Despite the variation in sand tailings mineralogy, no effect on the final settled clay solids contents of the sand-clay mixes were observed. As shown in Table 4-1, the Agrico sand-clay mix final settled clay solids contents were similar for both series of tests, although the sand tailings contained 60% quartz and 40% apatite in one series of tests and 85% quartz and 15% apatite in the other.

4.4 Void Ratio Versus Effective Stress

The final sand-clay mix settling test heights and clay solids contents were used to

*Due to the large amount of segregation observed, the test was terminated and no final solids contents or particle size analyses were performed.

estimate void ratio versus effective stress compressibility curves at the low effective stresses that result from self-weight consolidation. Since tests with varying initial heights were not performed for the sand-clay mixes, the compressibility curves were established assuming that: the final clay solids contents were constant with depth; the effective stress distribution was linear with depth; and the effective stress at mid-height governed compressibility. The clay void ratio, e_c and effective clay void ratio, $\bar{e}_c$, versus effective stress relationships developed for the Agrico, CF, and USSAC clays from this method are presented in Figures 4-6, 4-7 and 4-8, respectively. Tables G-1, G-2 and G-3 summarize individual calculated void ratios and effective stresses.

The clay void ratio versus effective stress relations for sand-clay mixes have been assumed by other investigators to be the same as the void ratio versus effective stress relation for clay alone. As shown in Figures 4-6 and 4-8 for the Agrico and USSAC clays, respectively, this assumption appears justified at low stresses, since the clay void ratio versus effective stress determined from sand-clay mix settling tests agrees well with the void ratio versus effective stress relationships determined from clay settling tests. Note, however, that the effective clay void ratio diverges from the established relationships at high SCR, indicating that the effective clay solids content at the same effective stress would be higher for the clay without sand (or with little sand). The void ratio versus effective stress data determined from the CF sand-clay mix settling tests (Figure 4-7) displayed greater relative variability than data determined from either the Agrico or USSAC clays. If data exhibiting partical segregation is discarded, the agreement between the effective clay void ratio, $\bar{e}_c$, and the void ratio versus effective stress relationship for clay alone is relatively good at a SCR of about 2:1. At a SCR of 1:1, $\bar{e}_c$ is lower and, hence, $\bar{S}_c$, is higher, than would have been predicted at the same effective stress from the clay without sand relationship. At a SCR of 3:1, the opposite trend is observed.

4.5 Summary and Practical Implications

Settling tests performed on sand-clay mixes on three phosphatic clays indicated a wide range of settling characteristics. The sedimentation behavior of the sand-clay mixes were evaluated to determine the effects of initial clay solids content, sand-clay ratio, and type of sand tailings. The three clays selected for preparing sand-clay mixes, Agrico, CF and USSAC, were representative of relatively poor, good and average settling clays, respectively, and should indicate the effect of sand-clay mix on the range of phosphatic clays likely to occur in Florida. The significant practical findings obtained from the sedimentation behavior of sand-clay mixes are summarized below.

Based on settling tests with an initial height of 24 cm, initial clay solids contents of 8, 12 and 16%, and sand-clay ratios of 1:1, 2:1, and 3:1, the following behavior was found characteristic of sand-clay mixes:

- Clays which settle to a relatively low final clay solids content without sand, also settle to a relatively low final clay solids content with sand. The addition of sand tailings does little to increase the final clay solids content of a relatively poor settling clay relative to that of a relatively good settling clay.

- The final clay solids content at the end of settling increases slightly with increasing sand-clay ratio but if the volume occupied by the sand is accounted for as an equivalent water phase, the effective clay solids content may be adversely affected at high sand-clay ratios.

- The initial clay solids content required to prevent segregation varies significantly for the phosphatic clays. The final settled clay solids content achieved for clay alone from an initial solids content of 3% appears adequate to prevent segregation.

- Variations in mineralogy of sand tailings from 60% quartz and 40% apatite to 85% quartz and 15% apatite were found to have no effect on sand-clay mix sedimentation behavior.

Void ratio versus effective stress compressibility curves were determined for the sand-clay mixes from the final settling test heights and final clay solids contents. Although the void-ratio versus effective stress relationship developed for the clay appears to be also valid for the clay phase of sand-clay mixes, siginificant deviations from this relationship were found for some clays at some sand-clay ratios.

Table 4-1

EFFECT OF SAND-CLAY MIX ON FINAL SETTLED CLAY SOLIDS CONTENT

Sample	SCR	Initial S_{ic} (%)	Initial S_{it} (%)	Final S_{Fc} (%)	Final S_{Ft} (%)	Final $\bar{S}_{Fc}$
Agrico-Saddle Creek	0:1	8.0	8.0	9.0	9.0	9.0
Agrico-Saddle Creek*	1:1	8.0	14.8	10.3	18.7	9.9
Agrico-Saddle Creek*	2:1	8.0	20.7	10.9	26.8	10.1
Agrico-Saddle Creek*	3:1	8.0	25.8	11.6	34.4	10.3
Agrico-Saddle Creek**	1:1	8.0	14.8	10.2	18.4	9.8
Agrico-Saddle Creek**	2:1	8.0	20.7	10.1	25.3	9.4
Agrico-Saddle Creek**	3:1	8.0	25.8	11.3	33.7	10.0
Agrico-Saddle Creek**	2:1	12.0	29.0	12.9	30.7	11.8
CF Mining-Hardee†	0:1	12.0	12.0	19.1	19.1	19.1
CF Mining-Hardee†	1:1	12.0	21.4	18.4	31.0	17.2
CF Mining-Hardee†	2:1	12.0	39.0	19.1	41.4	16.7
CF Mining-Hardee†	3:1	12.0	35.3	19.4	49.1	16.0
CF Mining-Hardee†	0:1	16.0	16.0	21.0	21.0	21.0
CF Mining-Hardee†	1:1	16.0	27.6	24.6	39.4	22.5
CF Mining-Hardee†	2:1	16.0	36.4	22.7	46.9	19.5
CF Mining-Hardee†	3:1	16.0	43.2	24.7	56.7	19.4
CF Mining-Hardee††	1:1	16.0	27.6	25.4	40.6	23.2
CF Mining-Hardee††	2:1	16.0	36.4	27.6	53.3	22.9
CF Mining-Hardee††	3:1	16.0	43.2	26.2	58.6	20.3
USSAC-Rockland	0:1	8.0	8.0	11.0	11.0	11.0
USSAC-Rockland	1:1	8.0	14.8	12.4	22.0	11.9
USSAC-Rockland	2:1	8.0	20.7	13.3	31.5	12.1
USSAC-Rockland	3:1	8.0	25.8	13.5	38.4	11.7
USSAC-Rockland	1:1	12.0	21.4	14.4	25.2	13.7
USSAC-Rockland	2:1	12.0	29.0	15.3	35.2	13.7
USSAC-Rockland	3:1	12.0	35.3	15.7	42.8	13.4

*Agrico clay mixed with Agrico sand tailings with $\rho_s = 2.86$.
**Agrico clay mixed with CF sand tailings with $\rho_s = 2.72$.
†CF clay mixed with CF sand tailings with $\rho_s = 2.72$.
††CF clay mixed with CF sand tailings with $\rho_s = 2.69$.
USSAC clay mixed with USSAC sand tailings with $\rho_s = 2.71$.

Where: SCR = Sand-clay ratio; S_t = Total solids content; s_c = Clay phase solids content; $\bar{S}_c$ = Effective clay solids content.

Table 4-2

EFFECT OF INITIAL CLAY SOLIDS CONTENT ON SEGREGATION OF SAND-CLAY MIXES

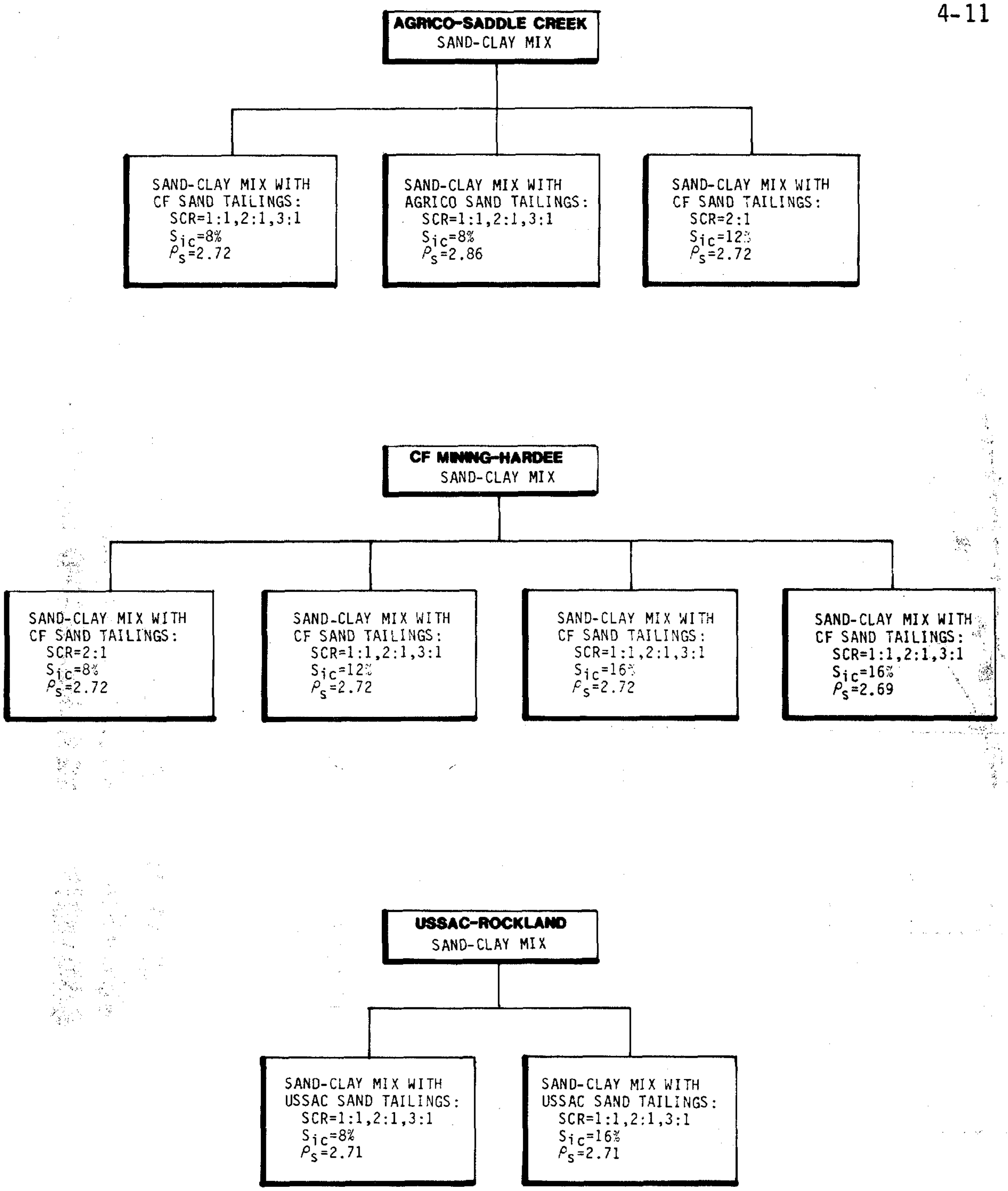
Sample	SCR	S_{ic} (%)	Ideal -74 μm (%)	Top Half -74 μm (%)	Lower Half -74 μm (%)
Agrico-Saddle Creek*	2:1	8.0	33	34	33
Agrico-Saddle Creek**	1:1	8.0	50	51	50
Agrico-Saddle Creek**	2:1	8.0	33	34	34
Agrico-Saddle Creek**	3:1	8.0	25	26	25
Agrico-Saddle Creek*	2:1	12.0	33	34	34
CF Mining-Hardee†	2:1	8.0	33	Segregated	
CF Mining-Hardee†	1:1	12.0	50	57	50
CF Mining-Hardee†	2:1	12.0	33	36	29
CF Mining-Hardee†	3:1	12.0	25	27	23
CF Mining-Hardee†	2:1	16.0	33	33	31
CF Mining-Hardee††	1:1	16.0	50	41	39
CF Mining-Hardee††	2:1	16.0	33	27	27
CF Mining-Hardee††	3:1	16.0	25	22	21
USSAC-Rockland	1:1	8.0	50	52	52
USSAC-Rockland	2:1	8.0	33	35	34
USSAC-Rockland	3:1	8.0	25	27	26
USSAC-Rockland	1:1	12.0	50	50	51
USSAC-Rockland	2:1	12.0	33	33	33
USSAC-Rockland	3:1	12.0	25	26	25

*Agrico clay mixed with CF sand tailings with ρ_s = 2.72.
**Agrico clay mixed with Agrico sand tailings with ρ_s = 2.86.
†CF clay mixed with CF sand tailings with ρ_s = 2.72.
††CF clay mixed with CF sand tailings with ρ_s = 2.69.
USSAC clay mixed with USSAC sand tailings with ρ_s = 2.71.

Table 4-3

INITIAL CLAY SOLIDS CONTENT REQUIRED TO PREVENT SAND-CLAY MIX SEGREGATION

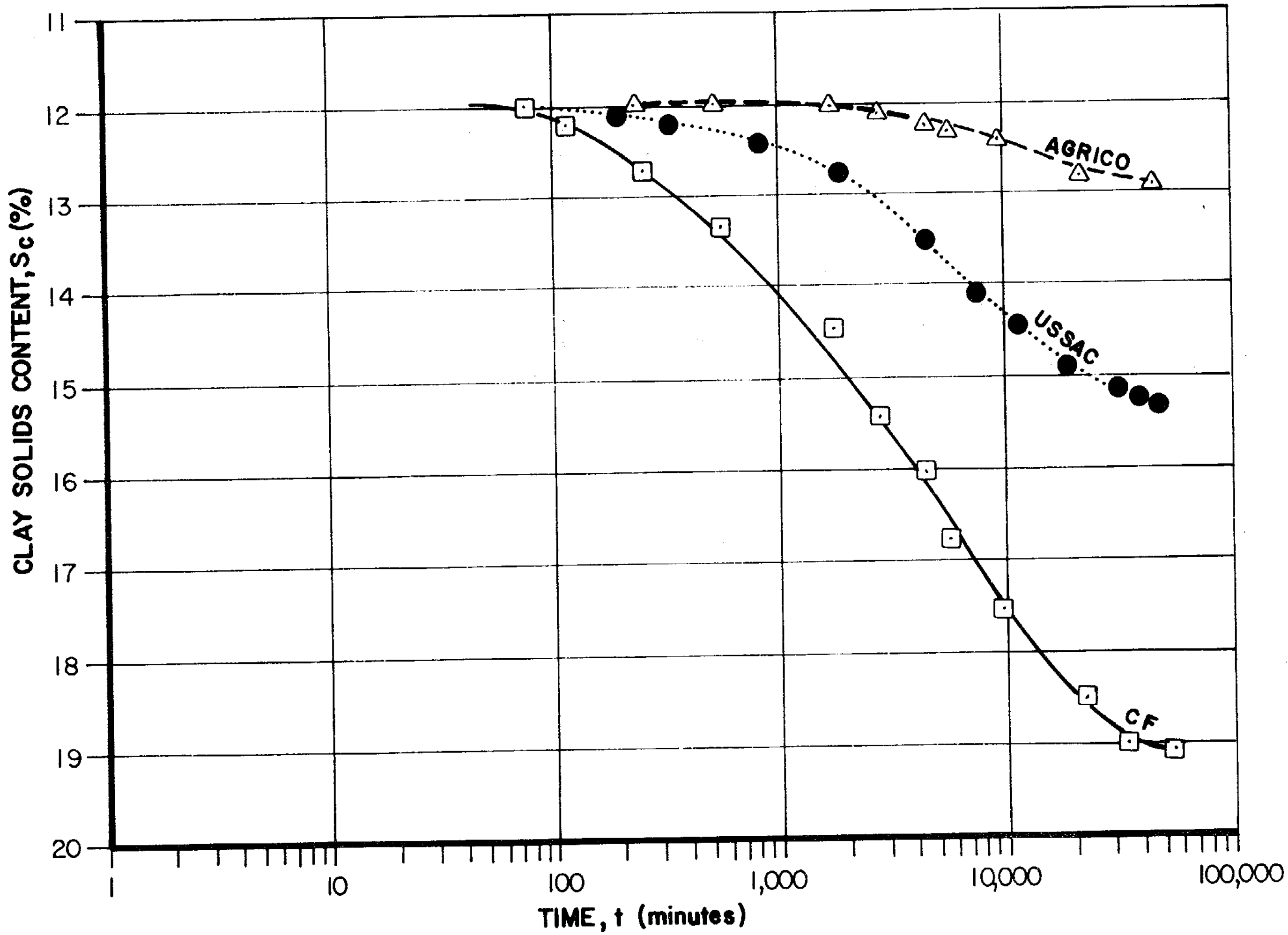
Sample	Clay Settling Tests S_F for S_i = 3% (%)	Sand-Clay Mix Settling Tests S_{ic} (%)	Sand-Clay Mix Settling Tests Degree of Segregation
Agrico-Saddle Creek	5.4	8.0	none
Agrico-Saddle Creek	5.4	12.0	none
CF Mining-Hardee	17.8	8.0	complete
CF Mining-Hardee	17.8	12.0	partial
CF Mining-Hardee	17.8	16.0	none
USSAC-Rockland	8.0	8.0	none
USSAC-Rockland	8.0	12.0	none



NOTATION: SCR=SAND-CLAY RATIO; S_{ic}=INITIAL CLAY SOLIDS CONTENT;
ρ_s=SPECIFIC GRAVITY OF SAND TAILINGS.

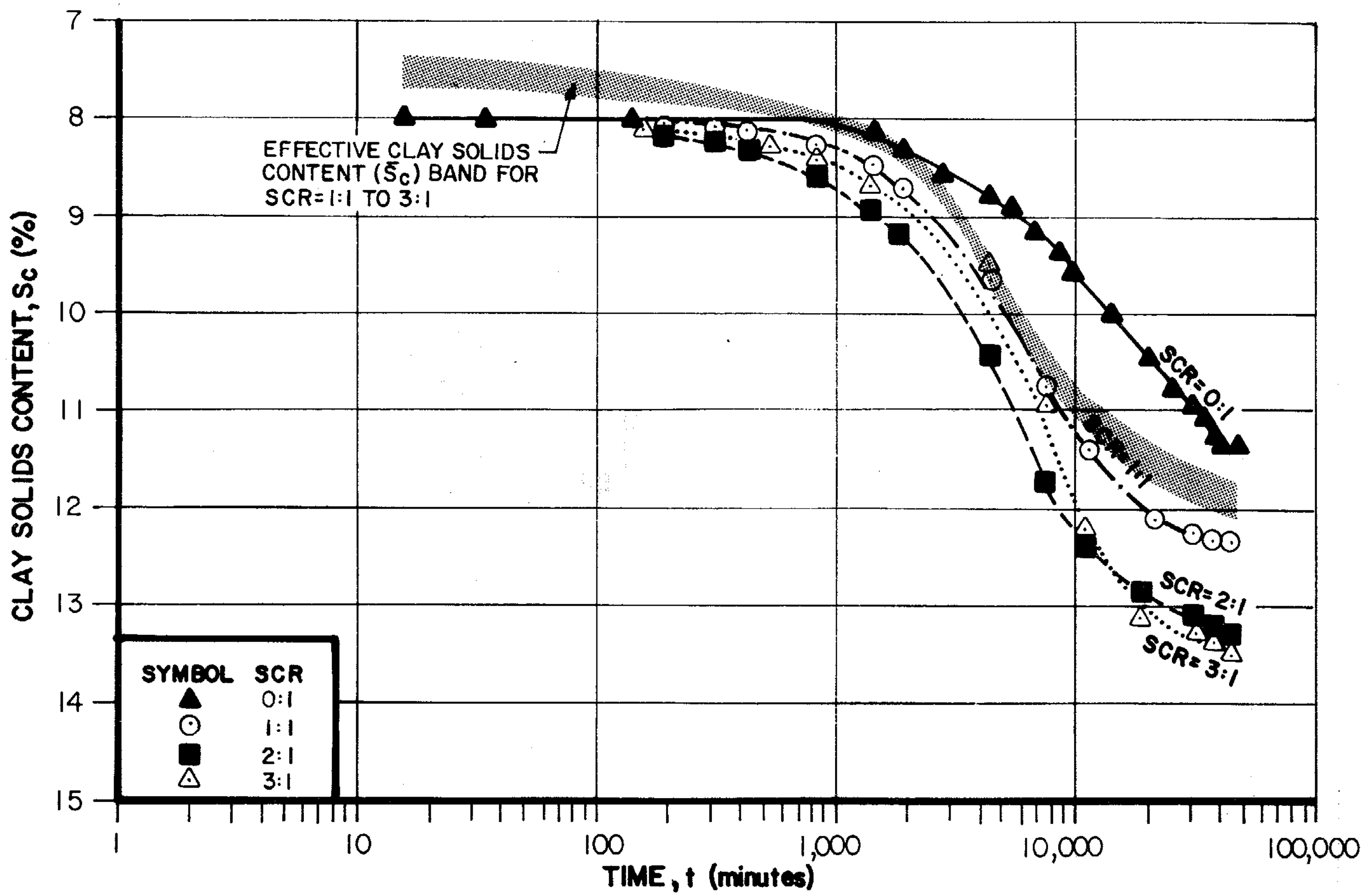
**SUMMARY OF SAND-CLAY MIX
LABORATORY SETTLING TEST PROGRAM**

FIGURE 4-2

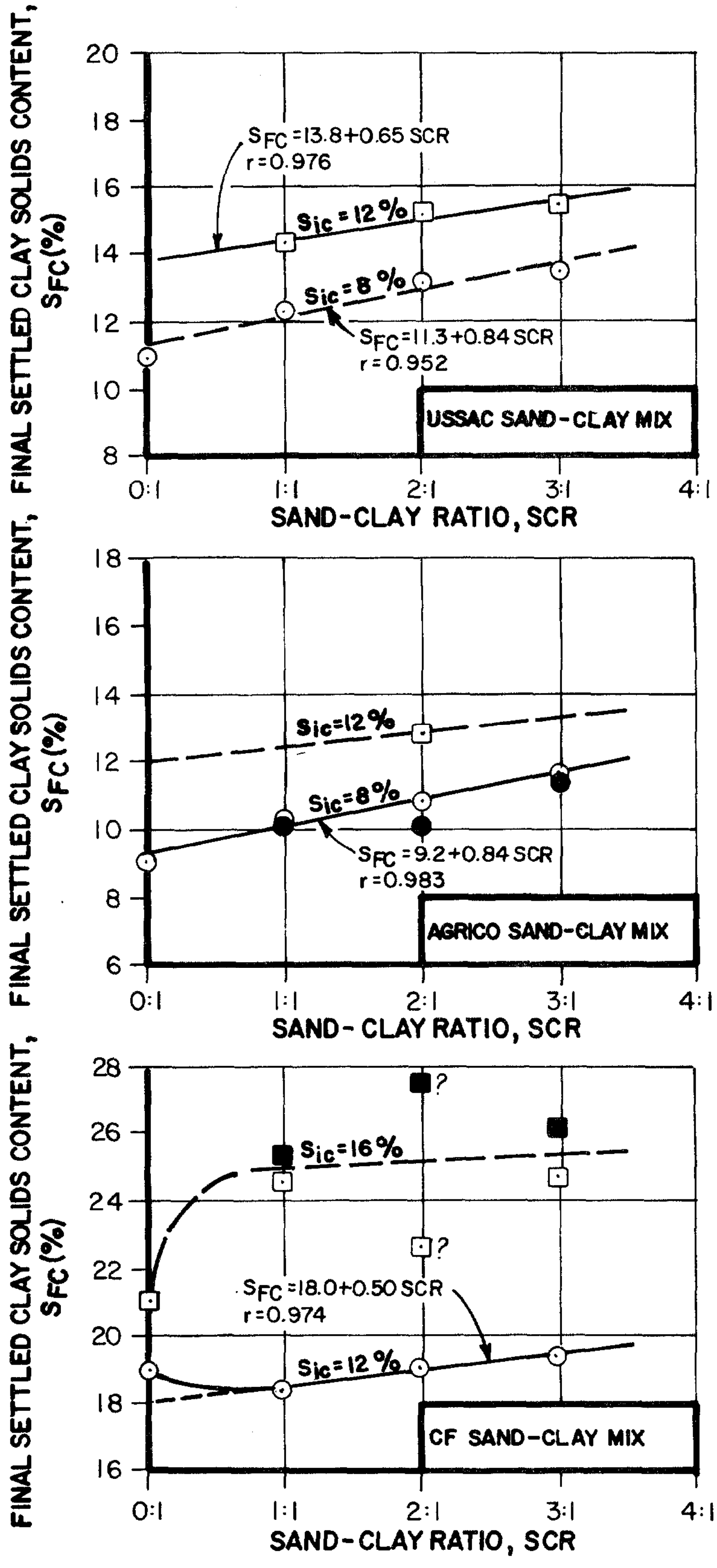


CLAY SOLIDS CONTENT VS. **LOG TIME FOR PHOSPHATIC CLAYS WITH INITIAL CLAY SOLIDS CONTENT OF 12% AND SAND CLAY RATIO OF 2:1**

FIGURE 4-3

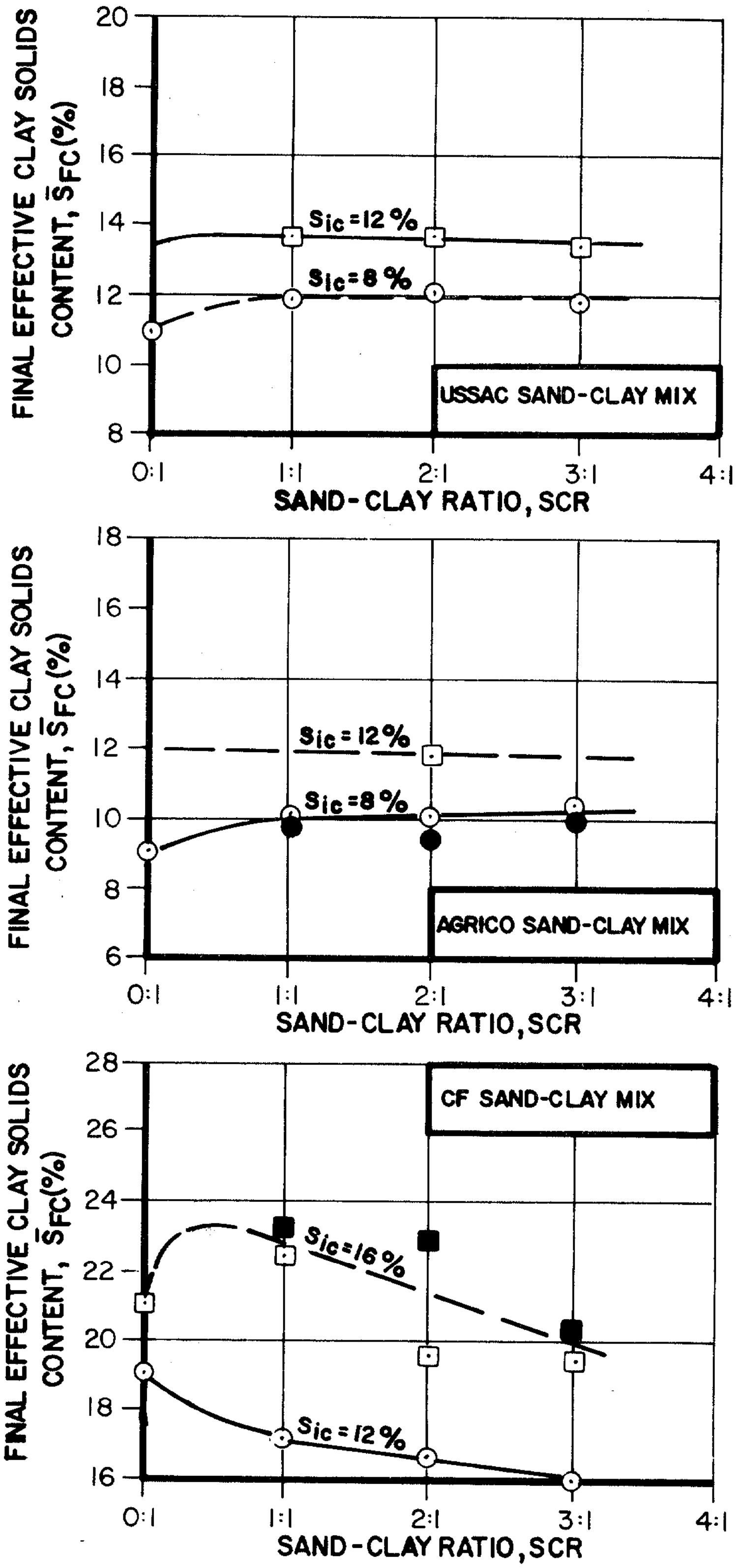


CLAY SOLIDS CONTENT VS. LOG TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%



EFFECT OF SAND-CLAY RATIO ON FINAL SETTLED CLAY SOLIDS CONTENT

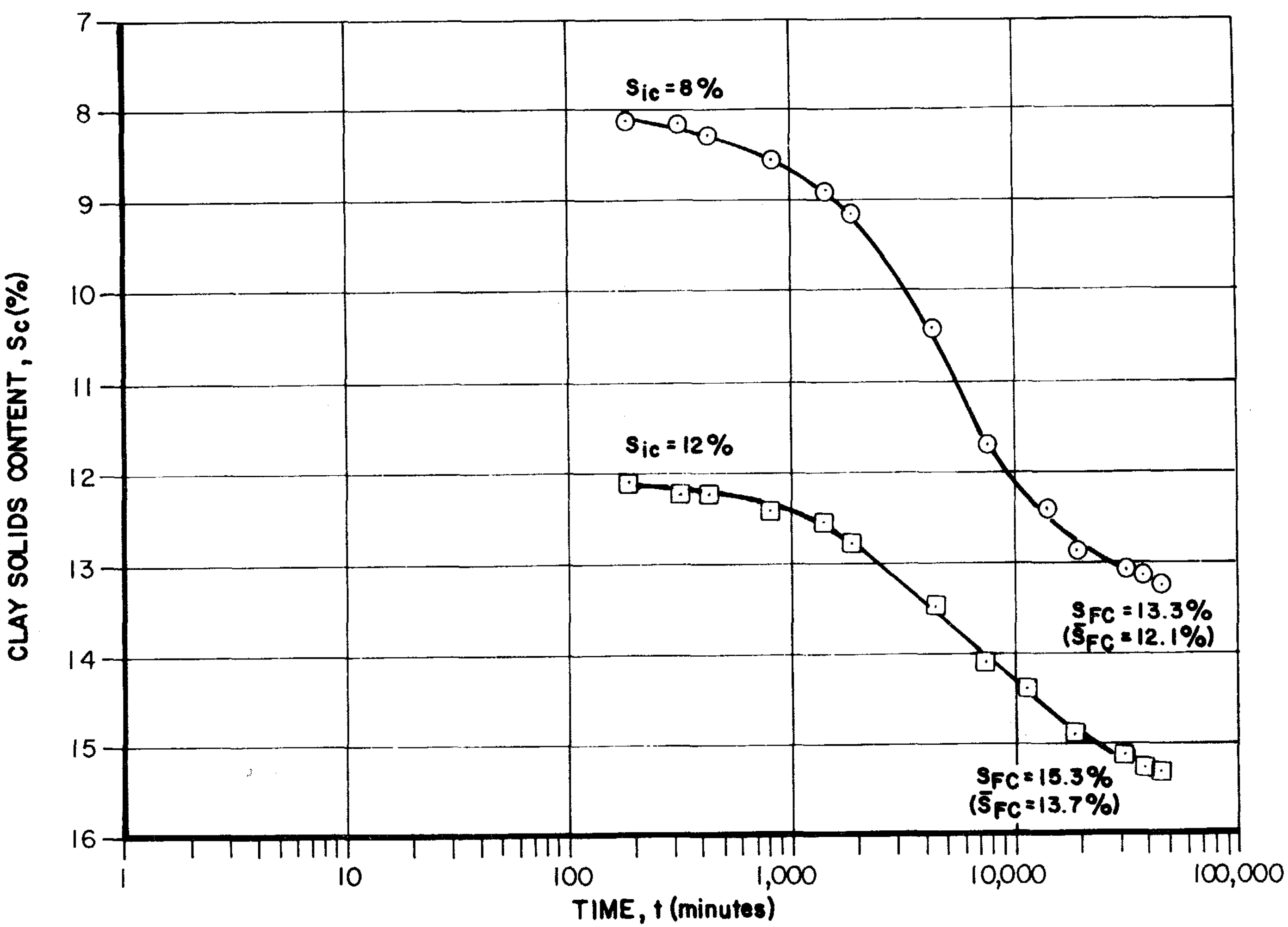
FIGURE 4-4



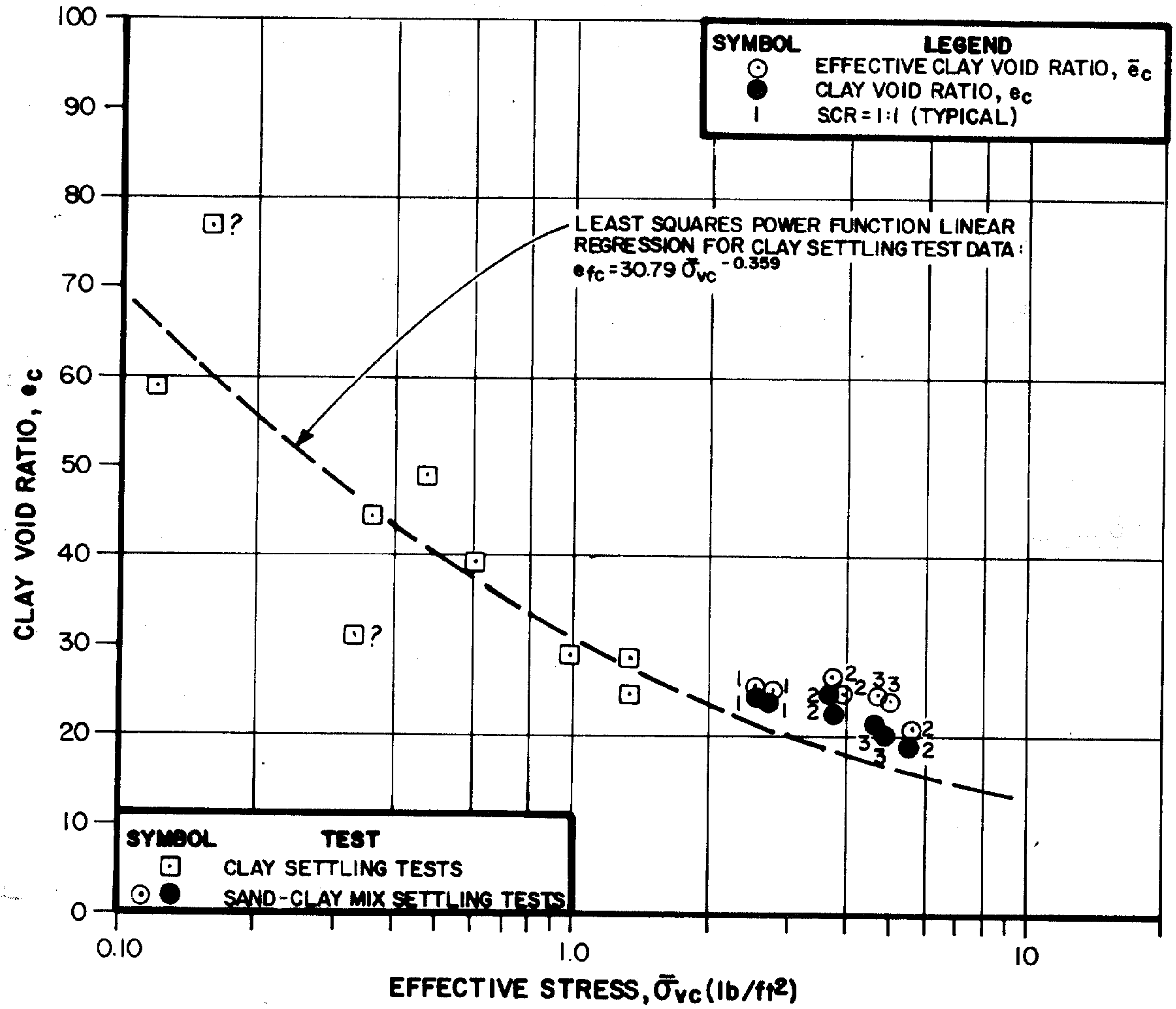
EFFECT OF SAND-CLAY RATIO ON FINAL EFFECTIVE CLAY SOLIDS CONTENT

FIGURE 4-5

FIGURE 4-6

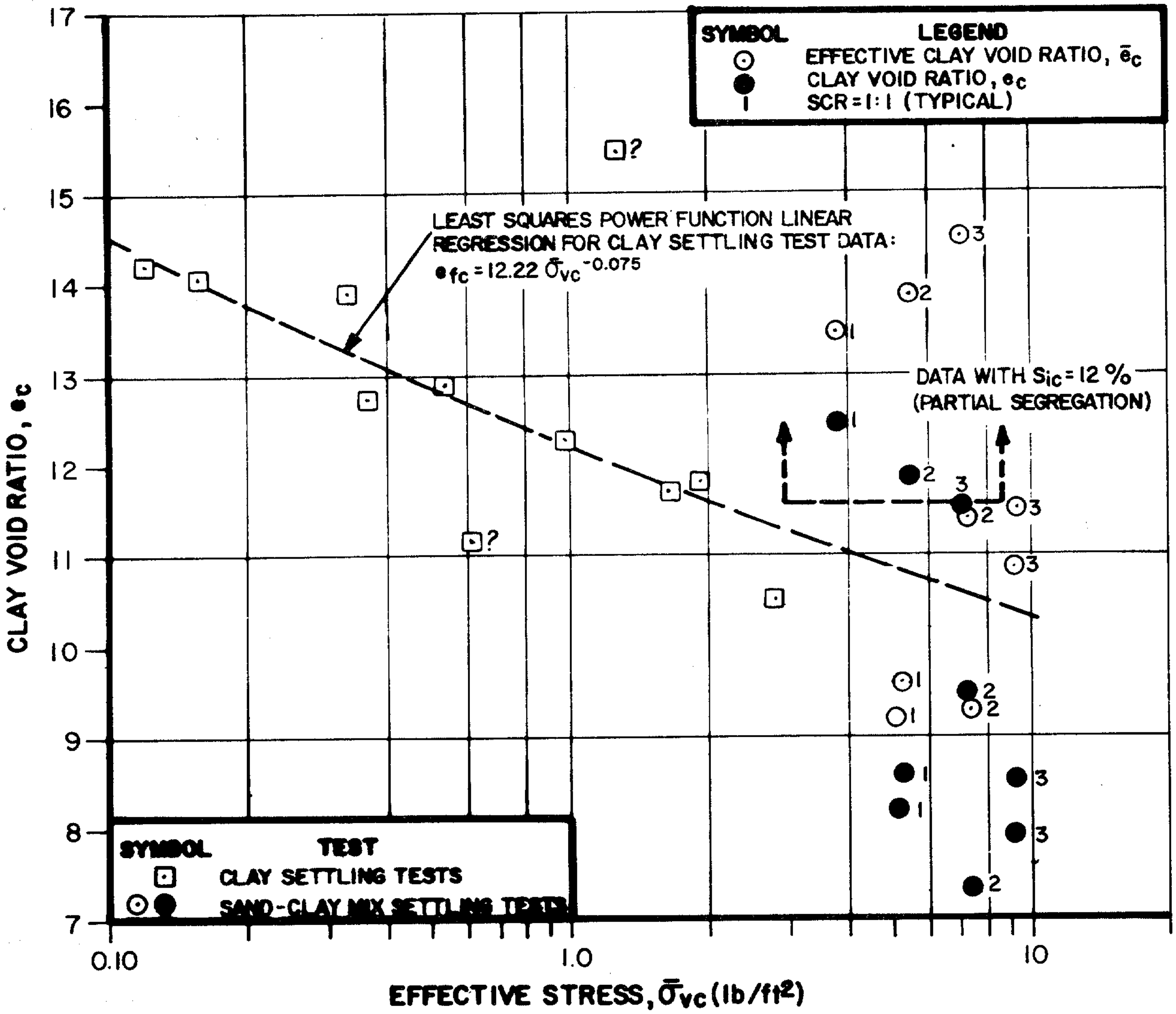


CLAY SOLIDS CONTENT VS. LOG TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH SCR OF 2:1



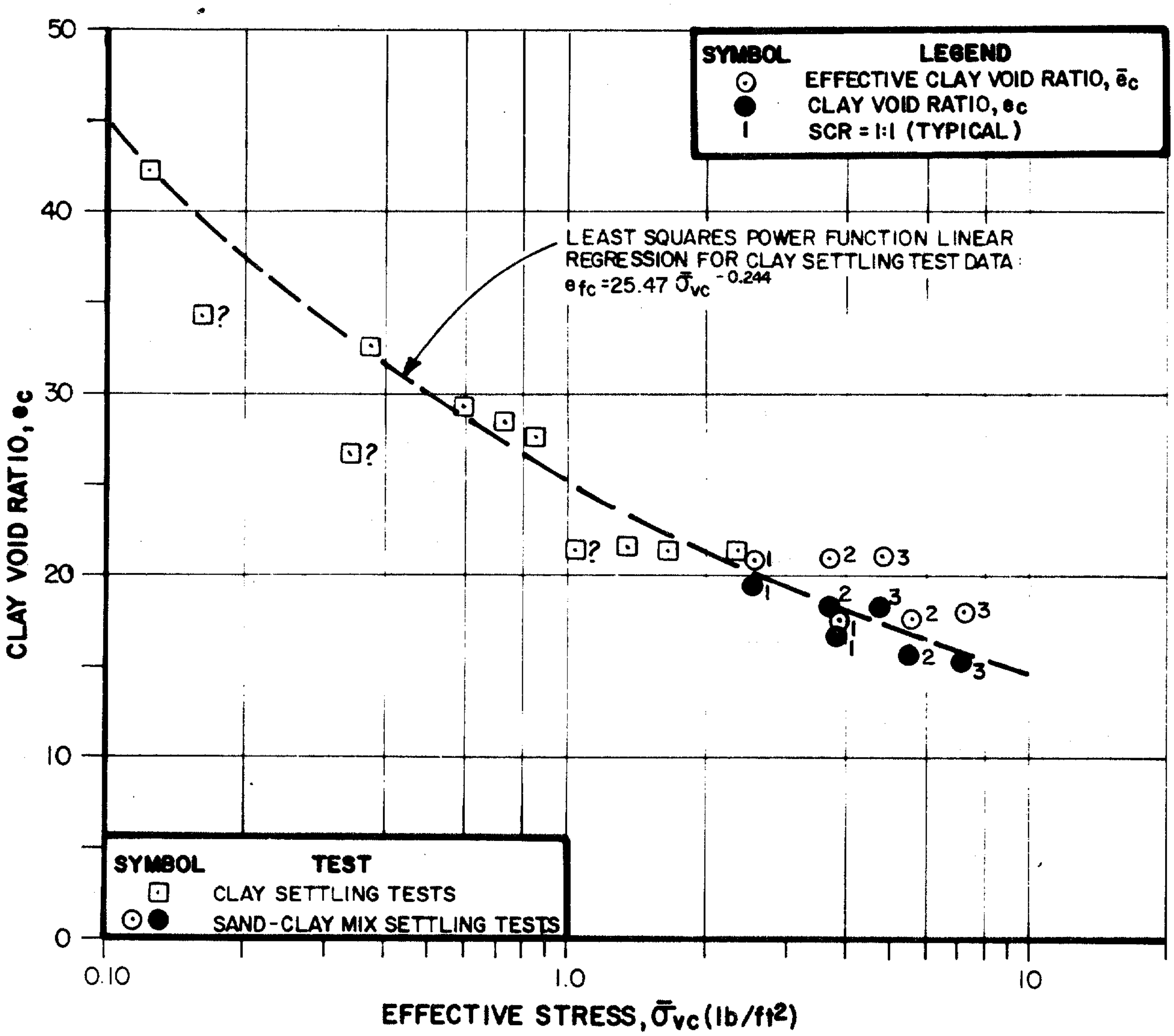
CLAY VOID RATIO VS. EFFECTIVE STRESS FOR
AGRICO-SADDLE CREEK SAND-CLAY MIXES

FIGURE 4-7



CLAY VOID RATIO VS. EFFECTIVE STRESS FOR
OF MINING-HARDEE SAND-CLAY MIXES

FIGURE 4-8



CLAY VOID RATIO VS. EFFECTIVE STRESS FOR USSAC-ROCKLAND SAND-CLAY MIXES

FIGURE 4-9

Section 5

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Appendix A

SUMMARY OF TEST RESULTS FROM CONSTANT AND VARIABLE INITIAL HEIGHT SETTLING TESTS

Table A-1

SETTLING TEST RESULTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	Initial Conditions ϕ_K	Initial Conditions Z_o (cm)	Initial Conditions $Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Final Conditions Z_F (cm)	Settling Rates Q_1 (cm/hour)	Settling Rates Q'_1 (cm/hour)	Settling Rates t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4} cm)
Primary	6.4	0.0240	27.0	0.648	7.5	22.7	0.035	—	3,105	-	-	-	-
Secondary	1.0	0.0036	26.6	0.096	4.3	6.3	52.00	—	26	-	-	-	-
SA-2	1.0	0.0036	24.0	0.087	3.5	6.8	0.708	—	678	-	-	-	-
SA-2	3.0	0.0110	24.0	0.264	5.4	13.2	0.156	0.720	881	9.0	0.313	0.588	26.98
SA-2	3.0	0.0110	18.0	0.198	5.5	9.7	0.360	0.720	139	9.0	0.313	0.588	26.98
SA-2	3.0	0.0110	12.0	0.132	5.1	7.0	0.180	0.720	140	9.0	0.313	0.588	26.98
SA-2	3.0	0.0110	6.0	0.066	4.5	4.0	0.096	0.720	238	9.0	0.313	0.588	26.98
SA-2	8.0	0.0303	24.0	0.728	9.0	21.2	0.031	0.063	2,159	9.7	0.525	0.987	26.98
SA-2	8.0	0.0303	18.0	0.546	9.0	15.9	0.039	0.063	2,357	9.7	0.525	0.987	26.98
SA-2	8.0	0.0303	12.0	0.364	8.5	11.2	0.009	0.063	3,788	9.7	0.525	0.987	26.98
SA-2	8.0	0.0303	6.0	0.182	8.3	5.8	0.004	0.063	2,512	9.7	0.525	0.987	26.98

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_0 = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_f = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-2

SETTLING TEST RESULTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Z_F (cm)	Settling Rates Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4}cm)
SA BF-1	1.0	0.0037	24.0	0.088	17.8	1.2	-	-	-	-	-	-	-
SA BF-1	3.0	0.0111	24.0	0.267	16.4	4.0	5.60	6.15	46	2.4	0.108	0.420	66.82
SA BF-1	3.0	0.0111	18.0	0.200	15.1	3.2	4.91	6.15	67	2.4	0.108	0.420	66.82
SA BF-1	3.0	0.0111	12.0	0.134	16.4	2.0	5.40	6.15	49	2.4	0.108	0.420	66.82
SA BF-1	3.0	0.0111	6.0	0.066	18.0	0.9	3.60	6.15	35	2.4	0.108	0.420	66.82
SA BF-1	8.0	0.0307	24.0	0.736	19.7	9.0	2.65	2.74	171	2.1	0.229	0.907	66.82
SA BF-1	8.0	0.0307	18.0	0.552	18.8	7.1	2.25	2.74	113	2.1	0.229	0.907	66.82
SA BF-1	8.0	0.0307	12.0	0.368	18.6	4.8	3.50	2.74	68	2.1	0.229	0.907	66.82
SA BF-1	8.0	0.0307	6.0	0.184	18.9	2.4	1.80	2.74	26	2.1	0.229	0.907	66.82

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-3

SETTLING TEST RESULTS FOR
BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Z_F (cm)	Settling Rates Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4} cm)
Pilot Plant	1.0	0.0036	24.0	0.088	8.6	2.7	8.00	-	40	-	-	-	-
Pilot Plant	3.0	0.0111	24.0	0.266	10.5	6.6	3.86	-	169	-	-	-	-
Pilot Plant	8.0	0.0305	24.0	0.733	12.8	14.6	0.054	-	1,267	-	-	-	-
Pilot Plant	3.0	0.0111	24.0	0.266	10.1	6.8	4.75	5.80	153	5.9	0.162	0.461	67.13
Pilot Plant	3.0	0.0111	18.0	0.200	10.0	5.2	2.21	5.80	141	5.9	0.162	0.461	67.13
Pilot Plant	3.0	0.0111	12.0	0.133	9.5	3.6	3.15	5.80	153	5.9	0.162	0.461	67.13
Pilot Plant	3.0	0.0111	6.0	0.067	8.7	2.0	0.264	5.80	100	5.9	0.162	0.461	67.13
Pilot Plant	8.0	0.0305	24.0	0.733	13.2	14.1	0.084	0.120	776	7.2	0.350	0.996	67.13
Pilot Plant	8.0	0.0305	18.0	0.550	12.5	11.2	0.072	0.120	630	7.2	0.350	0.996	67.13
Pilot Plant	8.0	0.0305	12.0	0.367	12.2	7.6	0.048	0.120	243	7.2	0.350	0.996	67.13
Pilot Plant	8.0	0.0305	6.0	0.183	11.2	4.2	0.048	0.120	148	7.2	0.350	0.996	67.13

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_K$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-4

SETTLING TEST RESULTS FOR BREWSTER-HAYNSWORTH PHOSPHATIC CLAY

	Initial Conditions				Final Condition		Settling Rates	
Sample	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	t_1 (minutes)
Primary	4.3	0.0155	26.2	0.405	9.7	11.2	1.80	15
SA-L	1.0	0.0035	24.0	0.084	7.4	3.1	8.25	47
SA-L	3.0	0.0107	24.0	0.257	8.9	7.8	0.234	880
SA-L	8.0	0.0295	24.0	0.708	11.2	16.8	0.056	1,414

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids;S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate.

Table A-5

SETTLING TEST RESULTS FOR
CF MINING–HARDEE PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Z_F (cm)	Settling Rate Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4} cm)
Primary	2.8	0.0102	26.5	0.271	12.6	5.4	8.22	-	71	-	-	-	-
Secondary	0.8	0.0029	26.7	0.077	13.6	1.5	150.0	-	6	-	-	-	-
SA-N1	1.0	0.0036	24.0	0.087	17.2	1.3	52.50	-	5	-	-	-	-
SA-N1	3.0	0.0110	24.0	0.263	17.8	3.7	8.44	10.42	48	4.3	0.092	0.332	80.56
SA-N1	3.0	0.0110	18.0	0.197	18.0	2.7	8.10	10.42	25	4.3	0.092	0.332	80.56
SA-N1	3.0	0.0110	12.0	0.132	17.2	1.9	6.63	10.42	24	4.3	0.092	0.332	80.56
SA-N1	3.0	0.0110	6.0	0.066	16.4	1.0	5.55	10.42	22	4.3	0.092	0.332	80.56
SA-N1	8.0	0.0302	24.0	0.726	16.2	11.2	3.34	4.15	23	17.1	0.250	0.903	80.56
SA-N1	8.0	0.0302	24.0	0.726	17.8	10.0	1.20	4.15	39	17.1	0.250	0.903	80.56
SA-N1	8.0	0.0302	18.0	0.544	18.1	7.4	0.216	4.15	69	17.1	0.250	0.903	80.56
SA-N1	8.0	0.0302	12.0	0.363	17.6	5.1	0.144	4.15	243	17.1	0.250	0.903	80.56
SA-N1	8.0	0.0302	6.0	0.181	16.7	2.7	0.174	4.15	71	17.1	0.250	0.903	80.56
SA-N1	8.0	0.0302	6.0	0.181	16.2	2.8	0.114	4.15	267	17.1	0.250	0.903	80.56
SA-N1	12.0	0.0463	23.6	1.093	19.1	13.9	0.100	-	165	-	-	-	-
SA-N1	16.0	0.0635	24.0	1.524	21.0	17.4	0.050	-	160	-	-	-	-

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-6

SETTLING TEST RESULTS FOR ESTECH-WATSON PHOSPHATIC CLAY

	Initial Conditions				Final Conditions		Settling Rates						
Sample	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4} cm)
Primary	5.5	0.0198	24.0	0.475	12.6	9.8	0.60	-	39	-	-	-	-
Secondary	0.8	0.0028	24.0	0.067	14.6	1.2	75.00	-	5	-	-	-	-
SA-13	1.0	0.0035	24.0	0.084	11.7	1.9	53.00	-	10	-	-	-	-
SA-13	8.0	0.0293	24.0	0.703	14.0	13.2	0.144	-	247	-	-	-	-
SA-13	3.0	0.0106	24.0	0.255	11.6	5.9	1.50	3.67	29	14.2	0.150	-	-
SA-13	3.0	0.0106	18.0	0.191	12.0	4.3	0.774	3.67	203	14.2	0.150	-	-
SA-13	3.0	0.0106	12.0	0.128	11.3	3.0	0.600	3.67	68	14.2	0.150	-	-
SA-13	3.0	0.0106	6.0	0.064	11.7	1.5	0.498	3.67	68	14.2	0.150	-	-

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-7

SETTLING TEST RESULTS FOR
HOPEWELL-HILLSBOROUGH PILOT PLANT NH-116 PHOSPHATIC CLAY

	Initial Conditions				Final Conditions		Settling Rates	
Sample	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	t_1 (minutes)
Pilot Plant	1.0	0.0035	24.0	0.085	6.4	3.7	15.00	10
Pilot Plant	3.0	0.0108	24.0	0.258	8.7	7.0	2.40	306
Pilot Plant	8.0	0.0297	24.0	0.713	11.7	16.0	0.060	600

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximumfield settling rate; t_1 = Laboratory time of maximum settling rate.

Table A-8

SETTLING TEST RESULTS FOR IMC-NORALYN PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Z_F (cm)	Settling Rates Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4}cm)
Primary	6.0	0.0221	26.8	0.593	8.2	19.3	0.057	-	105	-	-	-	-
Secondary	0.5	0.0018	26.5	0.048	11.0	1.0	66.90	-	10	-	-	-	-
SA N-14	1.0	0.0036	24.0	0.086	10.5	2.2	21.75	-	11	-	-	-	-
SA N-14	3.0	0.0108	24.0	0.260	10.2	6.7	0.618	0.938	878	9.2	0.203		
SA N-14	8.0	0.0299	24.0	0.718	11.2	16.8	0.048	-	2,155	-	-	-	-
SA N-14	3.0	0.0108	24.0	0.260	8.6	8.1	0.324	0.938	212	9.2	0.200	0.466	27.06
SA N-14	3.0	0.0108	18.0	0.195	8.4	6.2	0.402	0.938	61	9.2	0.200	0.466	27.06
SA N-14	3.0	0.0108	12.0	0.130	7.8	4.5	0.240	0.938	365	9.2	0.200	0.466	27.06
SA N-14	3.0	0.0108	6.0	0.065	7.9	2.2	0.198	0.938	78	9.2	0.200	0.466	27.06
SA N-14	8.0	0.0299	24.0	0.718	11.1	17.0	0.156	0.247	542	7.6	0.413	0.949	27.06
SA N-14	8.0	0.0299	18.0	0.538	11.2	12.6	0.162	0.247	620	7.6	0.413	0.949	27.06
SA N-14	8.0	0.0299	12.0	0.359	10.4	9.0	0.084	0.247	744	7.6	0.413	0.949	27.06
SA N-14	8.0	0.0299	6.0	0.179	9.8	4.8	0.042	0.247	352	7.6	0.413	0.949	27.06

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-9

SETTLING TEST RESULTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY

Sample	Initial Conditions S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	Final Conditions S_F (%)	Z_F (cm)	Settling Rates Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Yield Height Z_{y1} (cm)	Floc Volume Concentration ϕ_F	Aggregate Volume Concentration ϕ_A	Pore Diameter d_p (10^{-4} cm)
Primary	3.7	0.0131	26.7	0.350	10.2	9.3	2.40	-	3	-	-	-	-
SA N-3	1.0	0.0035	24.0	0.084	9.8	2.3	36.00	-	5	-	-	-	-
SA N-3	3.0	0.0106	24.0	0.254	12.3	5.5	4.42	6.71	133	10.7	0.134	0.417	68.64
SA N-3	3.0	0.0106	18.0	0.191	12.1	4.2	1.680	6.71	264	10.7	0.134	0.417	68.64
SA N-3	3.0	0.0106	12.0	0.127	11.3	3.0	1.086	6.71	265	10.7	0.134	0.417	68.64
SA N-3	3.0	0.0106	6.0	0.064	10.7	1.6	0.468	6.71	37	10.7	0.134	0.417	68.64
SA N-3	8.0	0.0292	24.0	0.701	14.0	13.1	0.102	0.444	3153	9.7	0.317	0.985	68.64
SA N-3	8.0	0.0292	18.0	0.526	13.8	10.0	0.204	0.444	84	9.7	0.317	0.985	68.64
SA N-3	8.0	0.0292	12.0	0.350	13.0	7.2	0.084	0.444	690	9.7	0.317	0.985	68.64
SA N-3	8.0	0.0292	6.0	0.175	12.3	3.8	0.084	0.444	690	9.7	0.317	0.985	68.64

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_K$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-10

SETTLING TEST RESULTS FOR
OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY

Sample	Initial Conditions				Final Conditions		Settling Rates			Yield Height	Floc Volume Concentration	Aggregate Volume Concentration	Pore Diameter
	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Z_{y1} (cm)	ϕ_F	ϕ_A	d_p (10^{-4} cm)
SA-8	1.0	0.0036	24.0	0.087	8.3	2.8	19.50	-	18	-	-	-	-
SA-8	3.0	0.0110	24.0	0.264	9.6	7.2	0.330	0.510	130	8.5	0.175	0.377	18.52
SA-8	3.0	0.0110	18.0	0.198	9.6	5.4	0.270	0.510	481	8.5	0.175	0.377	18.52
SA-8	3.0	0.0110	12.0	0.132	8.9	3.9	0.216	0.510	67	8.5	0.175	0.377	18.52
SA-8	3.0	0.0110	6.0	0.066	8.5	2.1	0.174	0.510	68	8.5	0.175	0.377	18.52
SA-8	8.0	0.0303	24.0	0.728	10.8	17.5	0.048	0.120	2,153	14.4	0.439	0.946	18.52
SA-8	8.0	0.0303	18.0	0.546	11.1	12.7	0.024	0.120	895	14.4	0.439	0.946	18.52
SA-8	8.0	0.0303	12.0	0.364	10.6	8.9	0.024	0.120	896	14.4	0.439	0.946	18.52
SA-8	8.0	0.0303	6.0	0.182	10.3	4.6	0.018	0.120	1,618	14.4	0.439	0.946	18.52

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-11

SETTLING TEST RESULTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY

	Initial Conditions				Final Conditions		Settling Rates			Yield Height	Floc Volume Concentration	Aggregate Volume Concentration	Pore Diameter
Sample	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	Q'_1 (cm/hour)	t_1 (minutes)	Z_{y1} (cm)	ϕ_F	ϕ_A	d_p (10^{-4} cm)
Primary	3.5	0.0127	27.7	0.352	7.6	12.4	5.60	-	23	-	-	-	-
Secondary	1.1	0.0039	26.7	0.105	7.9	3.5	12.54	-	34	-	-	-	-
SA-6	1.0	0.0036	24.0	0.086	7.7	3.0	13.50	-	23	-	-	-	-
SA-6	3.0	0.0108	24.0	0.260	9.3	7.5	0.240	-	869	-	-	-	-
SA-6	8.0	0.0299	24.0	0.718	11.4	16.5	0.054	-	1,408	-	-	-	-
SA-6	3.0	0.0108	24.0	0.260	8.0	8.7	0.834	1.18	18	8.8	0.202	0.460	30.17
SA-6	3.0	0.0108	18.0	0.195	7.7	6.8	0.480	1.18	329	8.8	0.202	0.460	30.17
SA-6	3.0	0.0108	12.0	0.130	7.2	4.9	0.360	1.18	329	8.8	0.202	0.460	30.17
SA-6	3.0	0.0108	6.0	0.065	6.3	2.8	0.264	1.18	8.8	0.202	0.460	0.460	30.17
SA-6	8.0	0.0299	24.0	0.718	11.0	17.1	0.174	0.297	1,535	9.8	0.418	0.950	30.17
SA-6	8.0	0.0299	18.0	0.538	10.8	13.1	0.138	0.297	1,535	9.8	0.418	0.950	30.17
SA-6	8.0	0.0299	12.0	0.359	10.4	9.0	0.054	0.297	1,535	9.8	0.418	0.950	30.17
SA-6	8.0	0.0299	6.0	0.180	9.5	5.0	0.030	0.297	518	9.8	0.418	0.950	30.17

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids; Z_o = Initial height; S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1 = Maximum field settling rate; t_1 = Laboratory time of maximum settling rate; Z_{y1} = Yield height for maximum settling rate; ϕ_F = Floc volume concentration; ϕ_a = Aggregate volume concentration; and d_p = Average pore diameter.

Table A-12

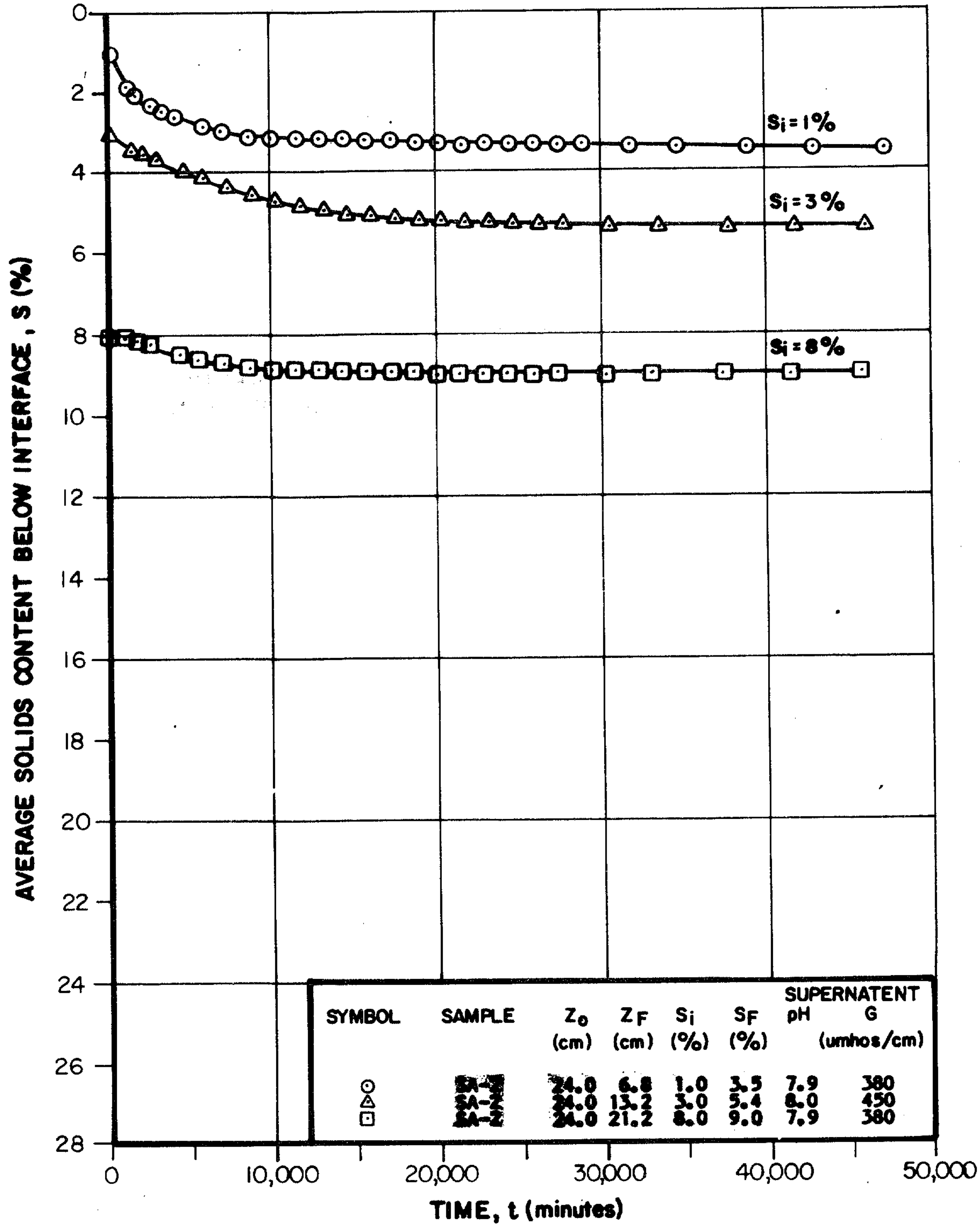
SETTLING TEST RESULTS FOR WR GRACE-FOUR CORNERS PHOSPHATIC CLAY

	Initial Conditions				Final Conditions		Settling Rates	
Sample	S_i (%)	ϕ_K	Z_o (cm)	$Z_o\phi_K$ (cm)	S_F (%)	Z_F (cm)	Q_1 (cm/hour)	t_1 (minutes)
Pilot Plant	1.0	0.0036	24.0	0.087	7.2	3.2	37.80	15
Pilot Plant	3.0	0.0110	24.0	0.246	9.5	7.3	0.918	475
Pilot Plant	8.0	0.0303	24.0	0.728	12.9	14.4	0.234	52

Where: S_i = Initial solids content; ϕ_K = Clay volume concentration; $Z_o\phi_k$ = Height of clay solids;S_F = Final solids content; Z_f = Final height; Q_1 = Maximum laboratory settling rate; Q'_1= Maximumfield settling rate; t_1 = Laboratory time of maximum settling rate.

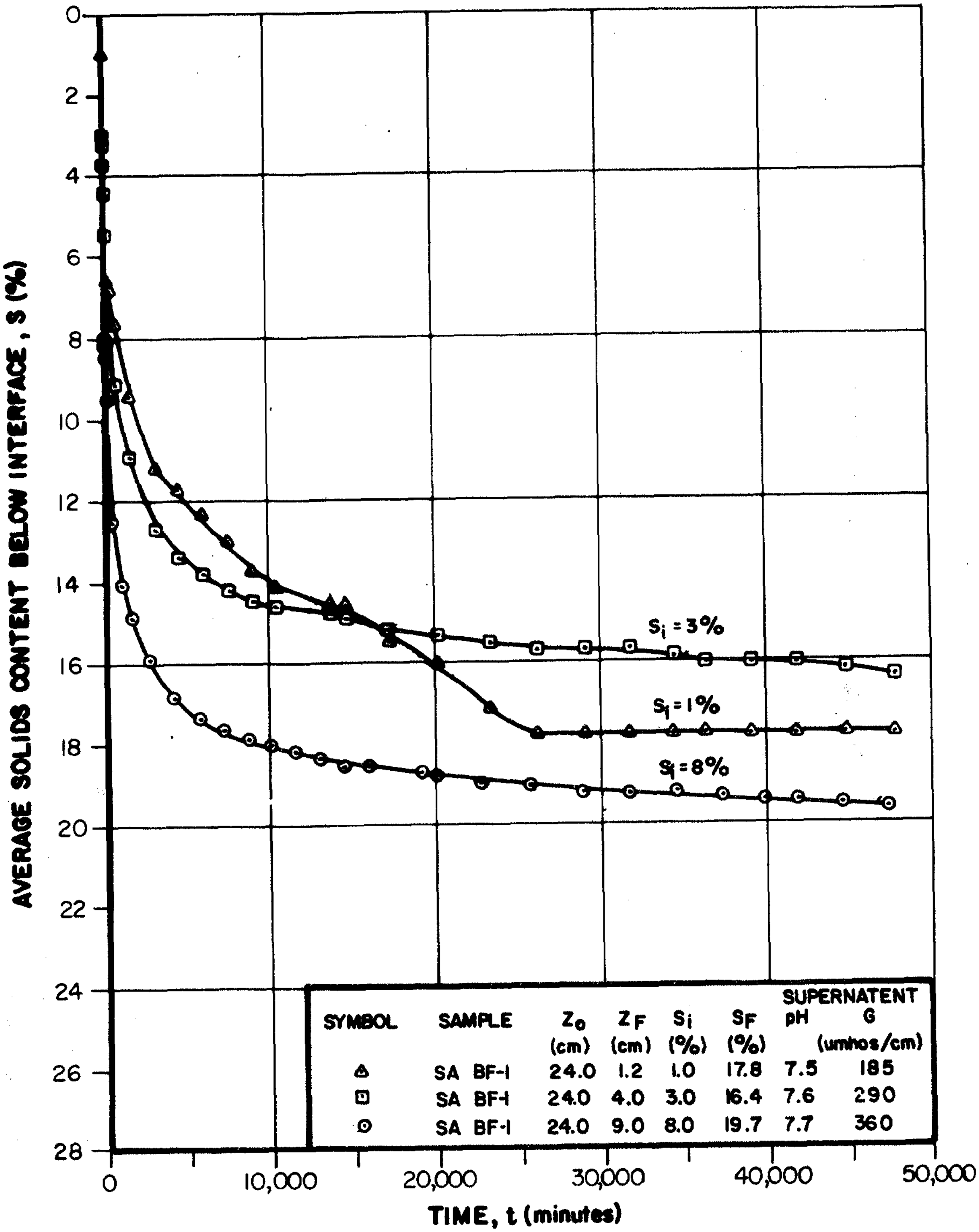
Appendix B

GRAPHICAL PLOTS OF SOLIDS CONTENT AND HEIGHT OF INTERFACE VERSUS TIME FOR CONSTANT INITIAL HEIGHT SETTLING TESTS



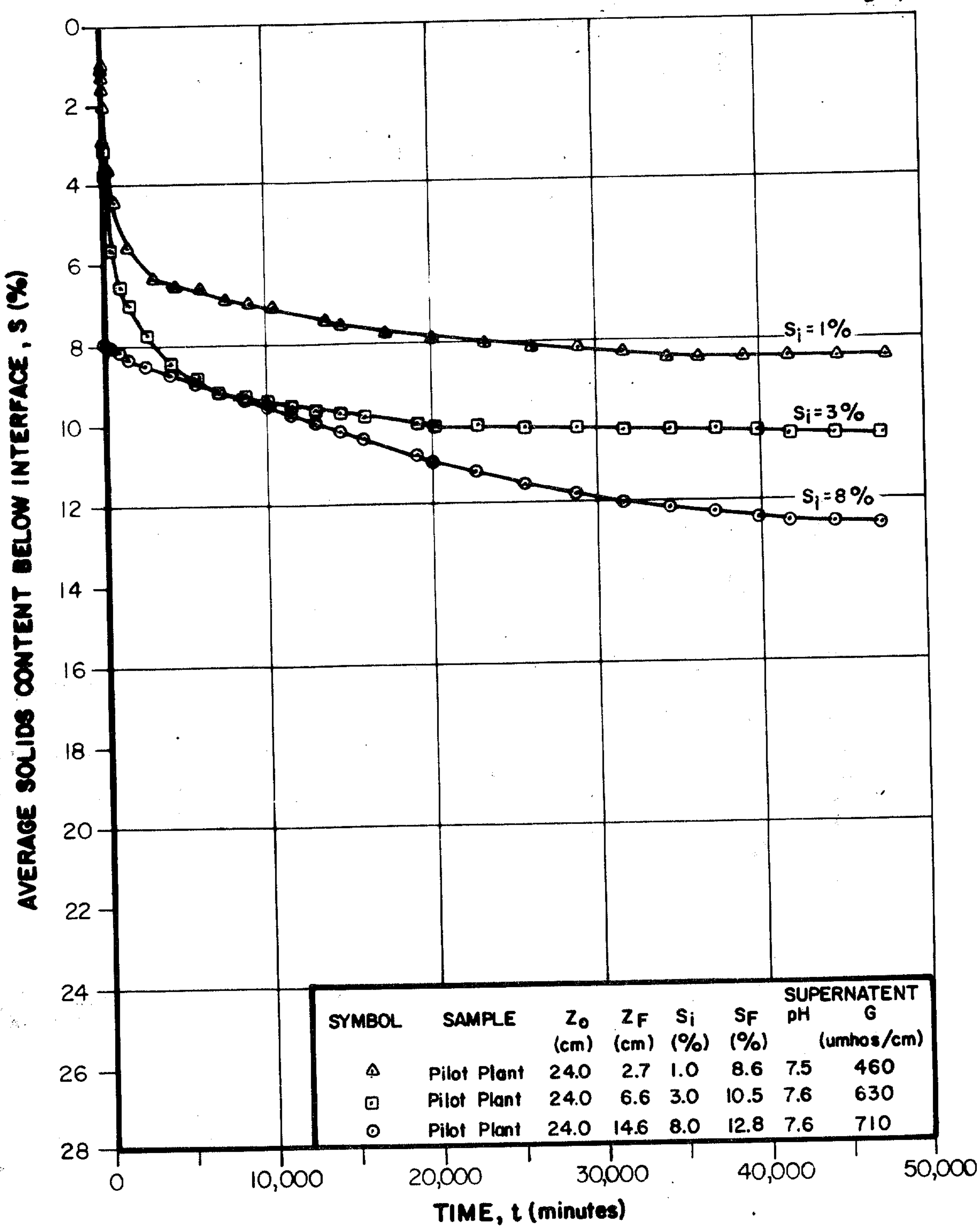
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR AGRICO - SADDLE CREEK PHOSPHATIC CLAY

FIGURE B-1



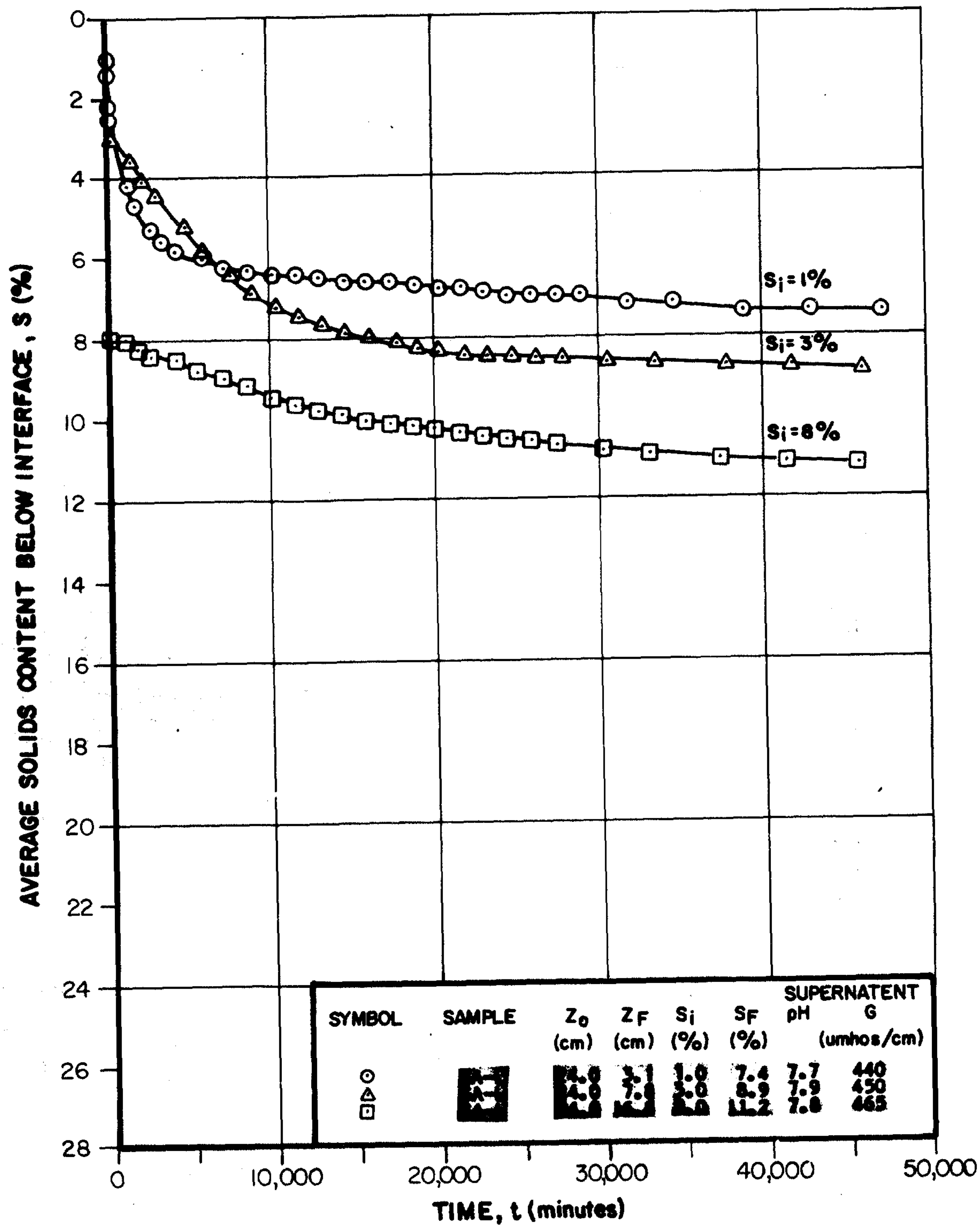
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR AMAX - BIG FOUR PHOSPHATIC CLAY

FIGURE B-2



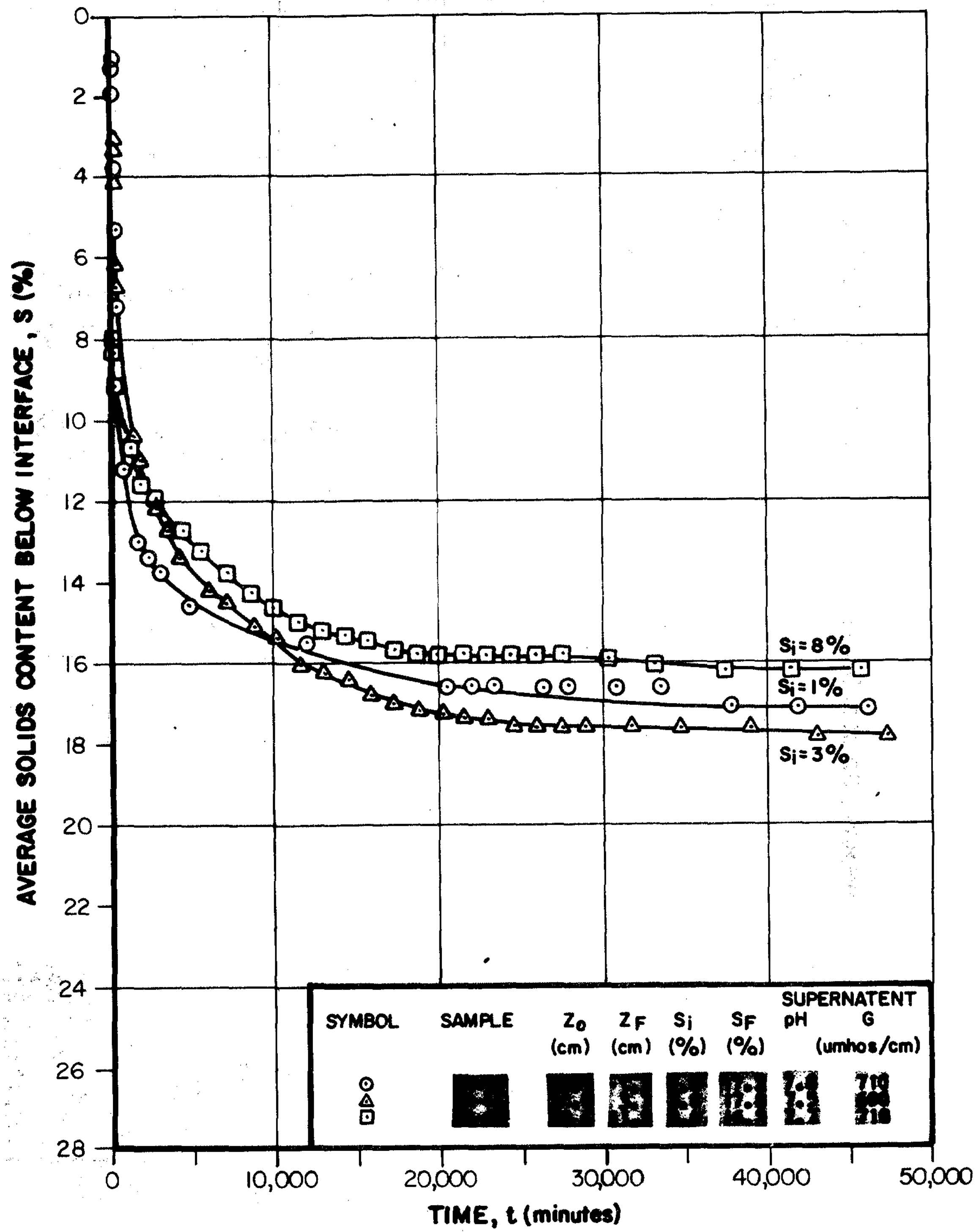
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR BEKER - WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY

FIGURE B-3



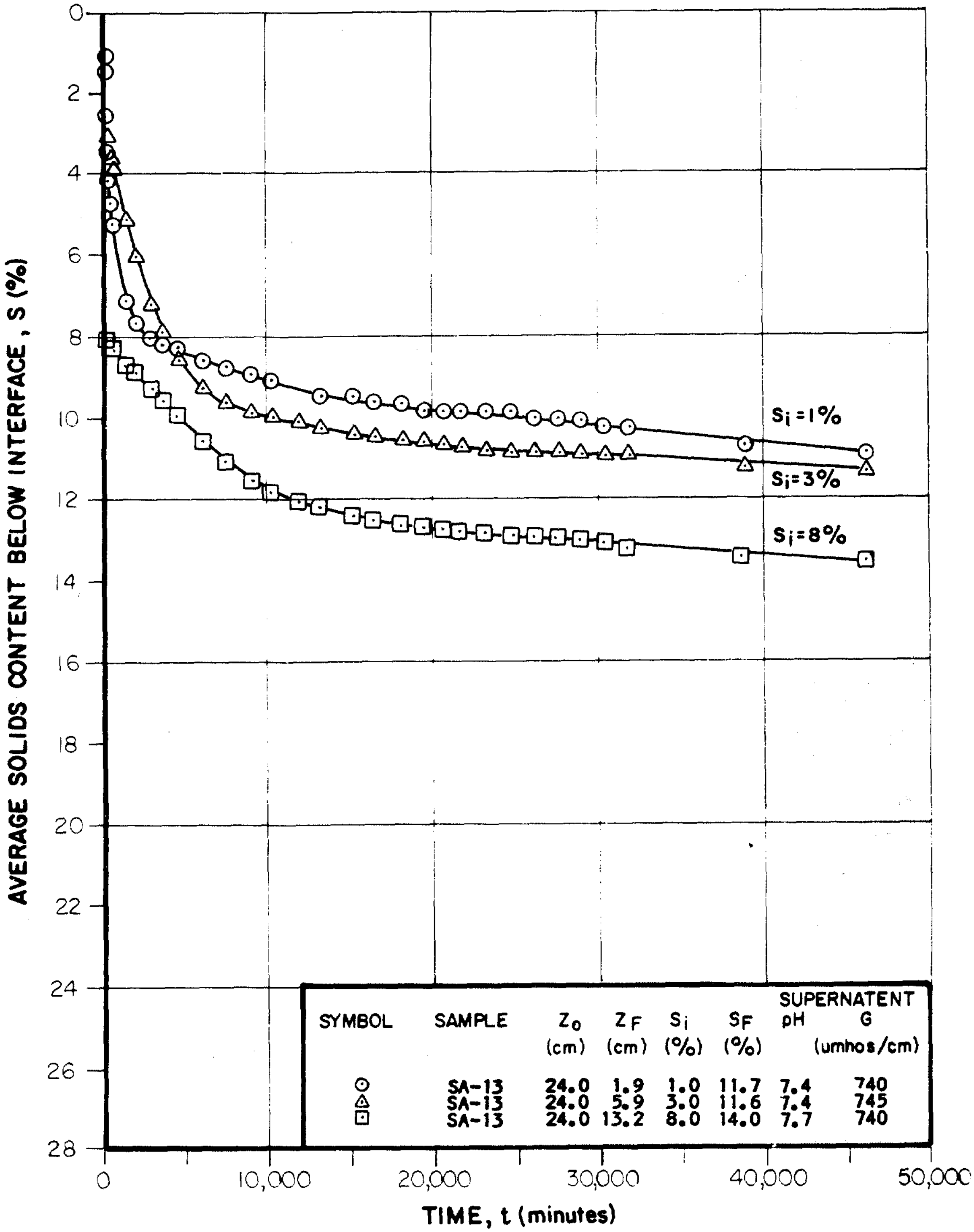
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR BREWSTER - HAYNSWORTH PHOSPHATIC CLAY.

FIGURE B-4



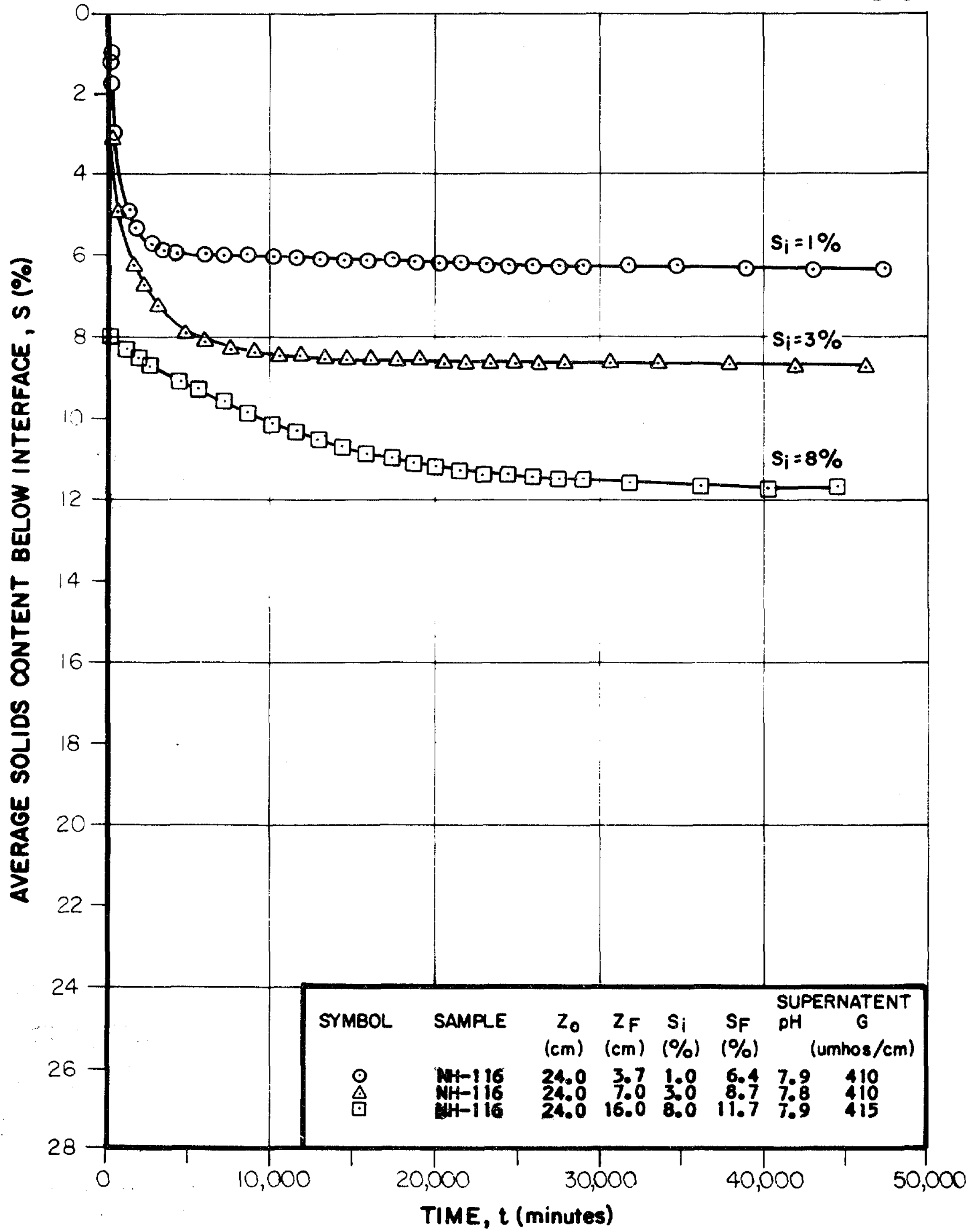
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR CF MINING - HARDEE PHOSPHATIC CLAY

FIGURE B-5



SETTLING TEST - SOLIDS CONTENT VS. TIME FOR ESTECH -- WATSON PHOSPHATIC CLAY

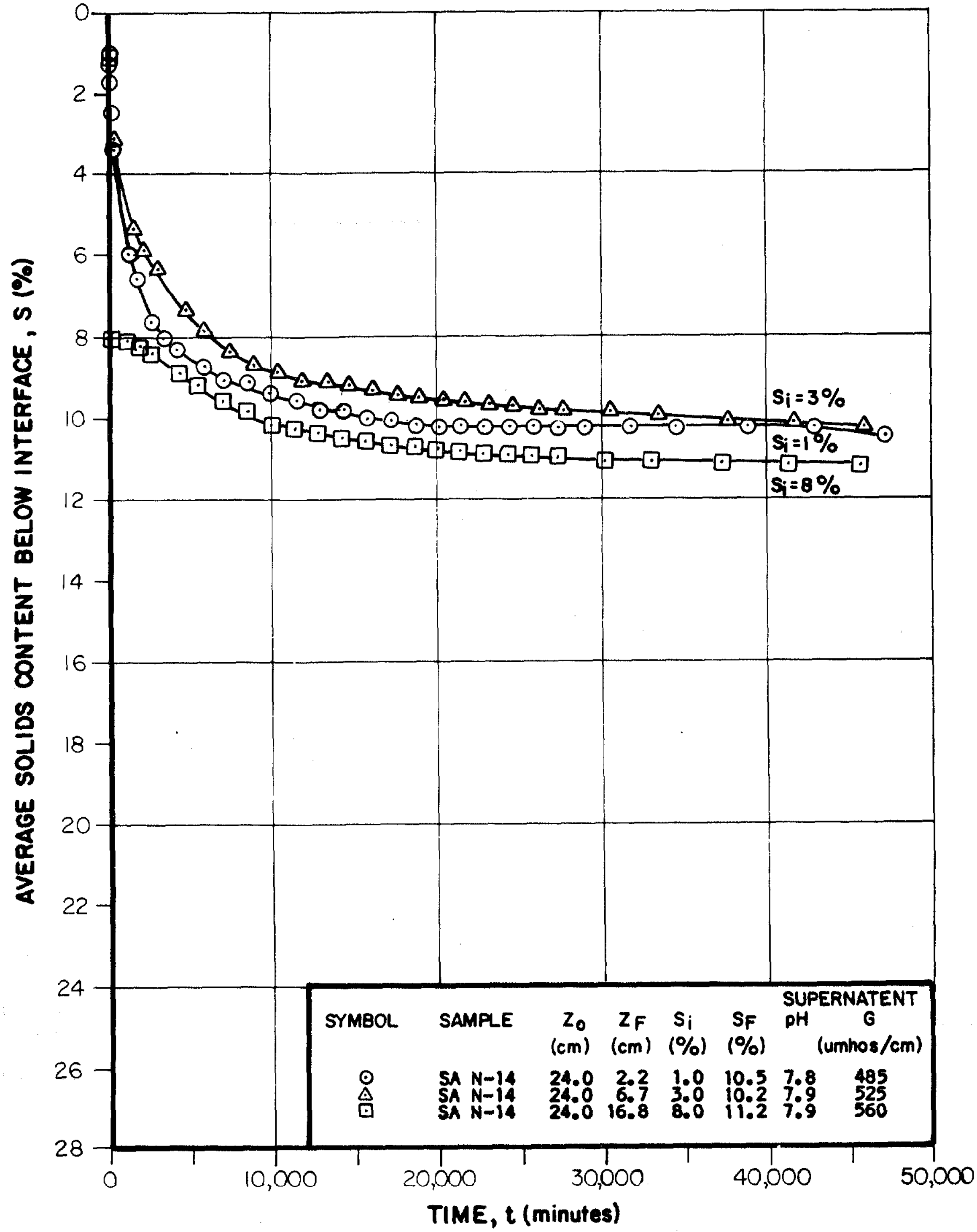
FIGURE B-6



SYMBOL	SAMPLE	Z_0 (cm)	Z_F (cm)	S_i (%)	S_F (%)	SUPERNATENT pH	SUPERNATENT G (umhos/cm)
⊙	NH-116	24.0	3.7	1.0	6.4	7.9	410
△	NH-116	24.0	7.0	3.0	8.7	7.8	410
⊡	NH-116	24.0	16.0	8.0	11.7	7.9	415

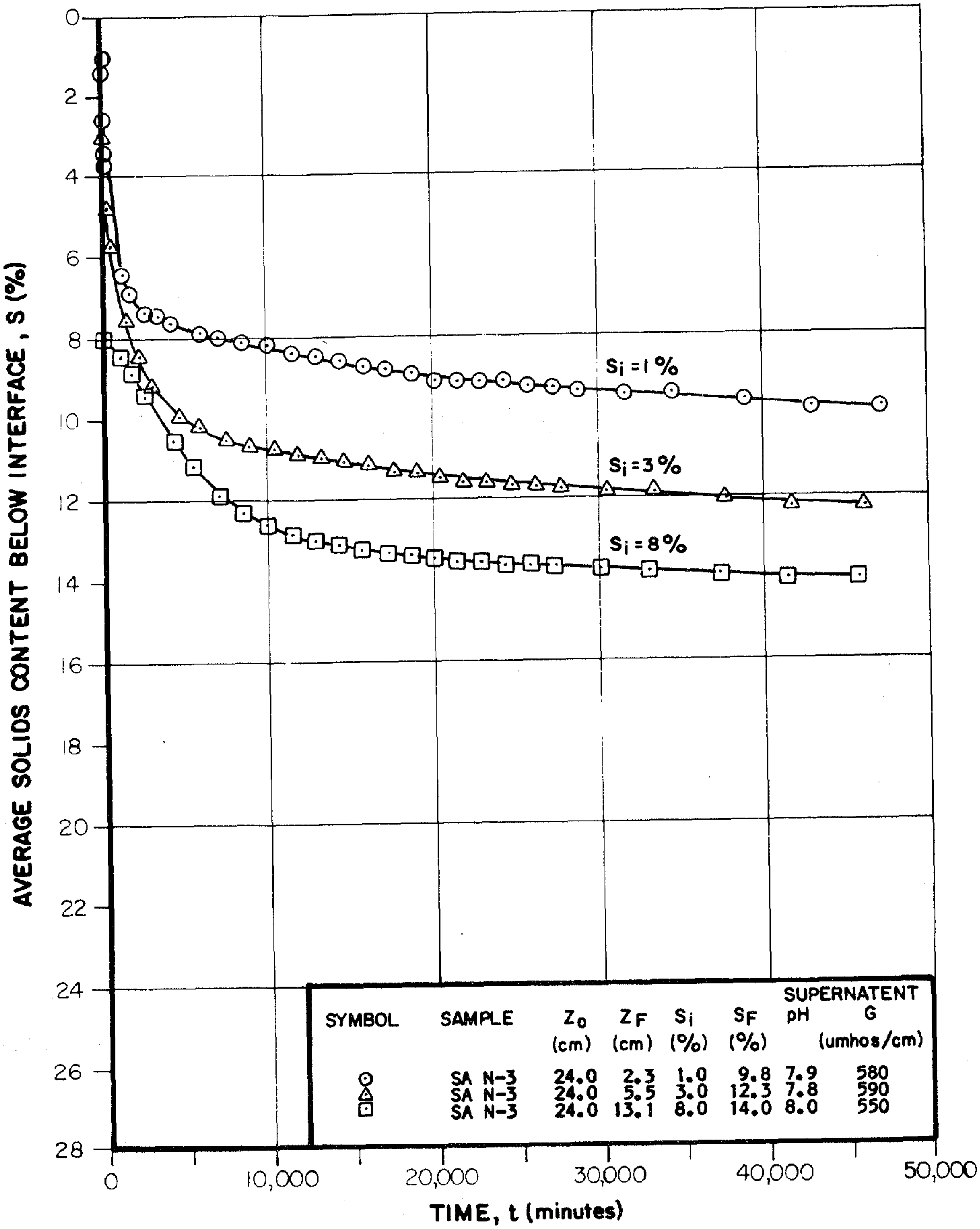
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR HOPEWELL - HILLSBOROUGH PILOT PLANT NH - 116 PHOSPHATIC CLAY

FIGURE B-7



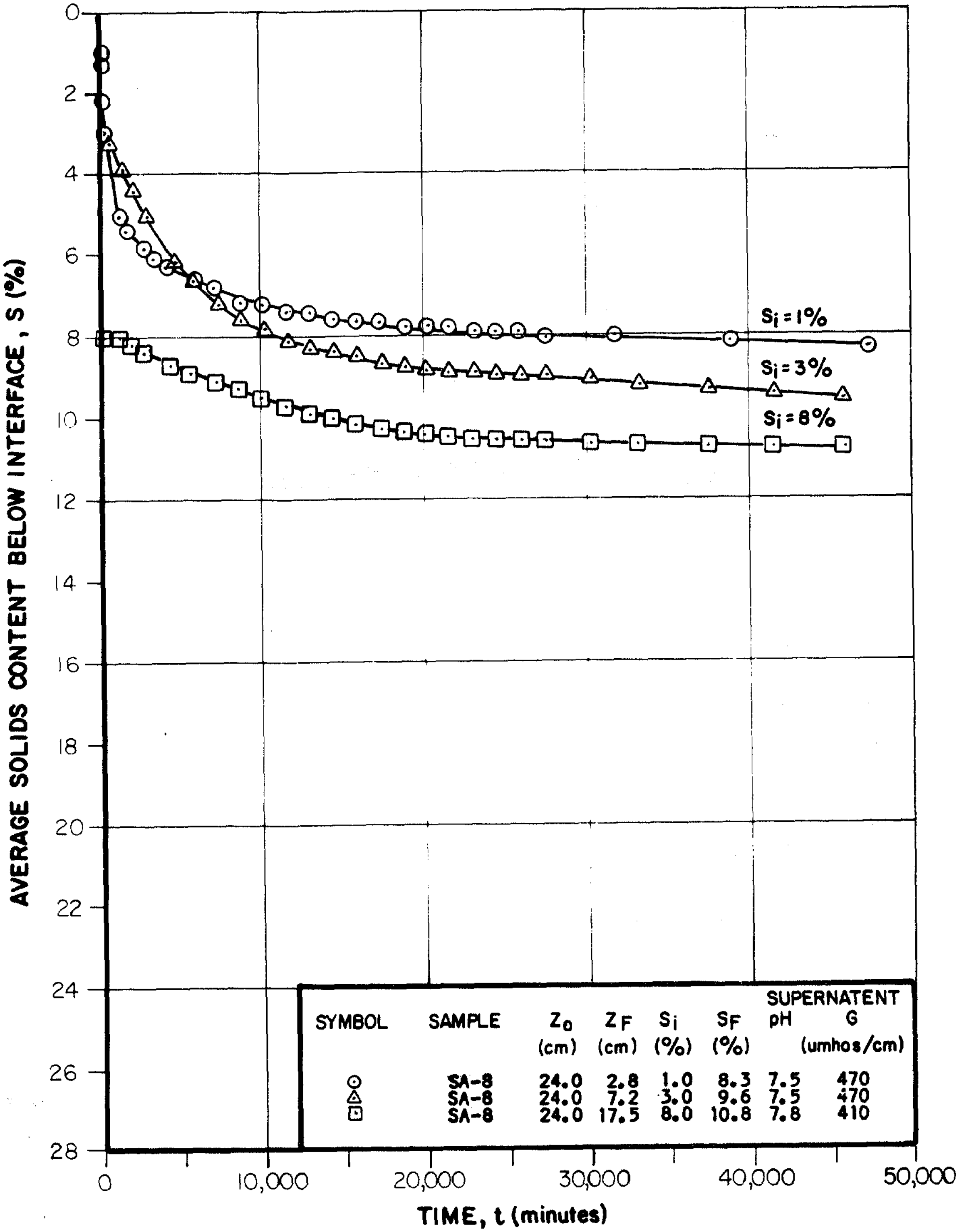
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR IMC - NORALYN PHOSPHATIC CLAY

FIGURE B-8



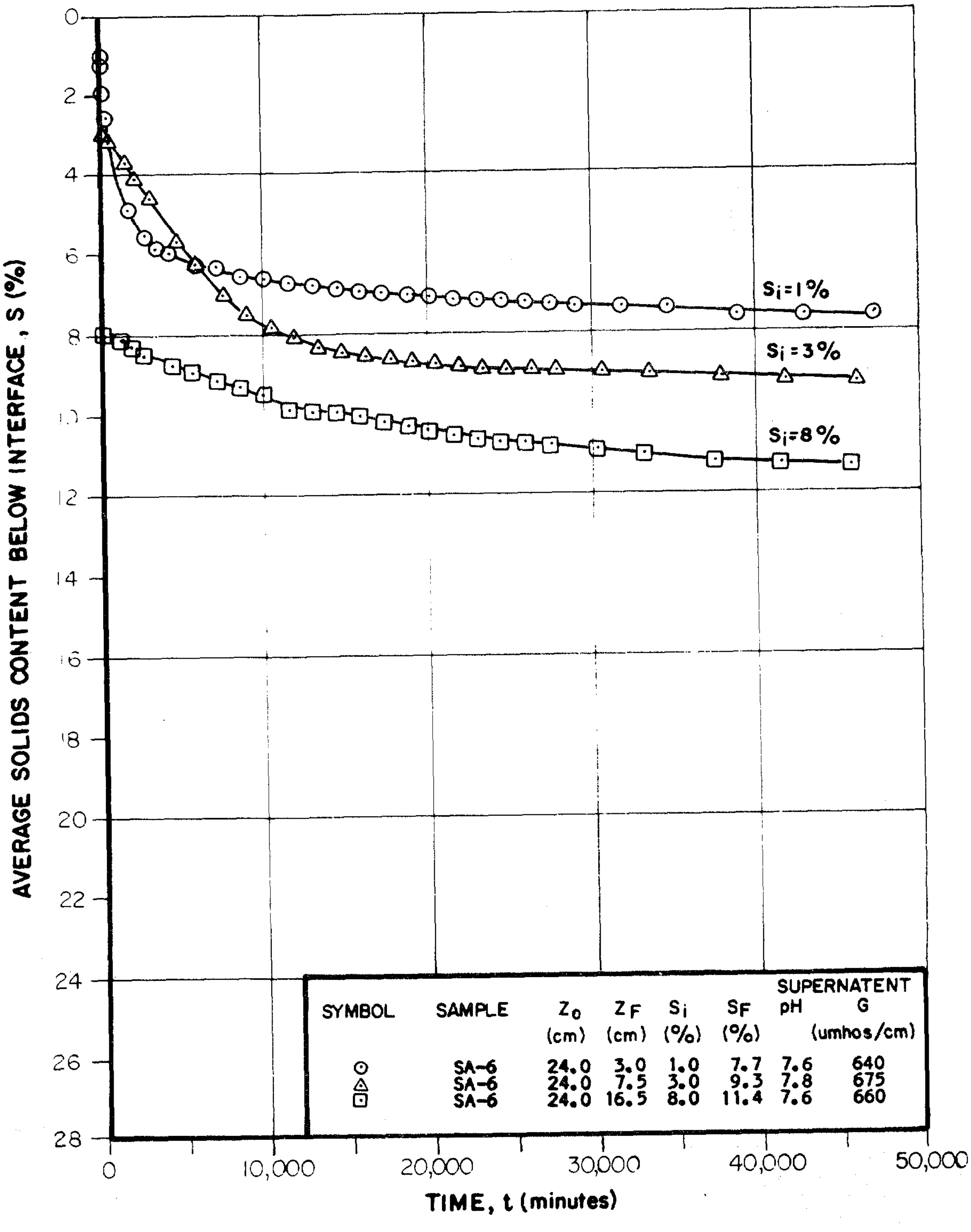
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR MOBIL - NICHOLS PHOSPHATIC CLAY

FIGURE B-9



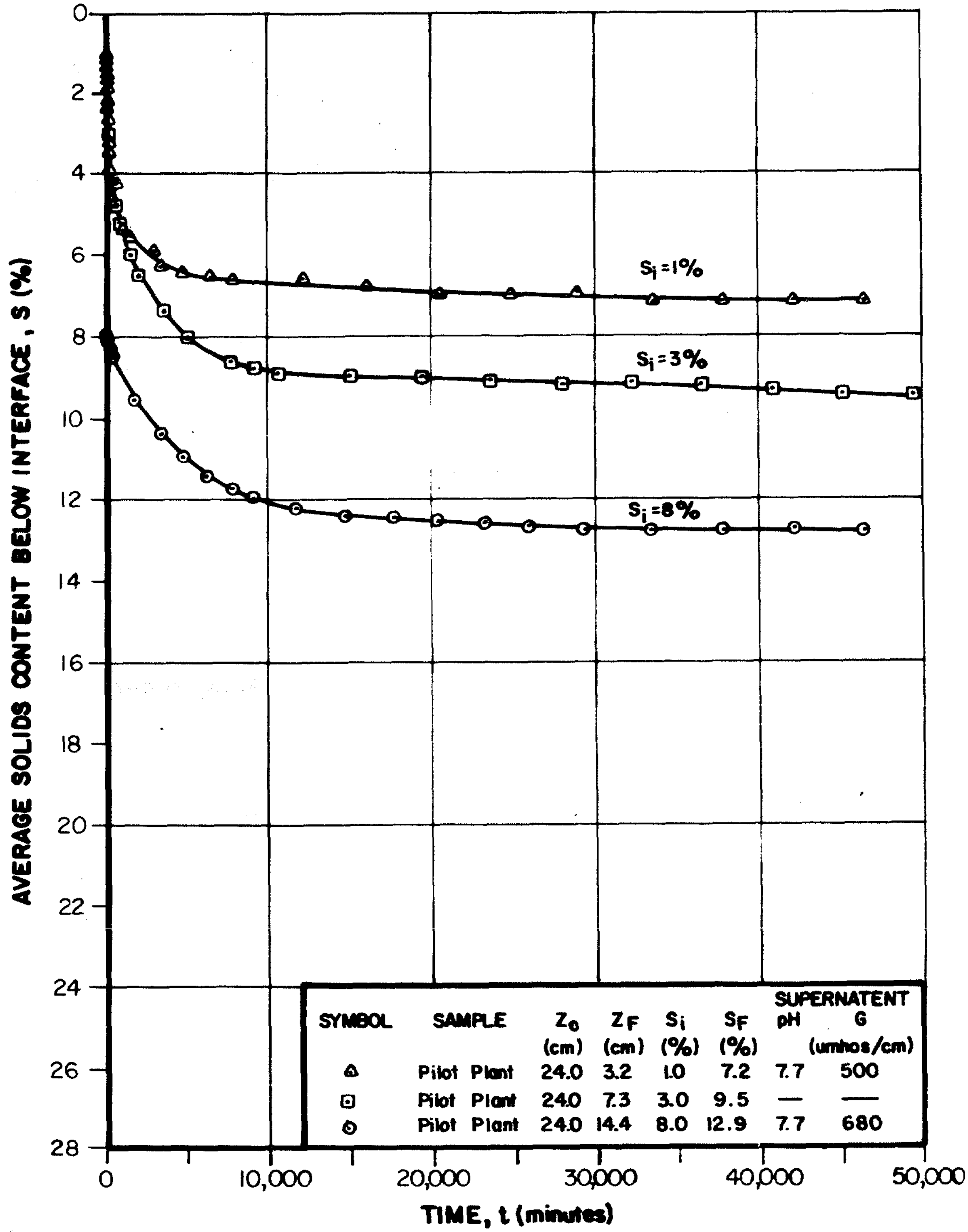
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR OCCIDENTIAL - SUWANNEE RIVER PHOSPHATIC CLAY

FIGURE B-10



SETTLING TEST - SOLIDS CONTENT VS. TIME FOR USSAC - ROCKLAND PHOSPHATIC CLAY

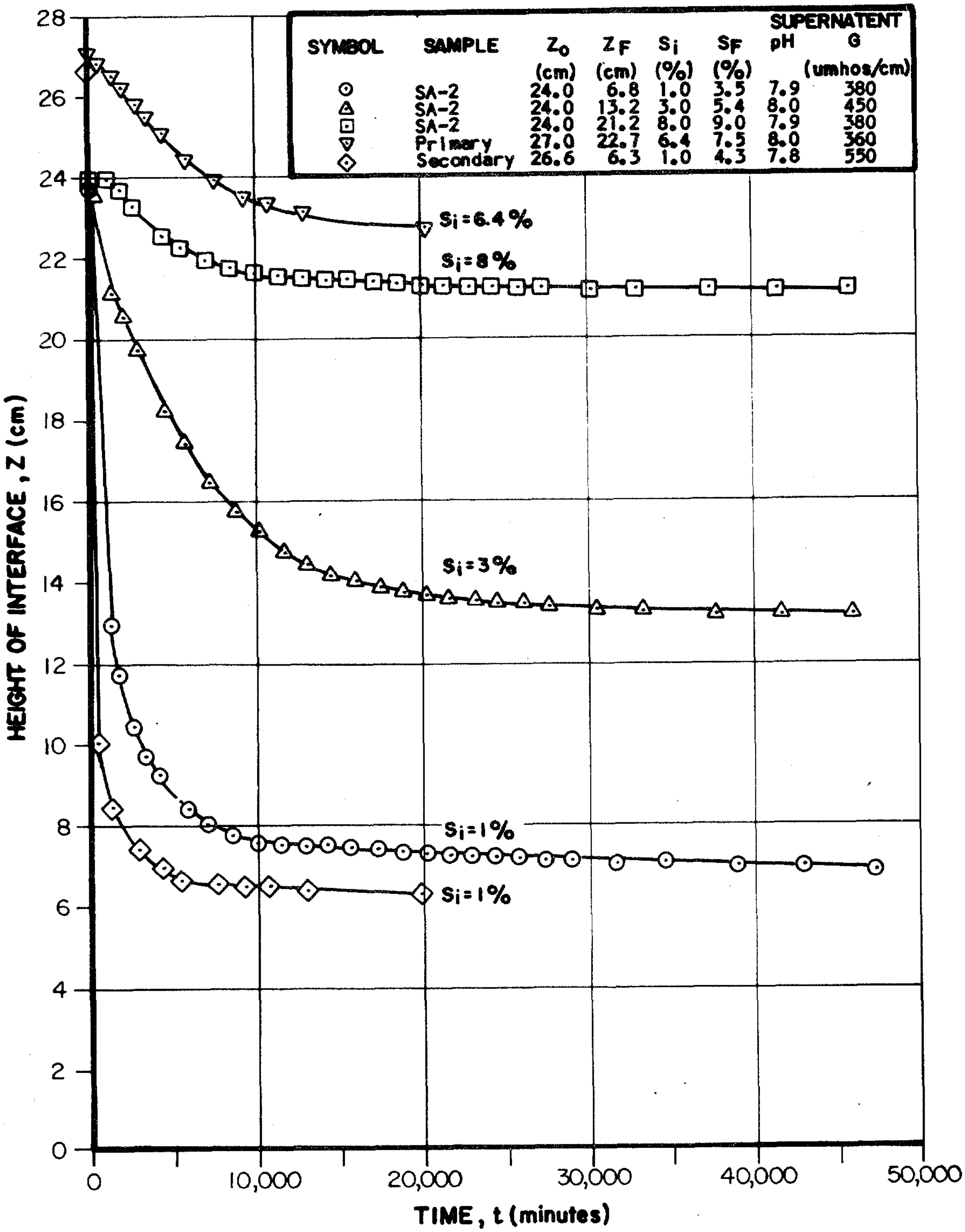
FIGURE B-11



SYMBOL	SAMPLE	Z_0 (cm)	Z_F (cm)	S_i (%)	S_F (%)	SUPERNATENT pH	G (umhos/cm)
△	Pilot Plant	24.0	3.2	1.0	7.2	7.7	500
⊡	Pilot Plant	24.0	7.3	3.0	9.5	—	—
⊙	Pilot Plant	24.0	14.4	8.0	12.9	7.7	680

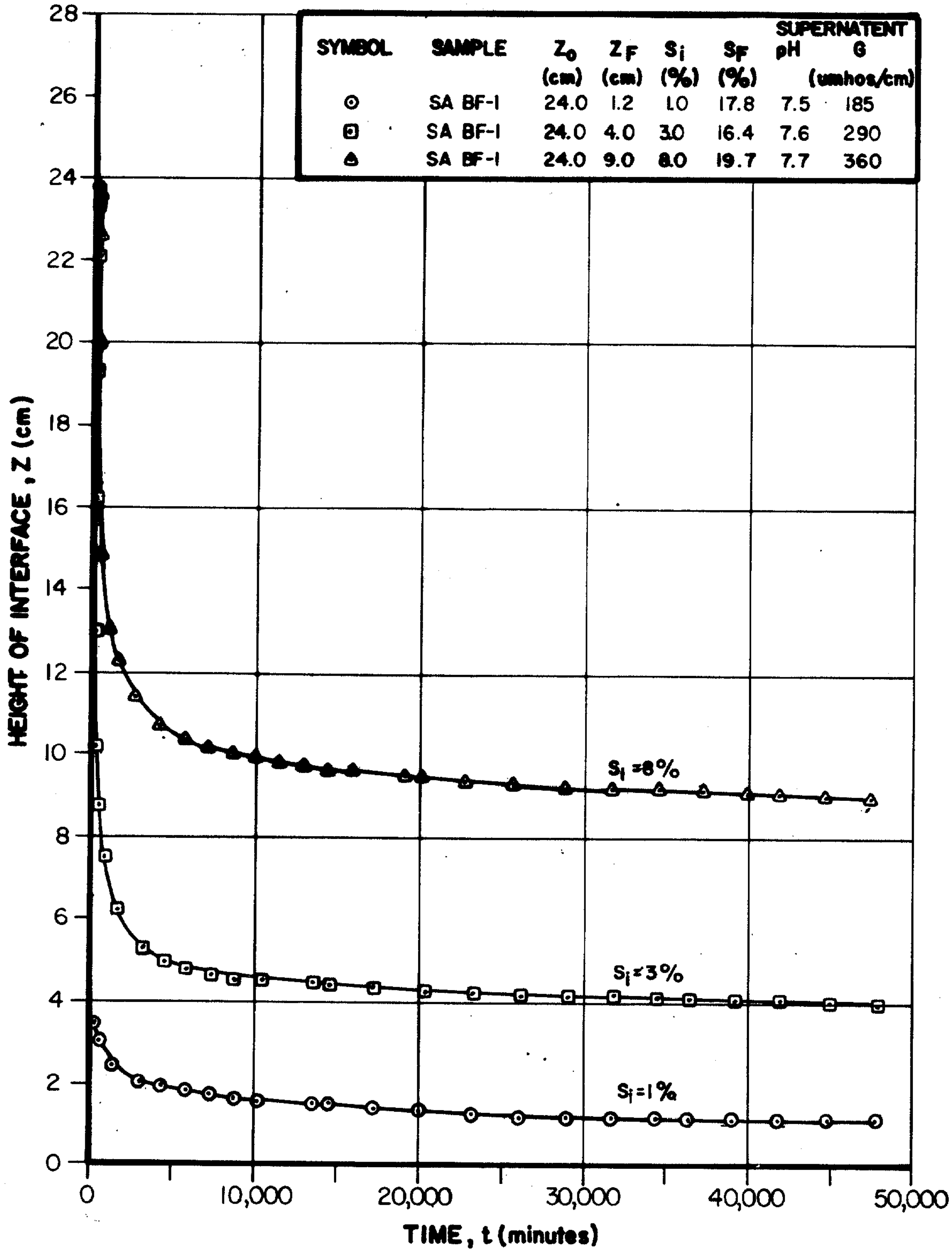
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR WR GRACE - FOUR CORNERS PILOT PLANT PHOSPHATIC CLAY

FIGURE B-12



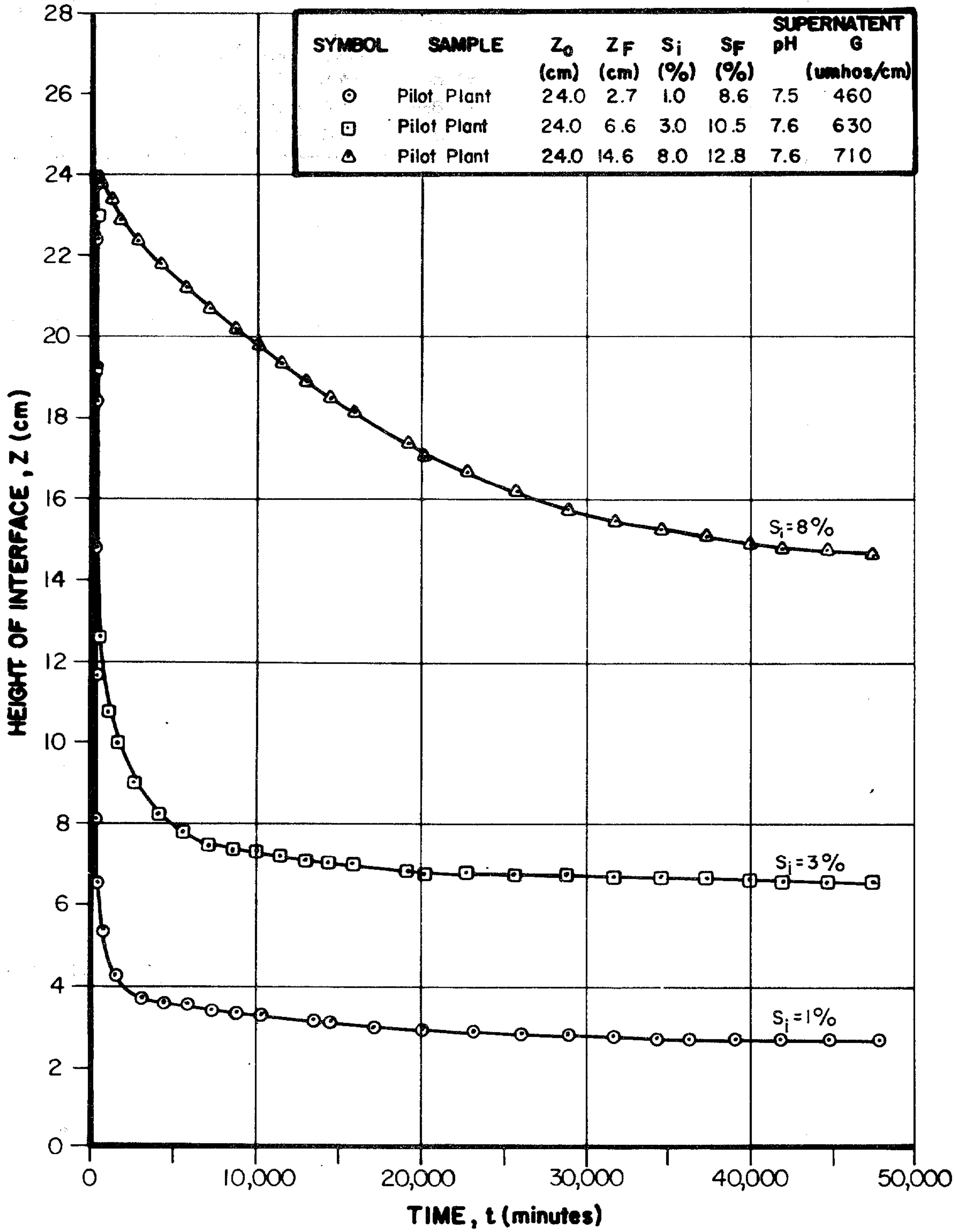
SETTLING TEST - HEIGHT VS. TIME FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY

FIGURE B-13



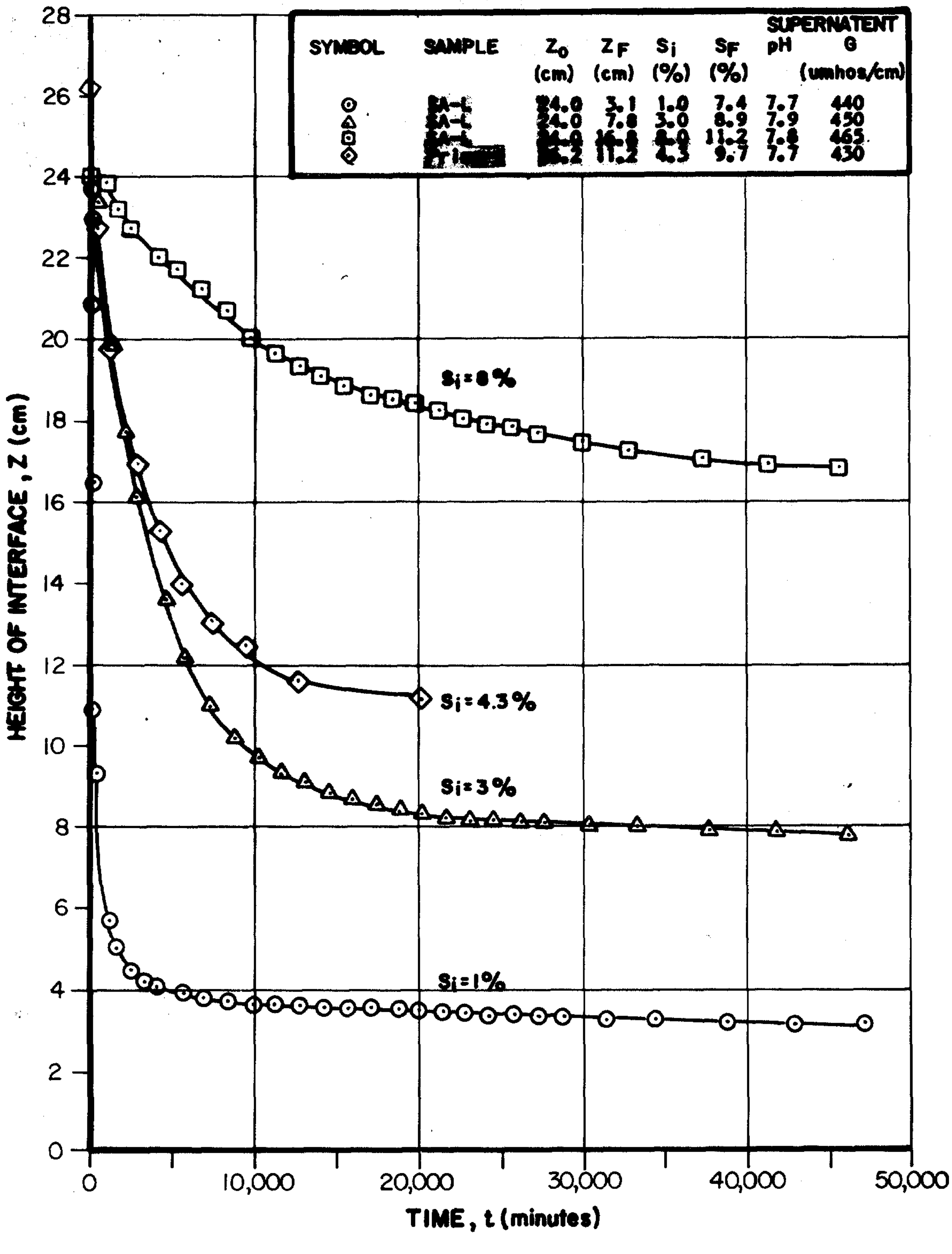
SETTLING TEST - HEIGHT VS. TIME FOR AMAX - BIG FOUR PHOSPHATIC CLAY

FIGURE B-14



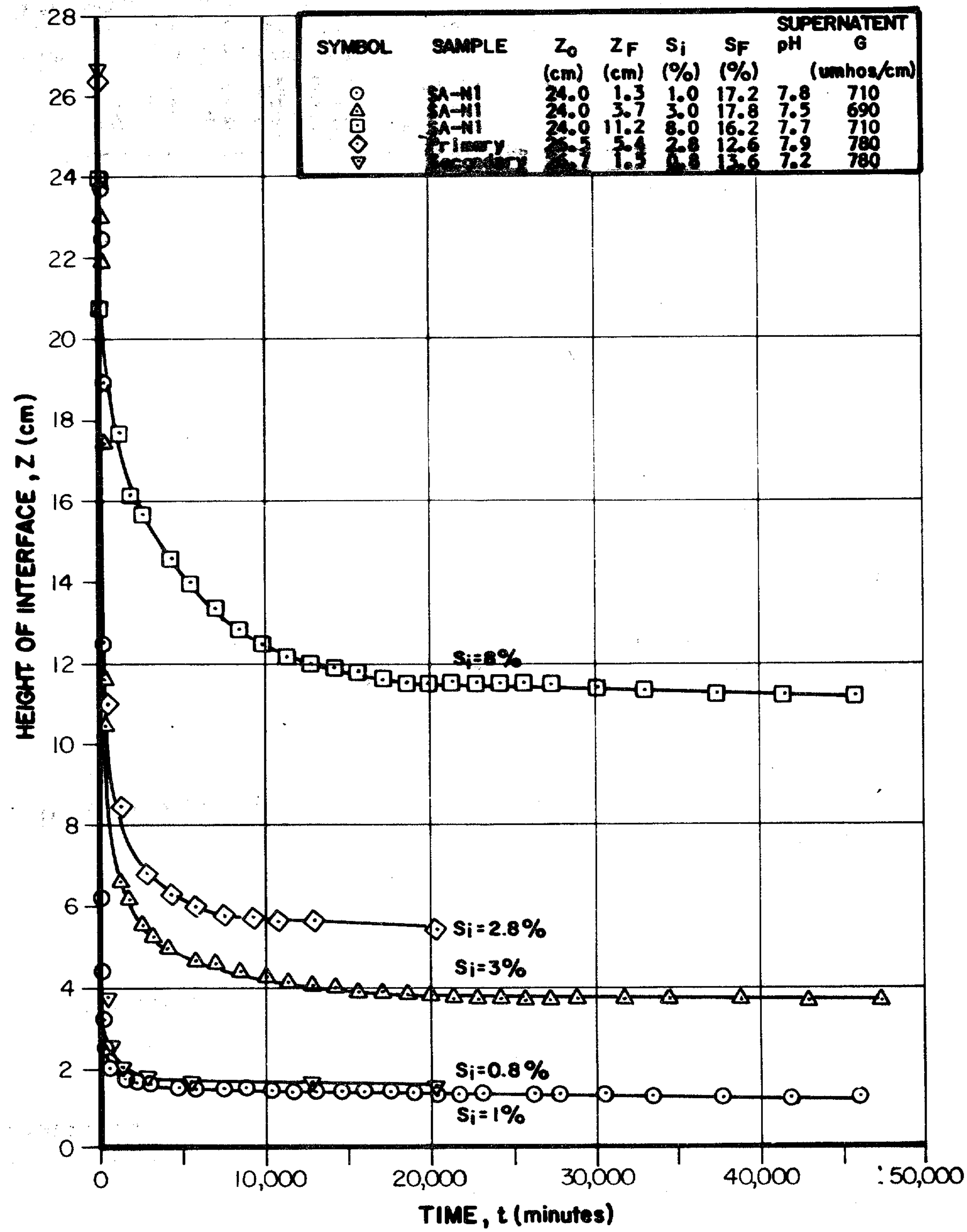
SETTLING TEST - HEIGHT VS. TIME FOR BEKER - WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY

FIGURE B-15



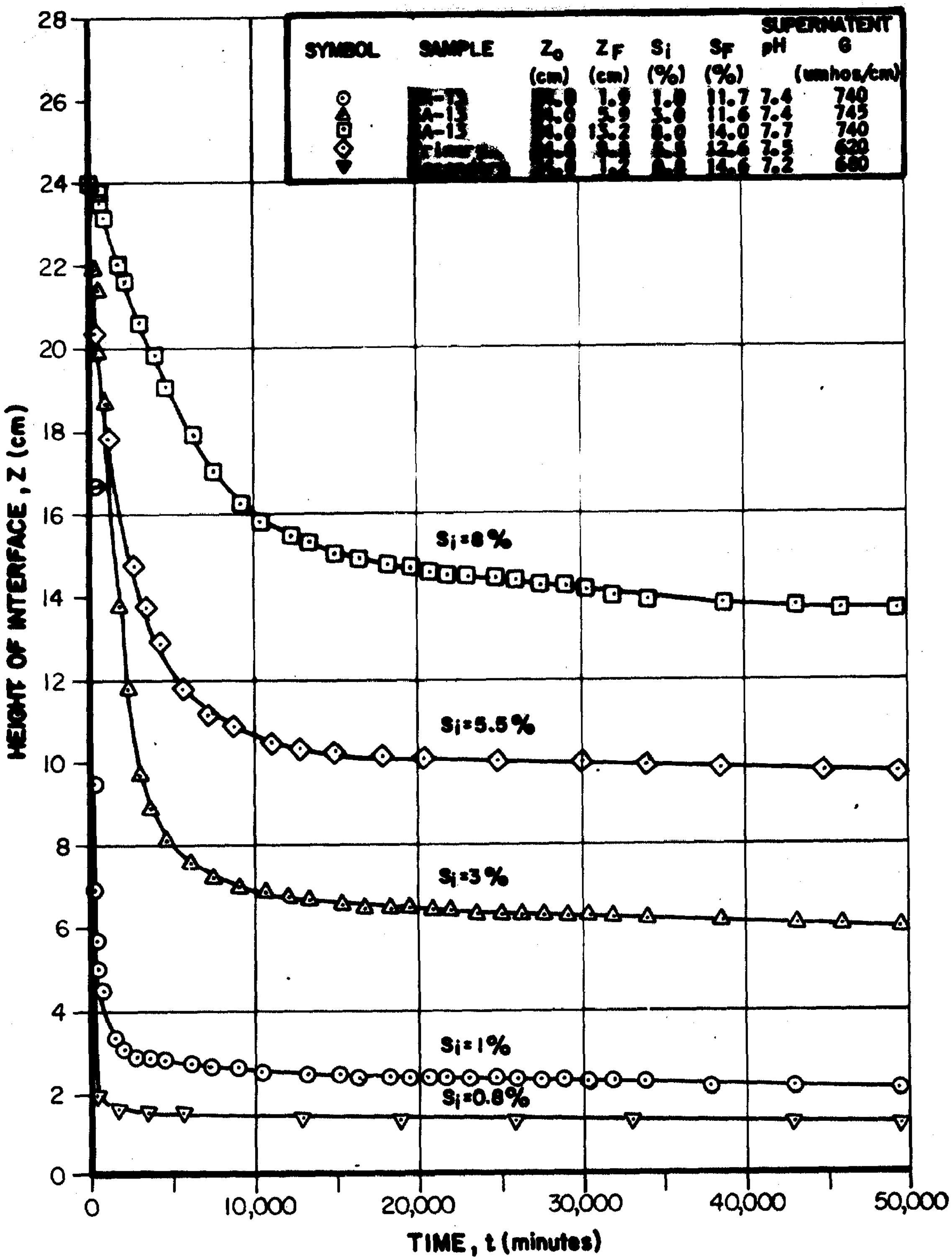
SETTLING TEST - HEIGHT VS. TIME FOR BREWSTER - HAYNSWORTH PHOSPHATIC CLAY

FIGURE B-16



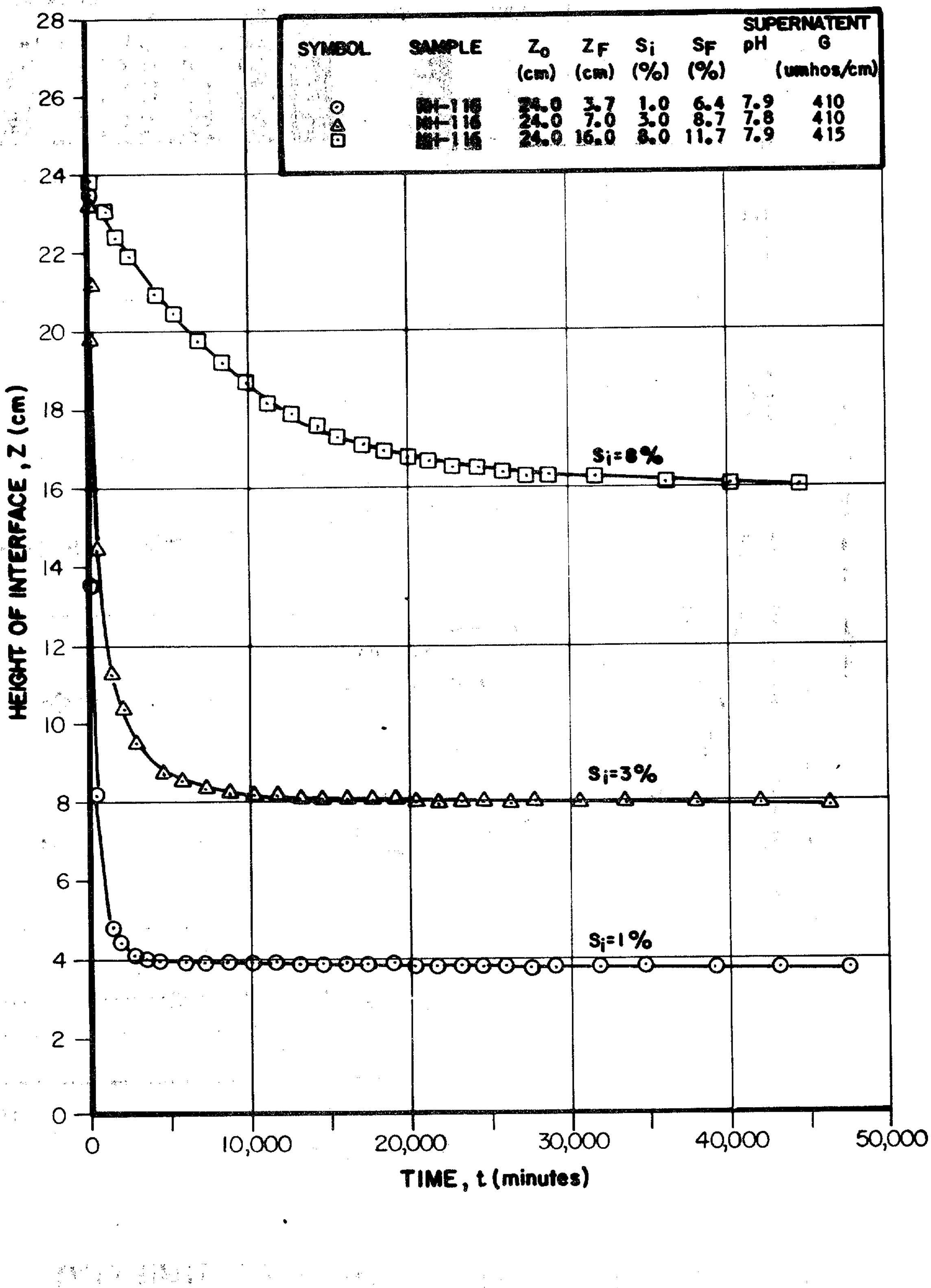
SETTLING TEST - HEIGHT VS. TIME FOR CF MINING - HARDEE PHOSPHATIC CLAY

FIGURE B-17



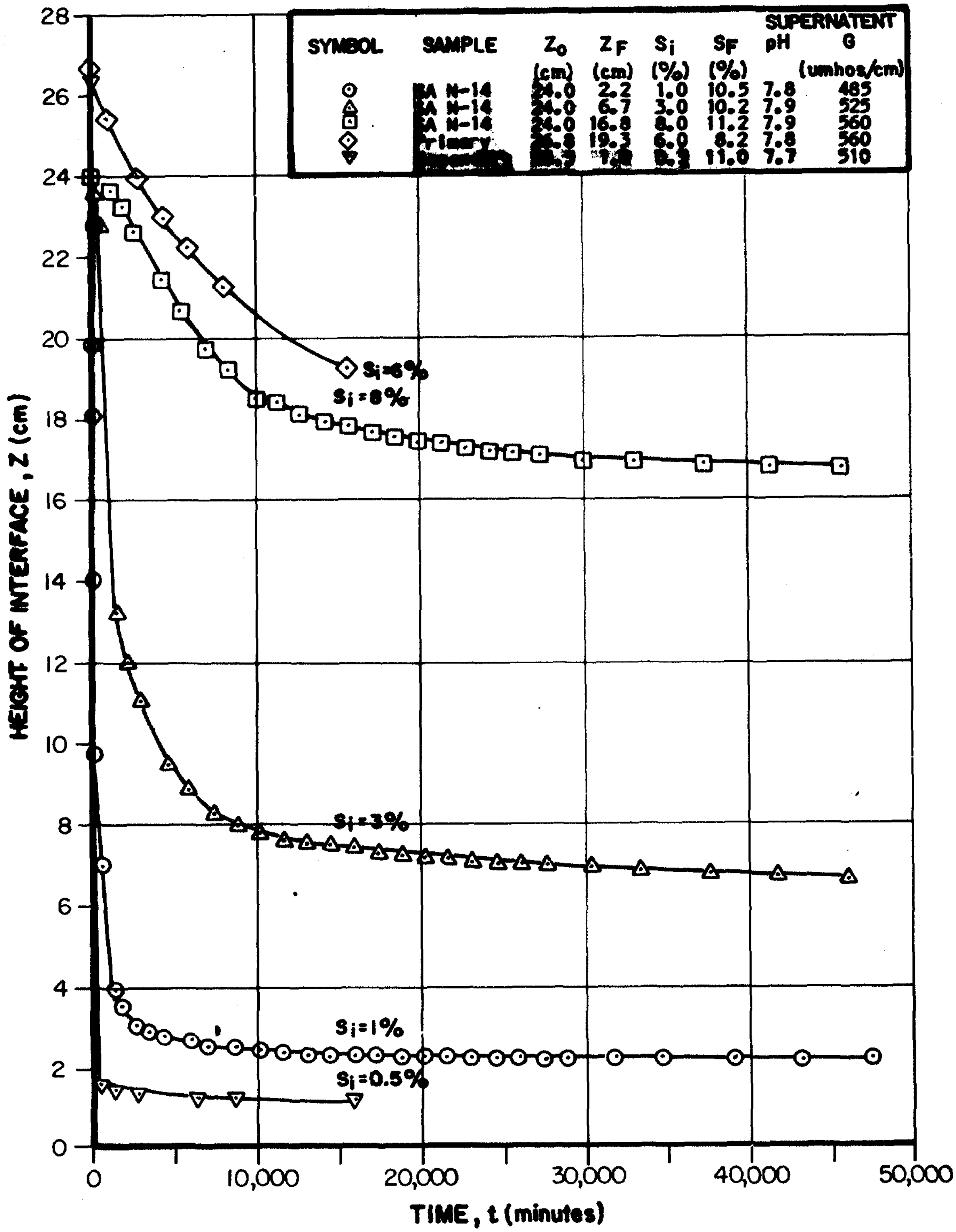
SETTLING TEST - HEIGHT VS. TIME FOR ESTECH - WATSON PHOSPHATIC CLAY

FIGURE B-18



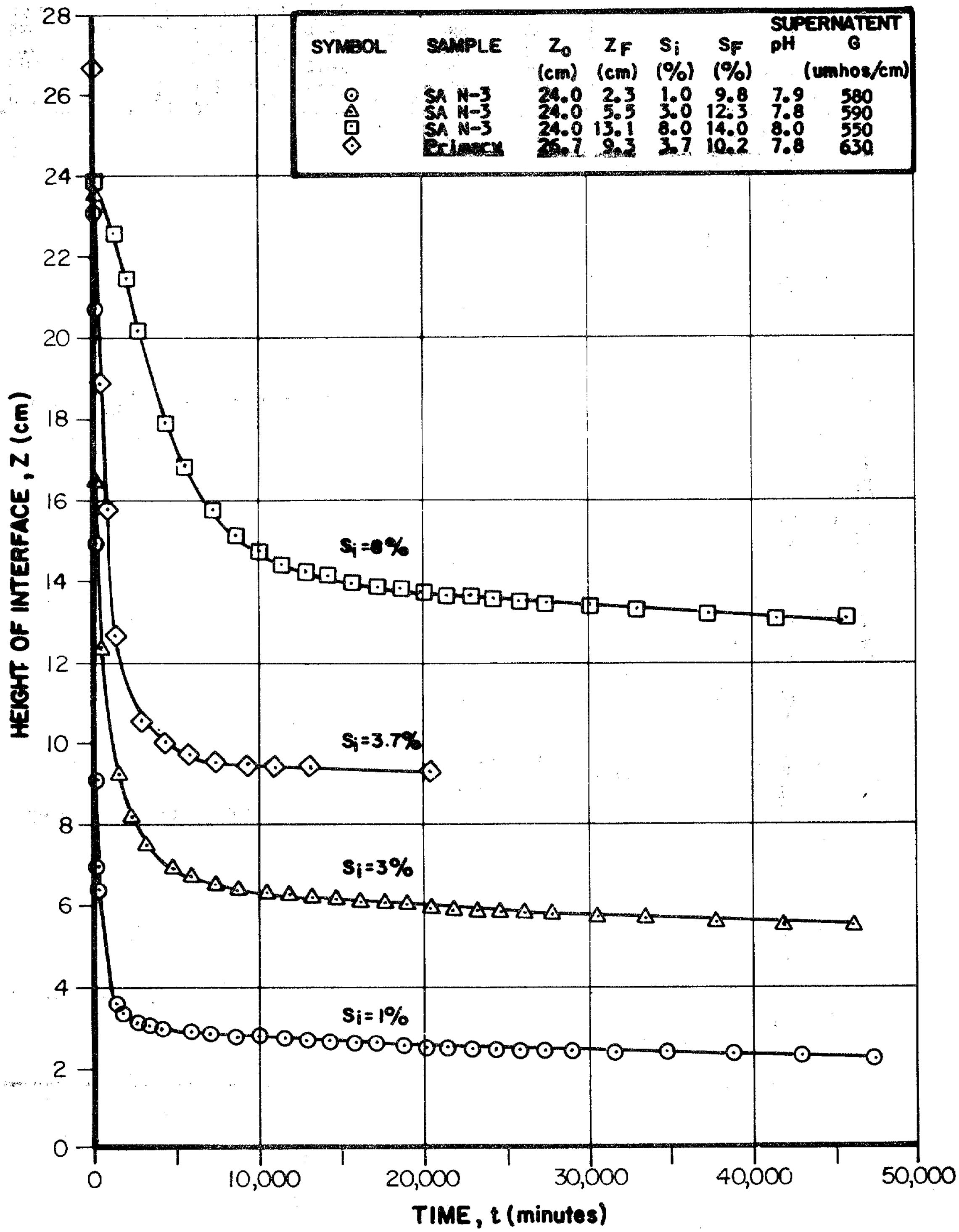
SETTLING TEST - HEIGHT VS. TIME FOR HOPEWELL - HILLSBOROUGH PILOT PLANT NH 116 PHOSPHATIC CLAY

FIGURE B-19



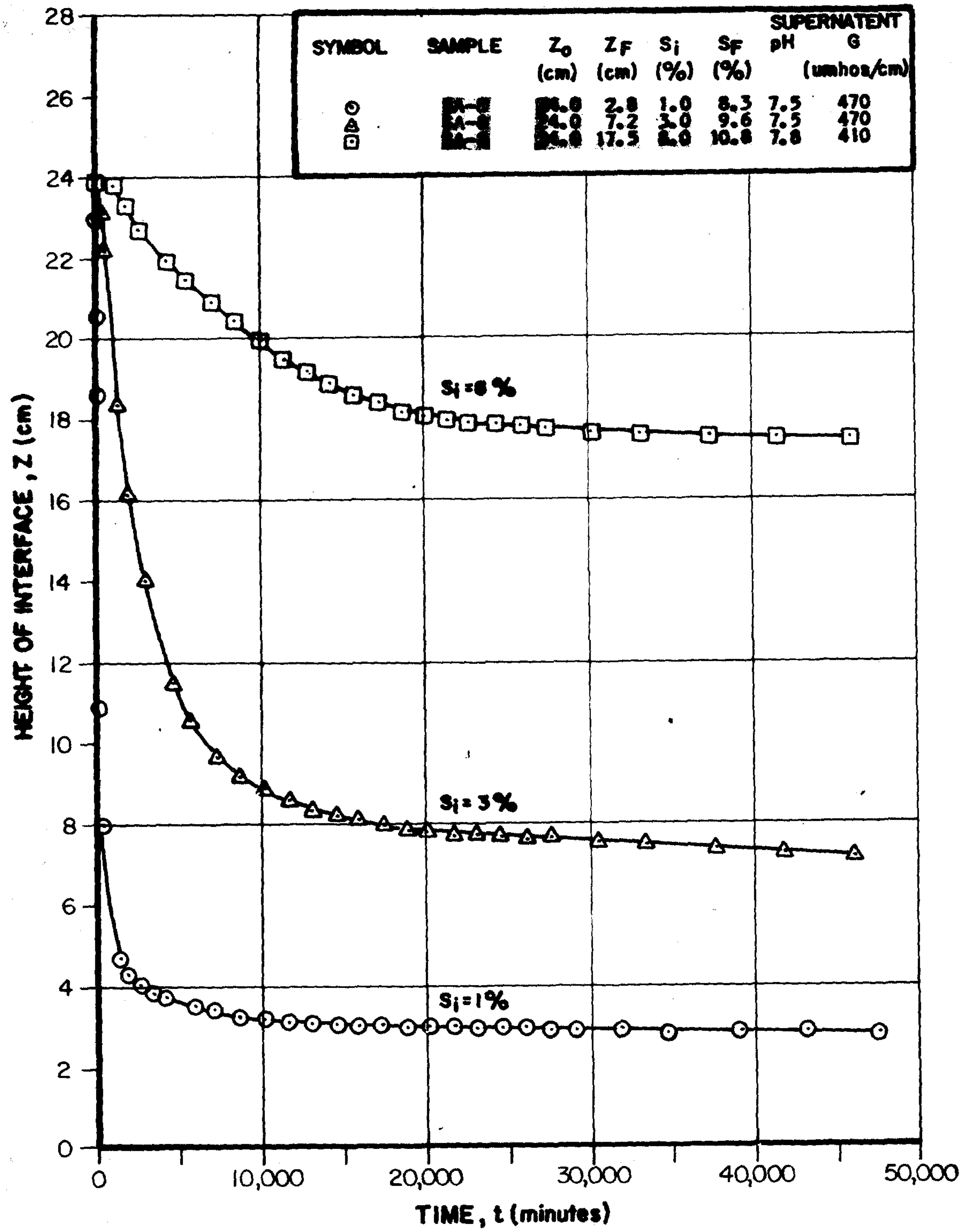
SETTLING TEST - HEIGHT VS. TIME FOR IMC - NORALYN PHOSPHATIC CLAY

FIGURE B-20



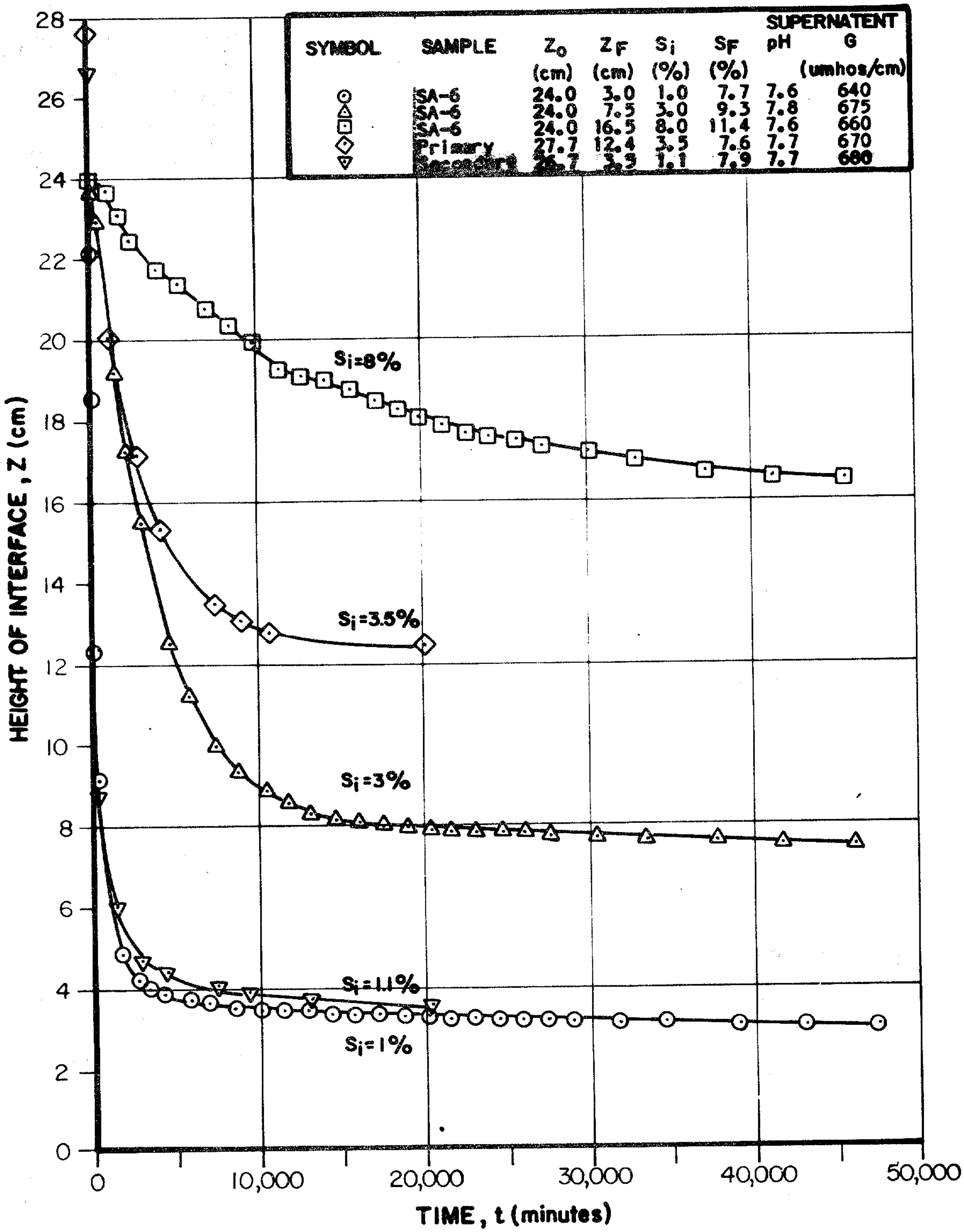
SETTLING TEST - HEIGHT VS. TIME FOR MOBIL - NICHOLS PHOSPHATIC CLAY

FIGURE B-21

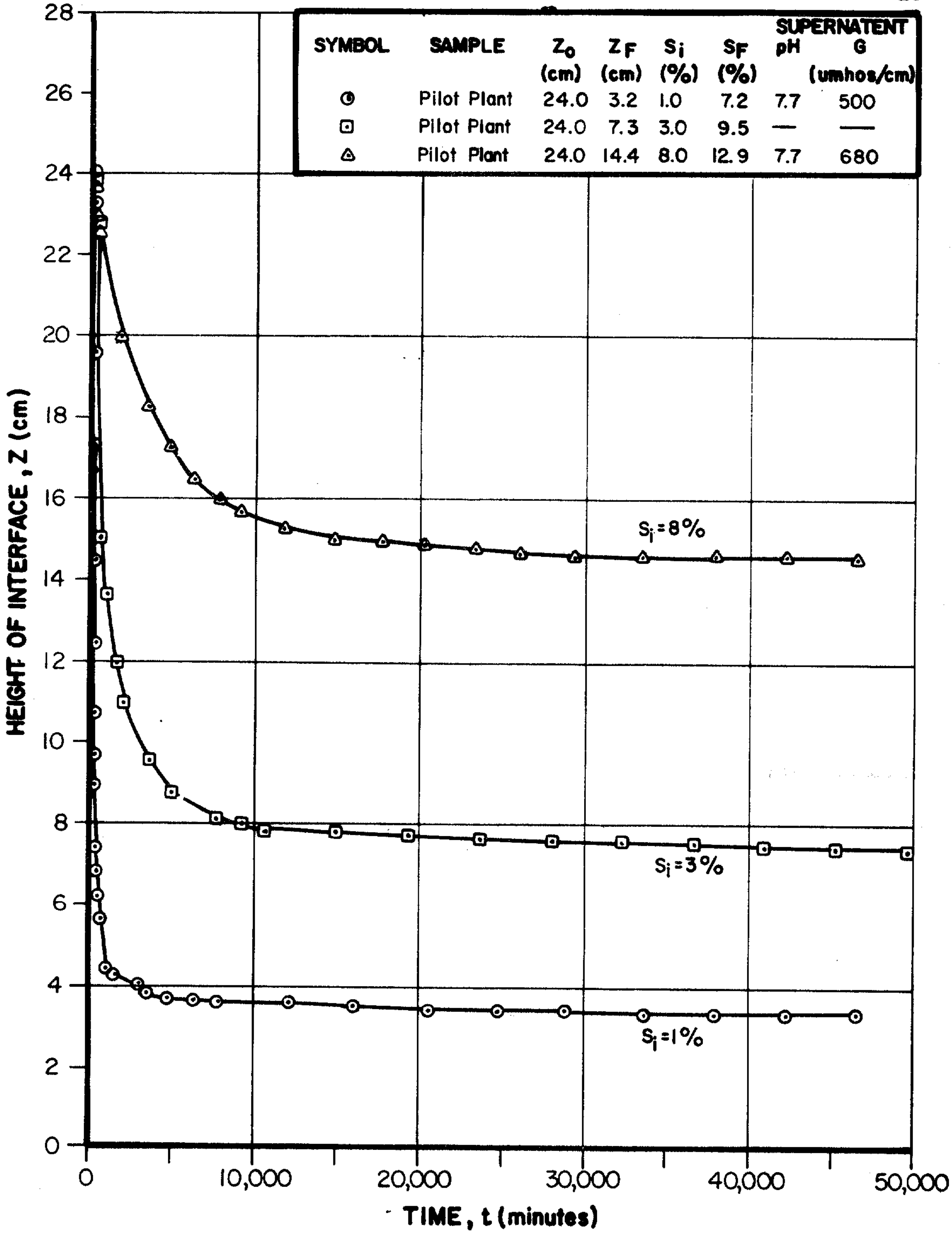


SETTLING TEST - HEIGHT VS. TIME FOR OCCIDENTAL - SUWANNEE RIVER PHOSPHATIC CLAY

FIGURE B-22



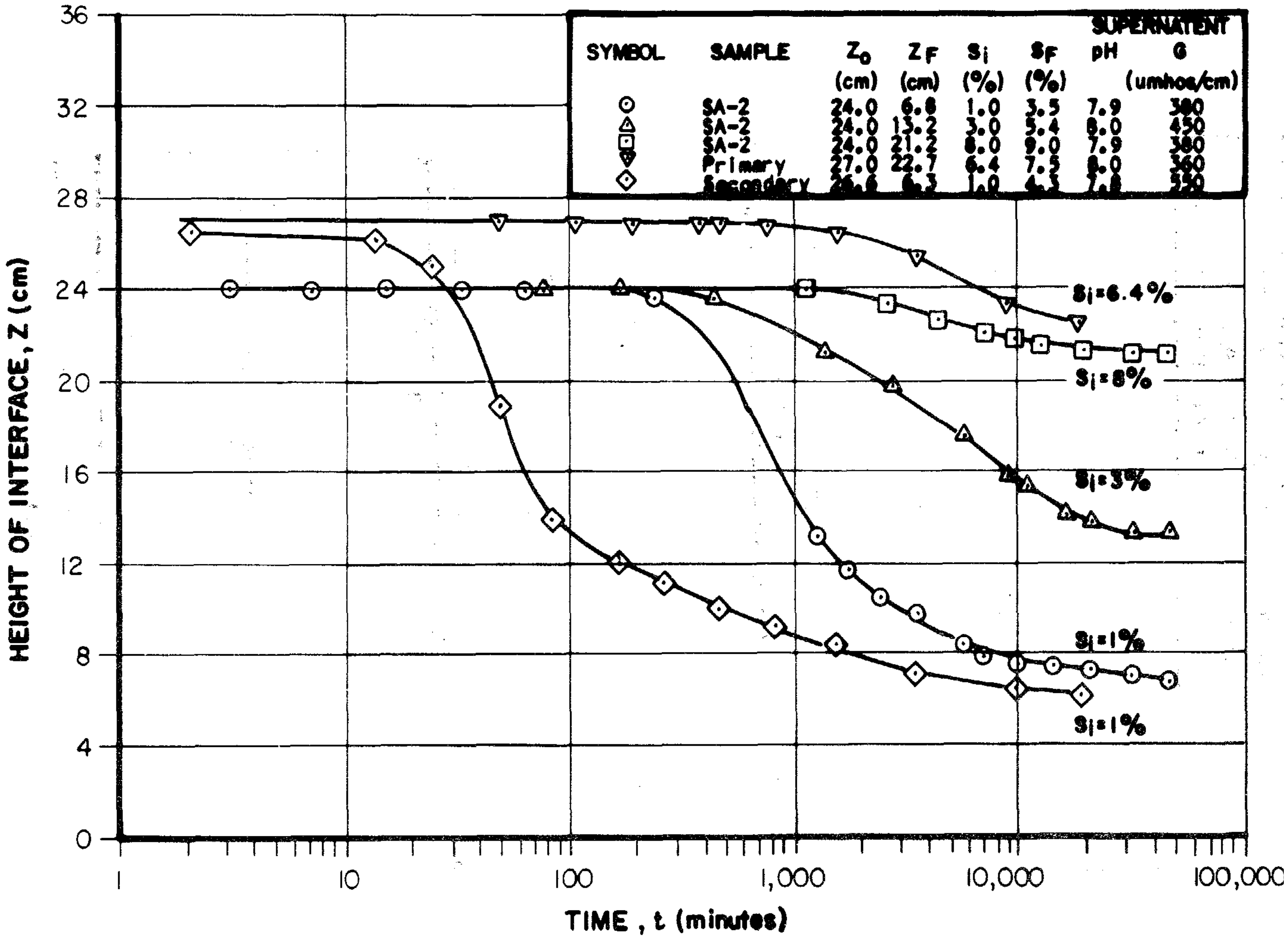
SETTLING TEST - HEIGHT VS. TIME FOR USSAC - ROCKLAND PHOSPHATIC CLAY



SETTLING TEST - HEIGHT VS. TIME FOR
WR GRACE - FOUR CORNERS PILOT PLANT PHOSPHATIC CLAY

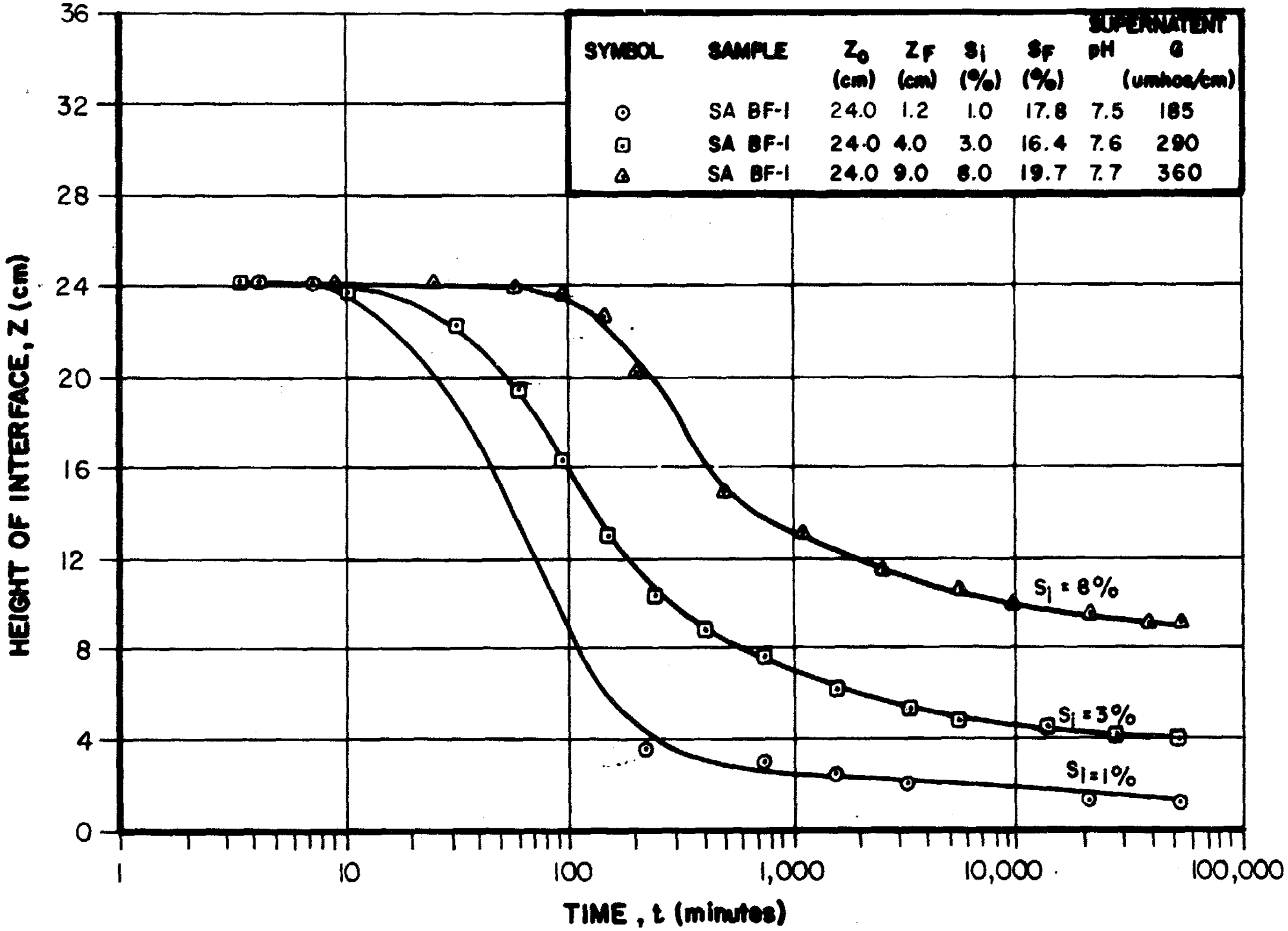
FIGURE B-24

FIGURE B-25



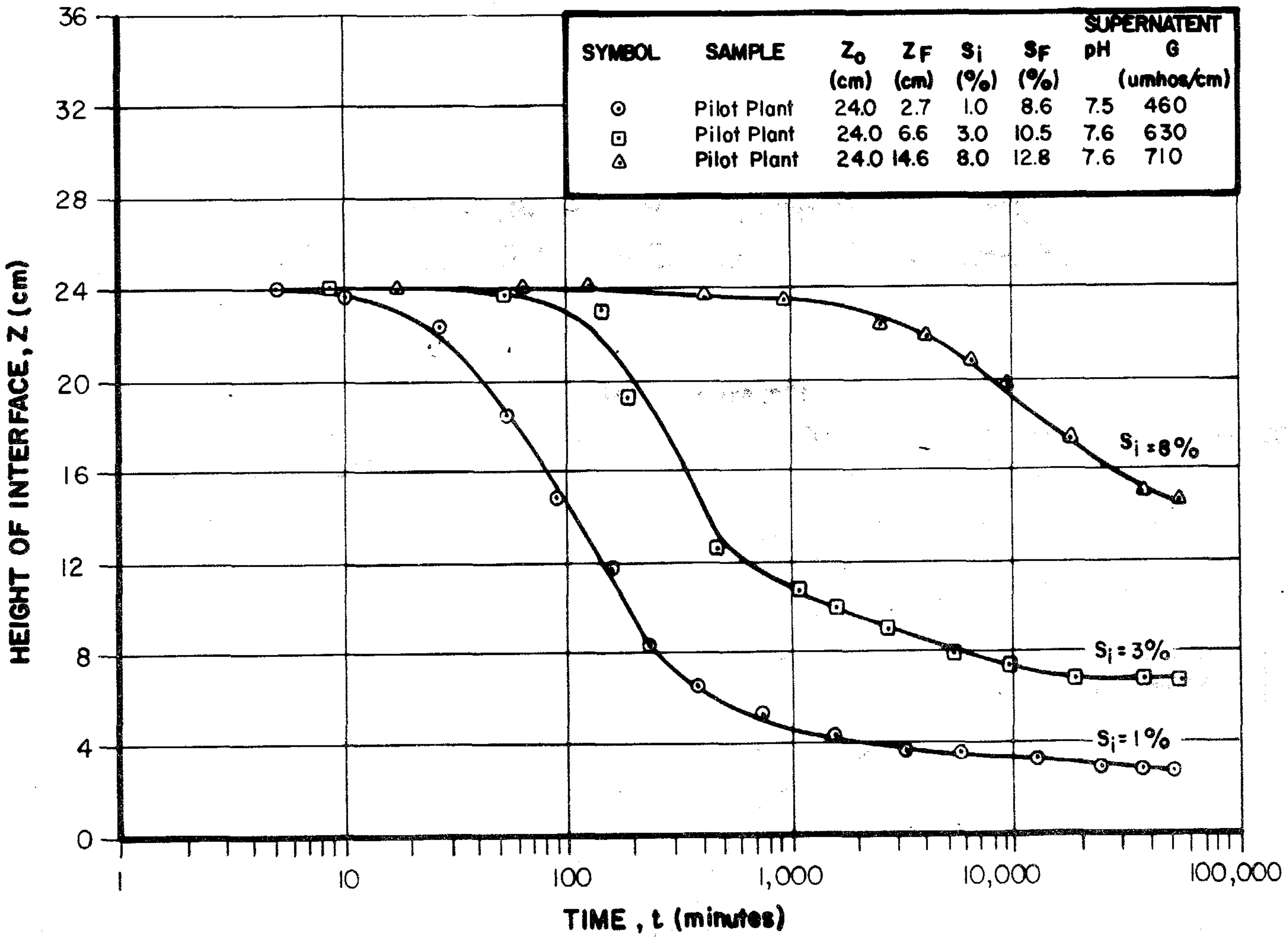
SETTLING TEST - HEIGHT VS. LOG TIME FOR AGRICO - SADDLE CREEK PHOSPHATIC CLAY

FIGURE B-26

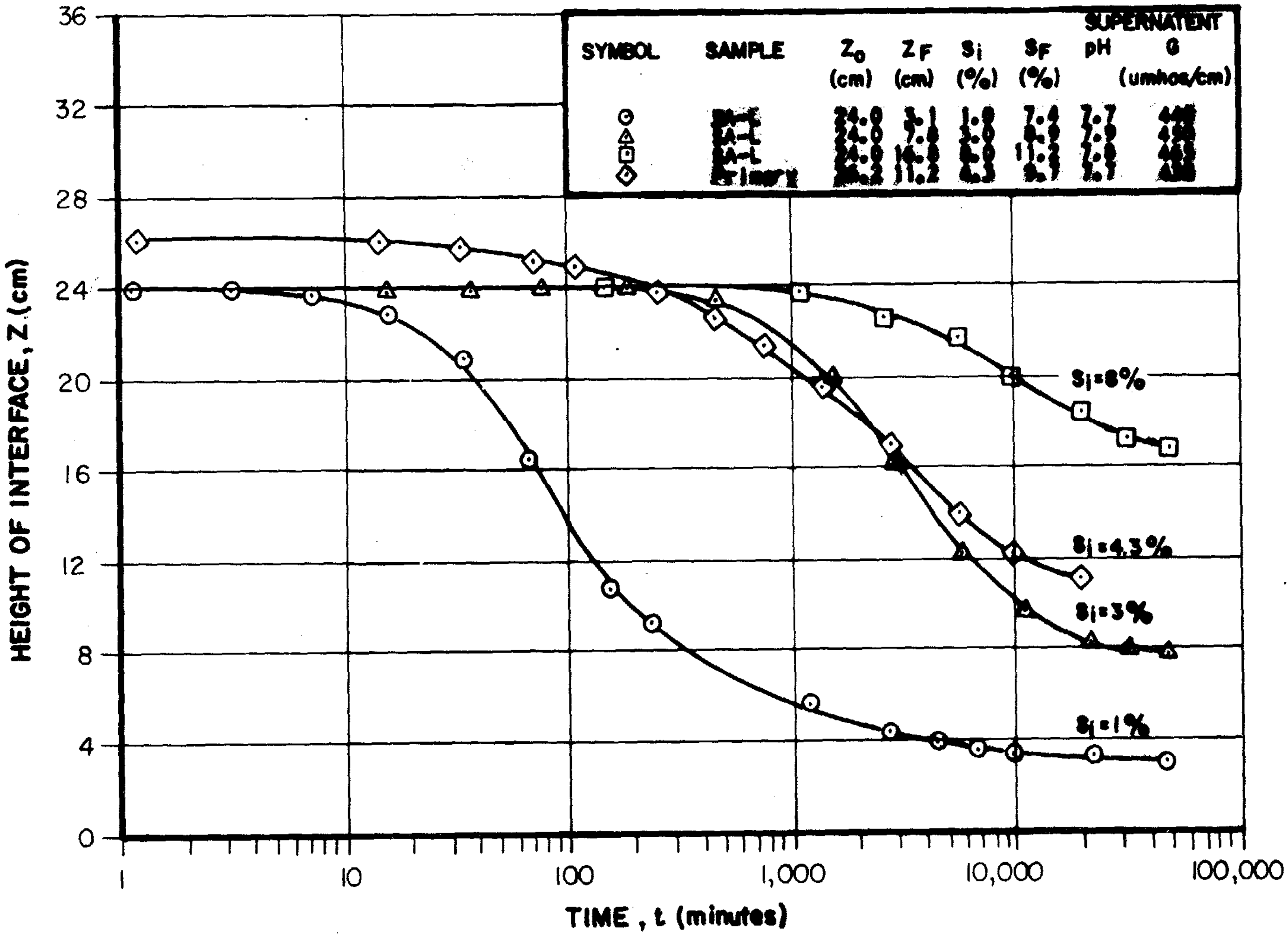


SETTLING TEST - HEIGHT VS. LOG TIME FOR AMAX - BIG FOUR PHOSPHATIC CLAY

FIGURE B-27

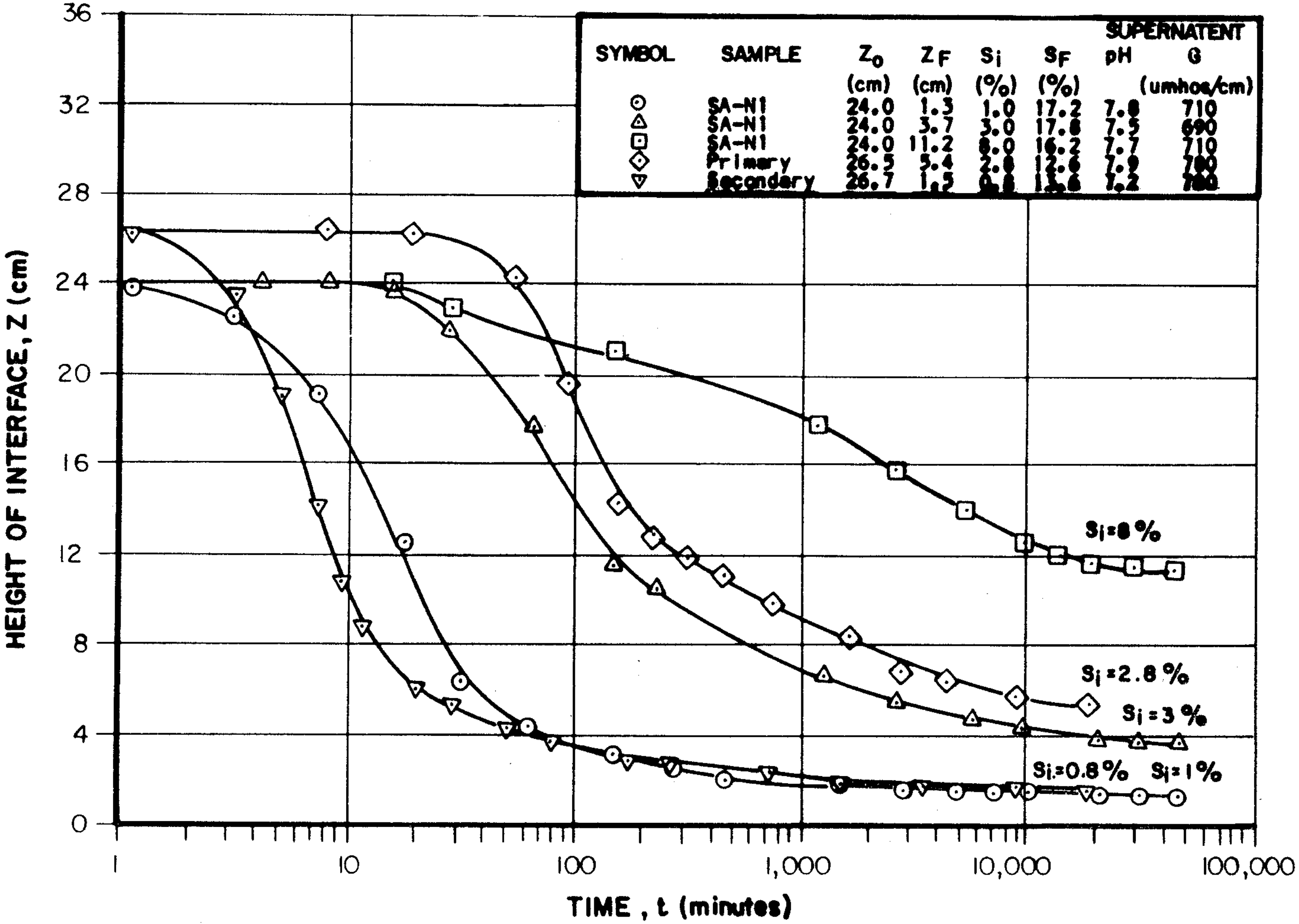


SETTLING TEST - HEIGHT VS. LOG TIME FOR BEKER - WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY



SETTLING TEST - HEIGHT VS. LOG TIME FOR BREWSTER - HAYNSWORTH PHOSPHATIC CLAY

FIGURE B-28



SETTLING TEST - HEIGHT VS. LOG TIME FOR
CF MINING - HARDEE PHOSPHATIC CLAY

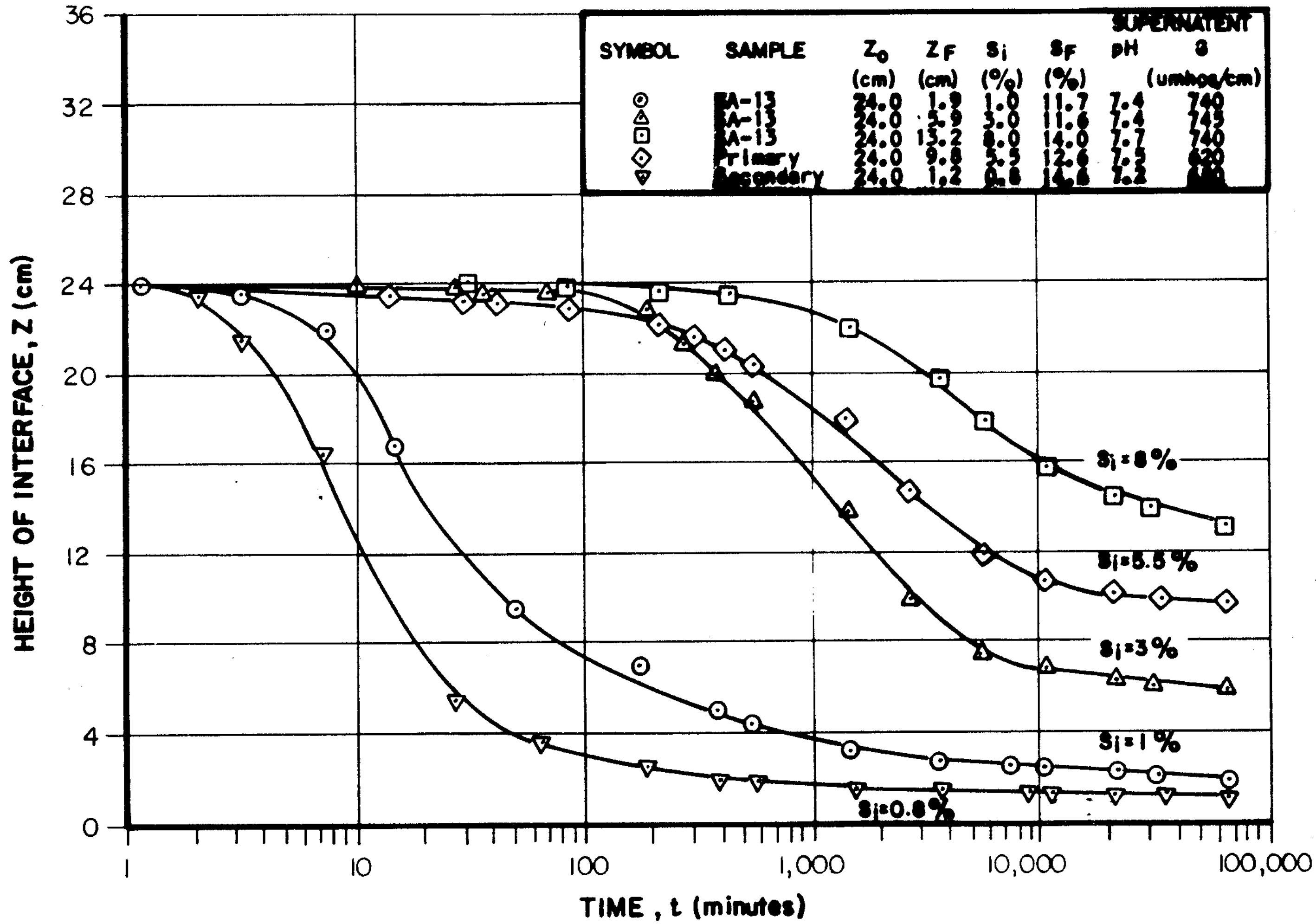
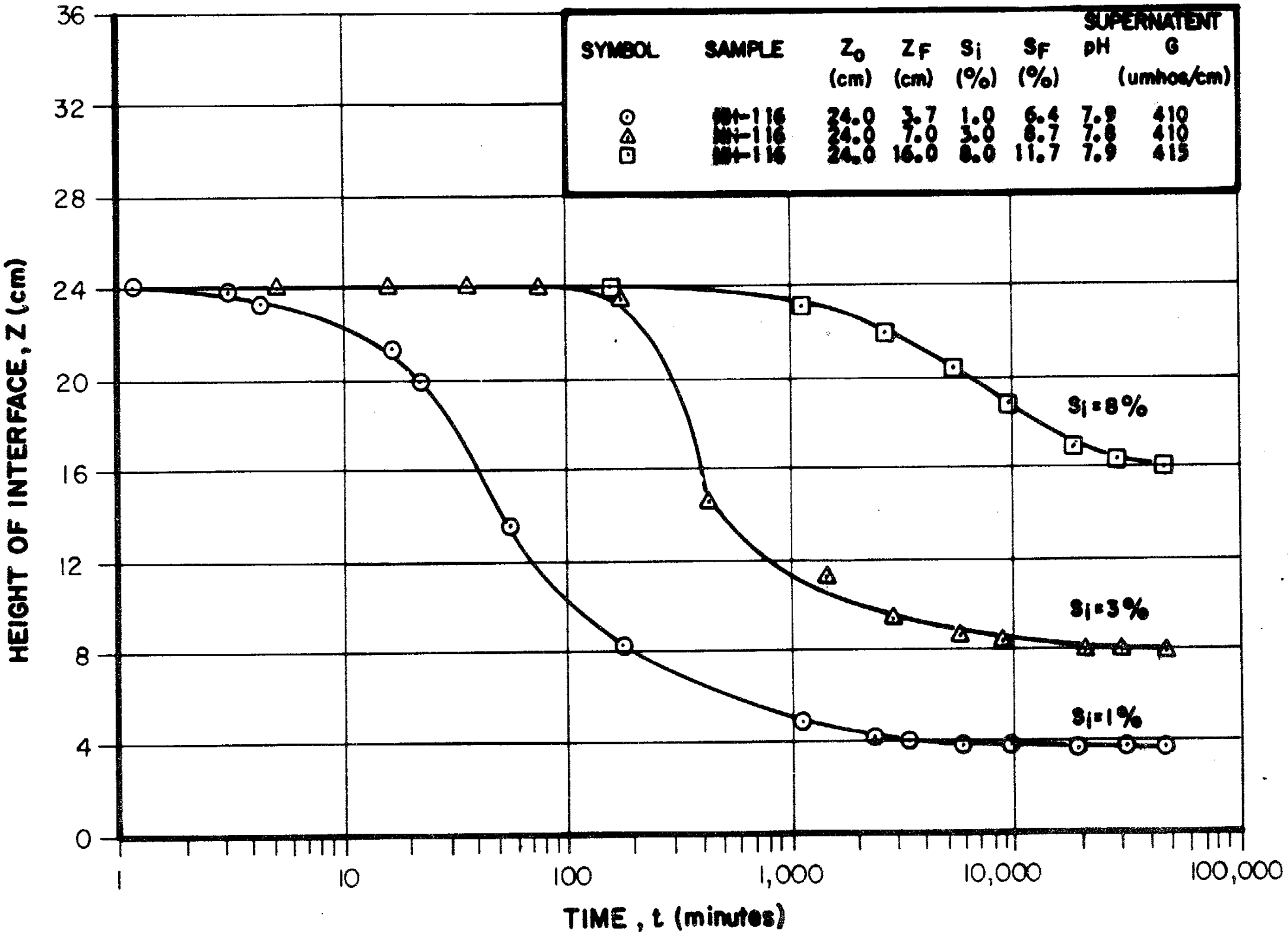


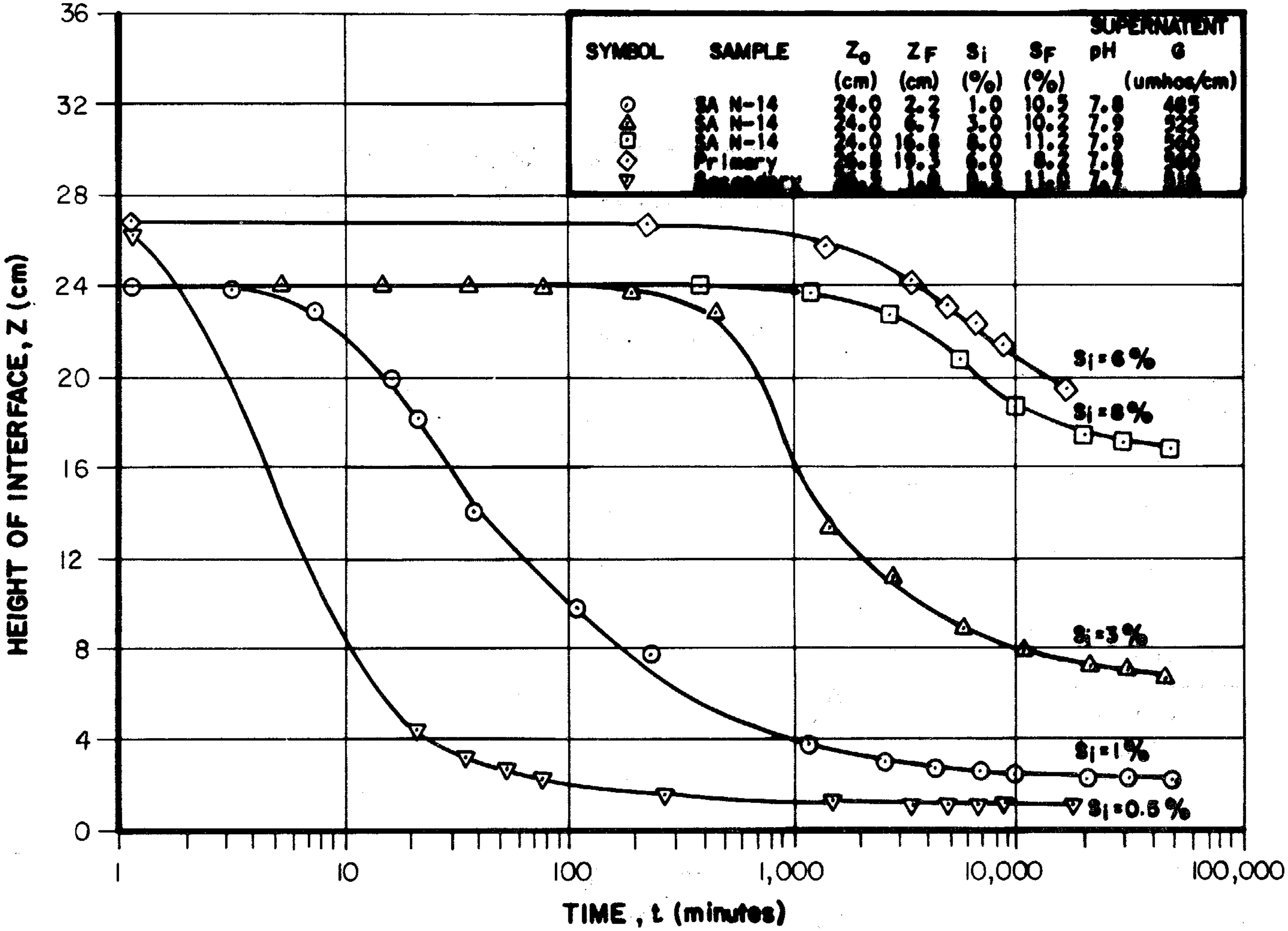
FIGURE B-30

SETTLING TEST - HEIGHT VS. LOG TIME FOR
ESTECH - WATSON PHOSPHATIC CLAY

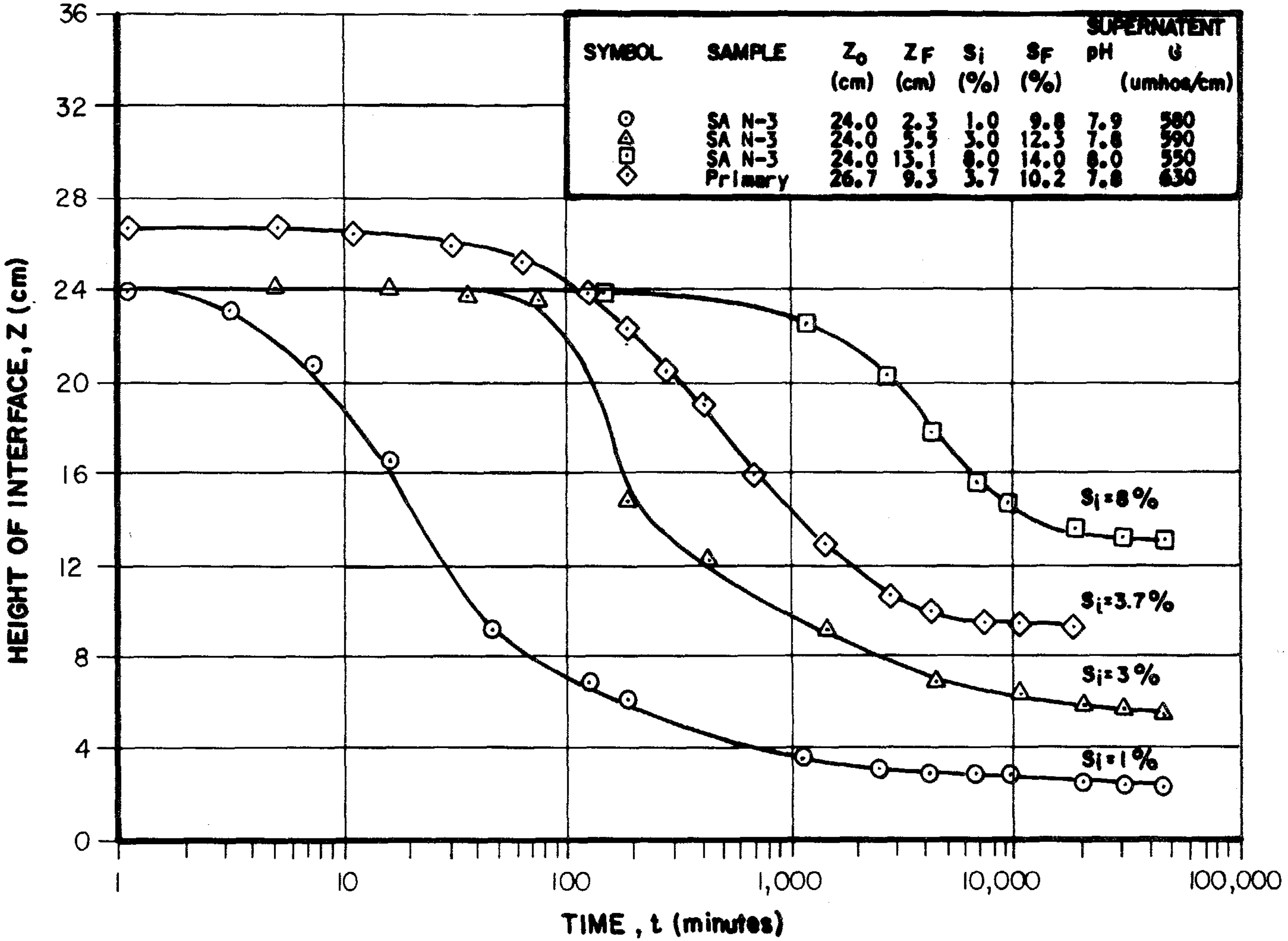
FIGURE B-31



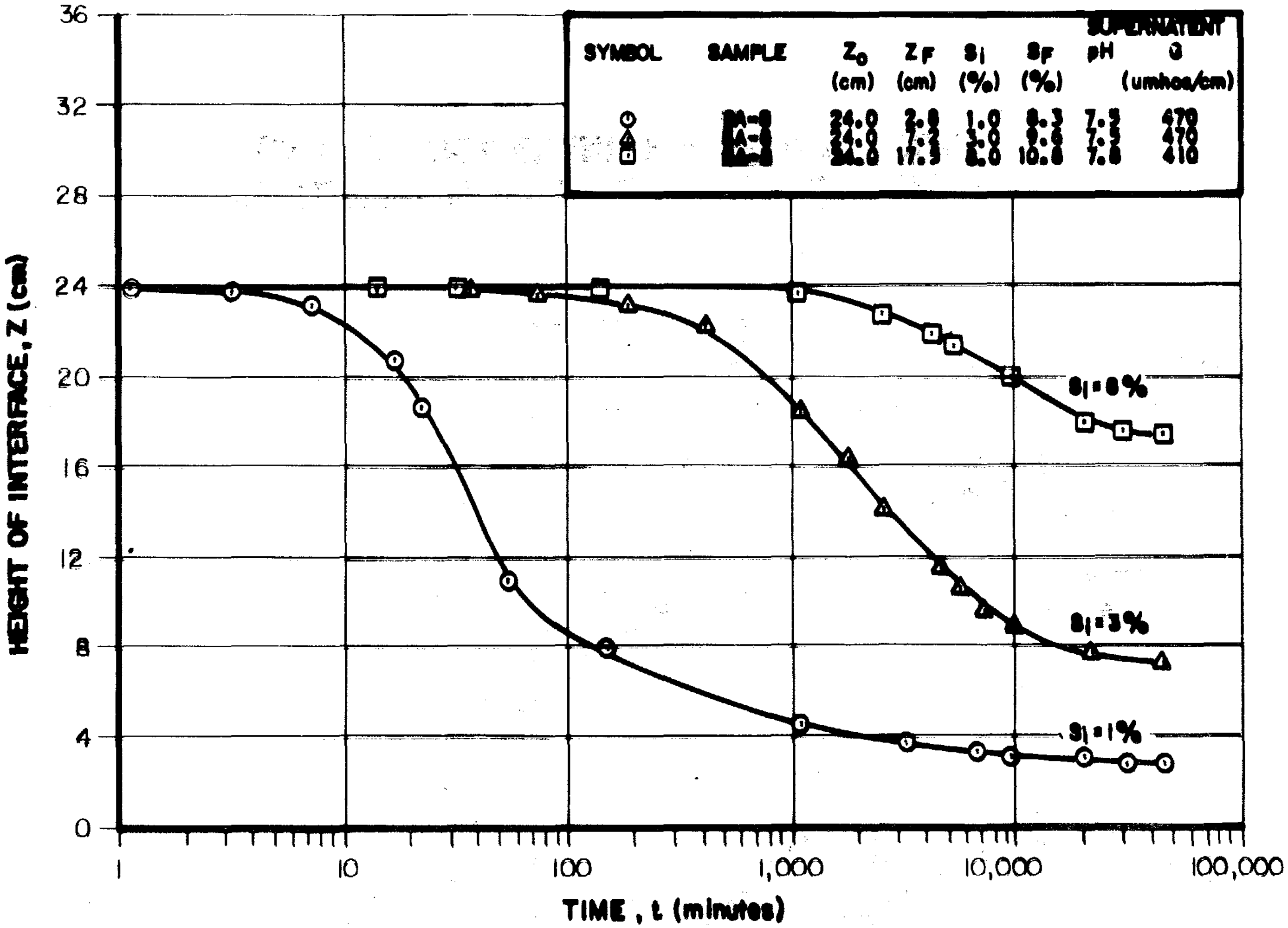
SETTLING TEST - HEIGHT VS. LOG TIME FOR HOPEWELL - HILLSBOROUGH PILOT PLANT NH -116 PHOSPHATIC CLAY



SETTLING TEST - HEIGHT VS. LOG TIME FOR IMC - NORALYN PHOSPHATIC CLAY

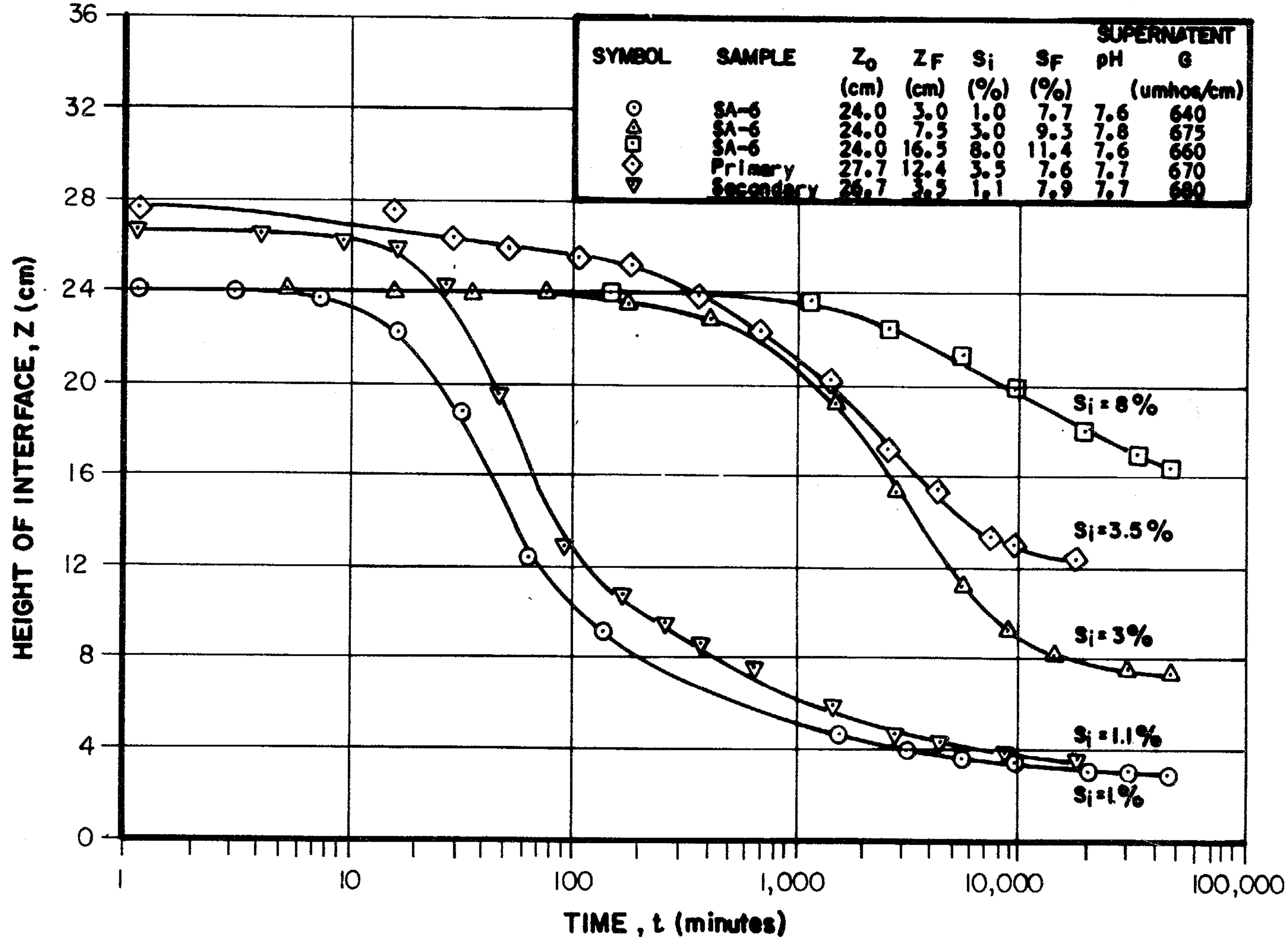


SETTLING TEST - HEIGHT VS. LOG TIME FOR MOBIL - NICHOLS PHOSPHATIC CLAY



SETTLING TEST - HEIGHT VS. LOG TIME FOR OCCIDENTAL - SUWANNEE RIVER PHOSPHATIC CLAY

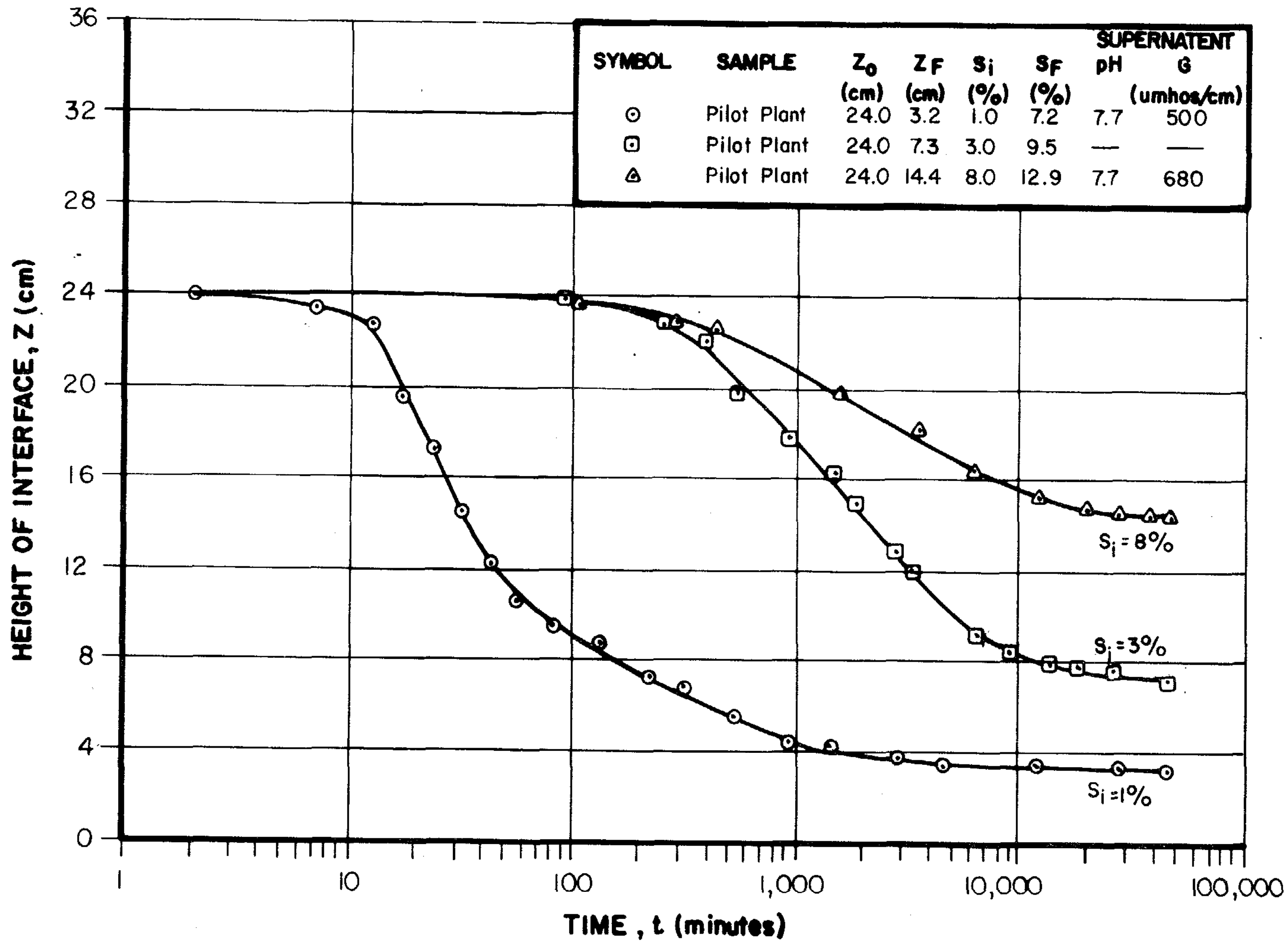
FIGURE B-34



SETTLING TEST - HEIGHT VS. LOG TIME FOR USSAC - ROCKLAND PHOSPHATIC CLAY

FIGURE B-35

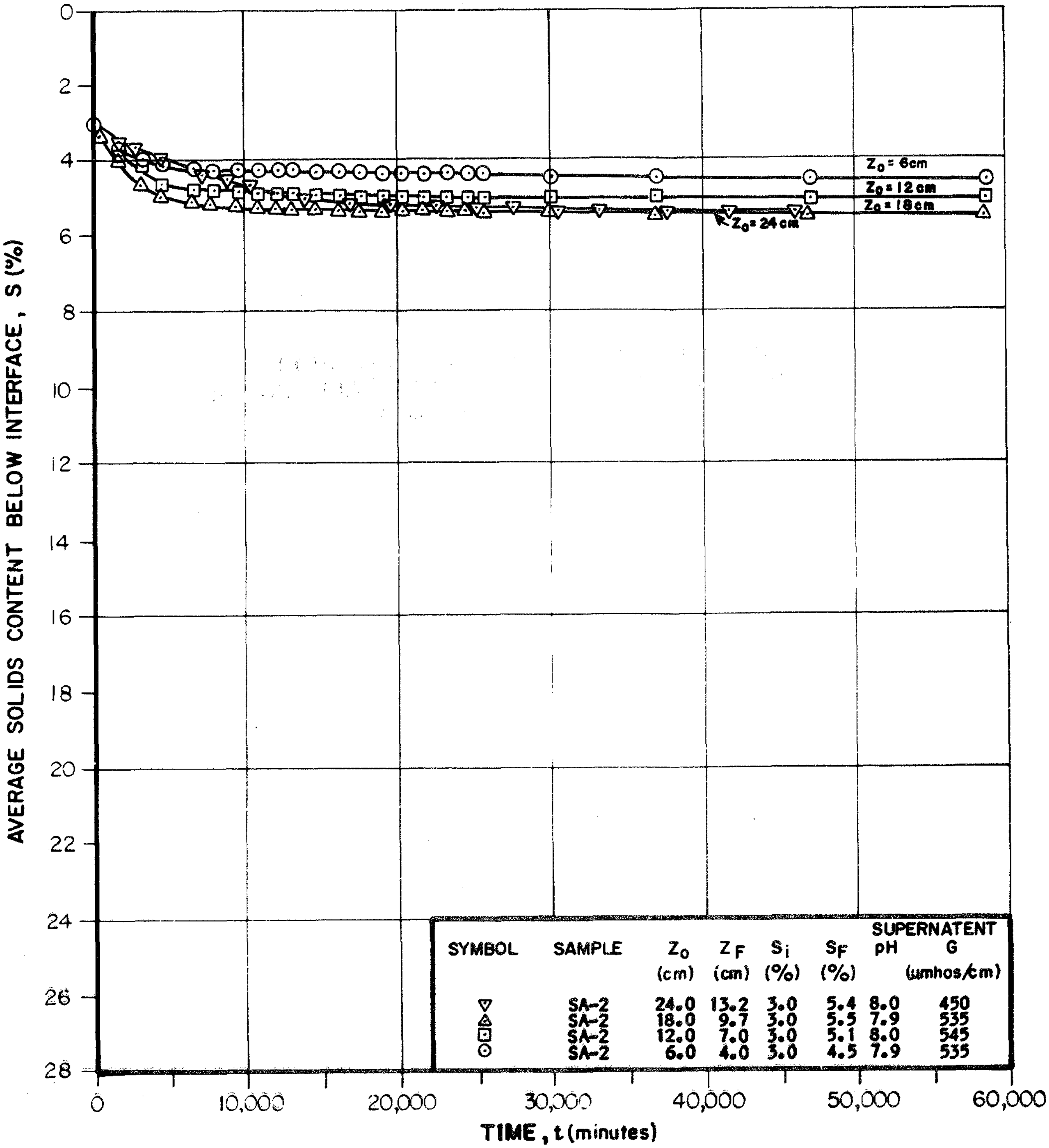
FIGURE B-36



SETTLING TEST - HEIGHT VS. LOG TIME FOR WR GRACE - FOUR CORNERS PILOT PLANT PHOSPHATIC CLAY

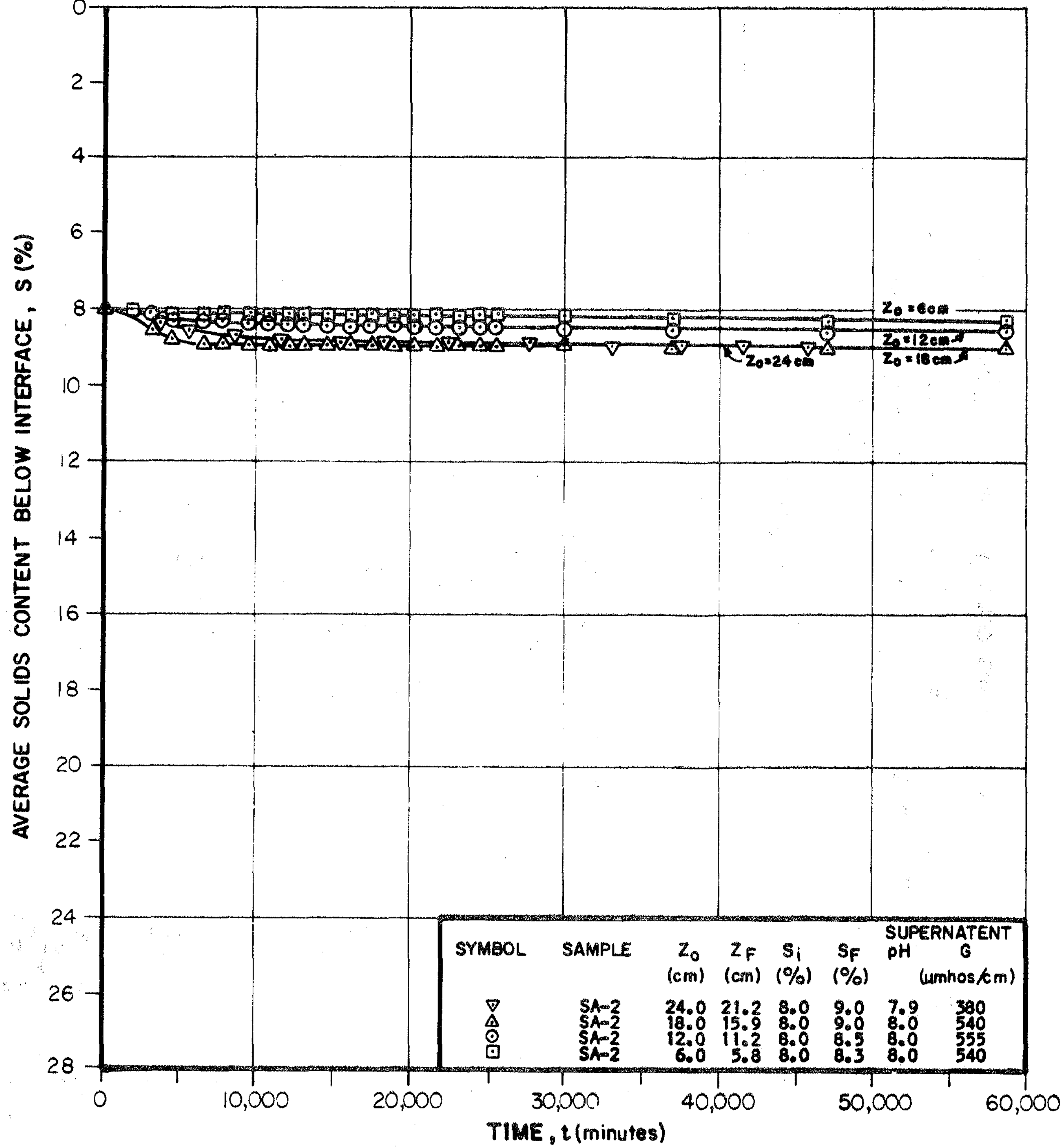
Appendix C

GRAPHICAL PLOTS OF SOLIDS CONTENT AND HEIGHT OF INTERFACE VERSUS TIME FOR VARIABLE INITIAL HEIGHT SETTLING TESTS



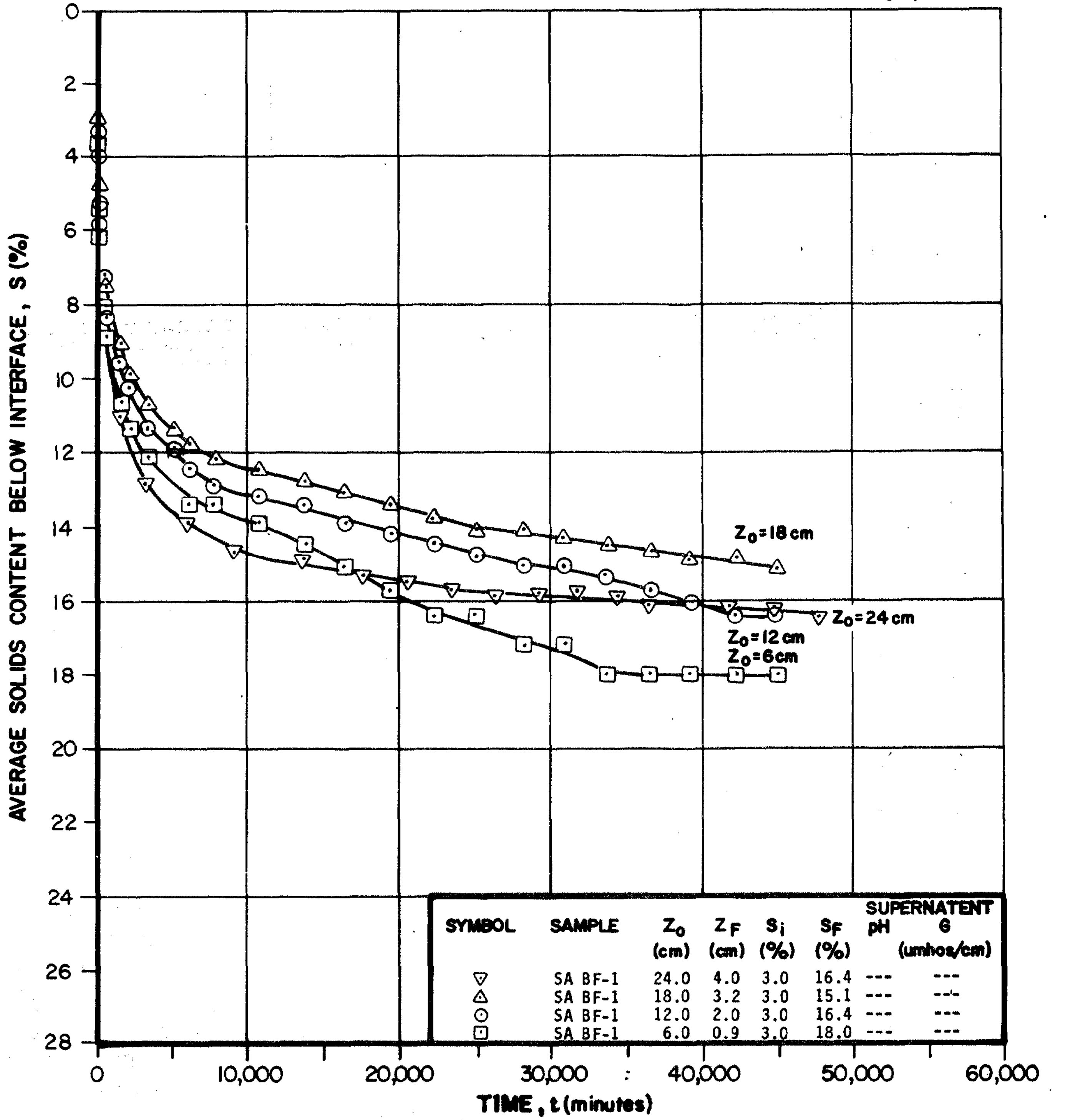
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-1



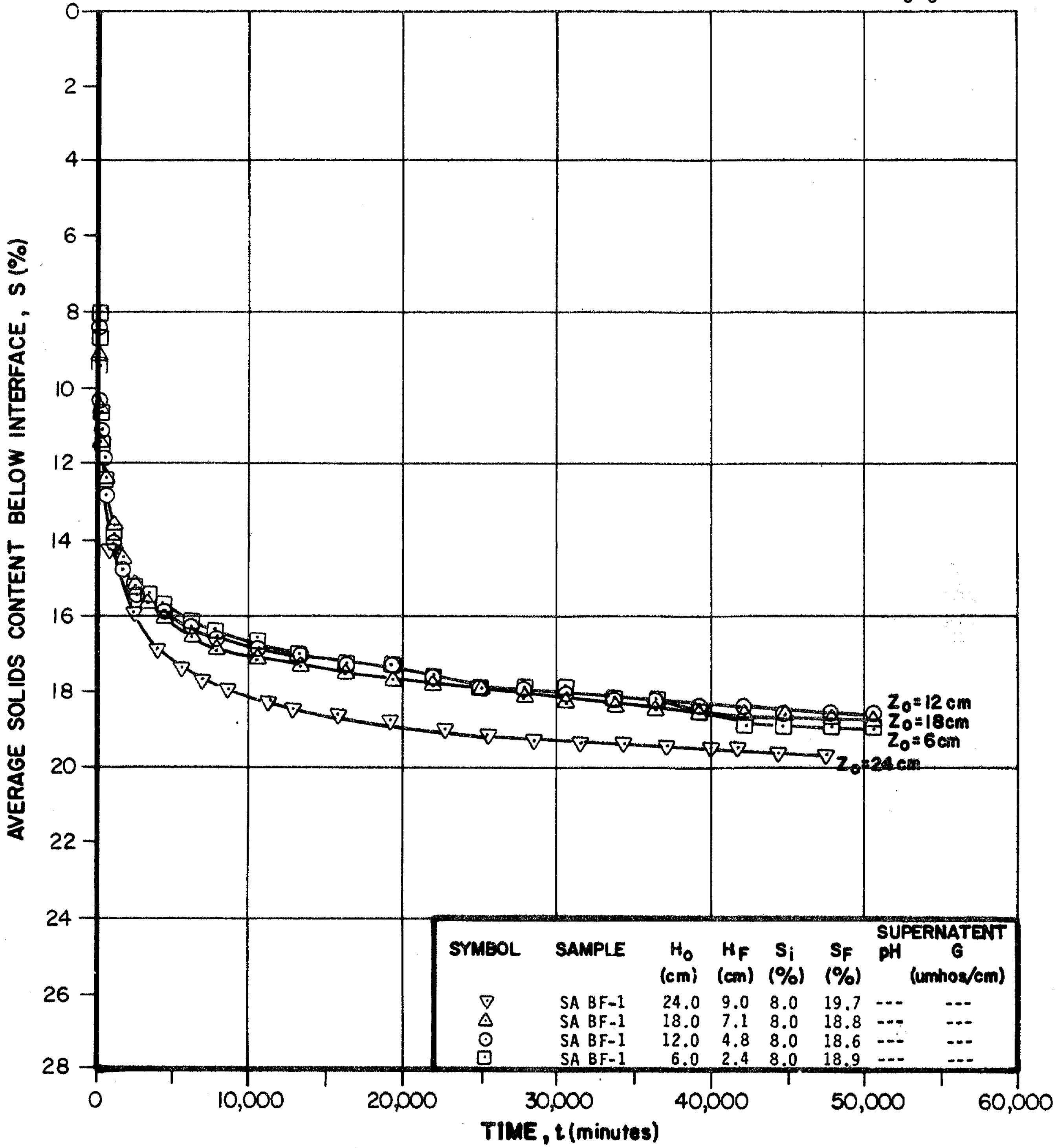
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-2



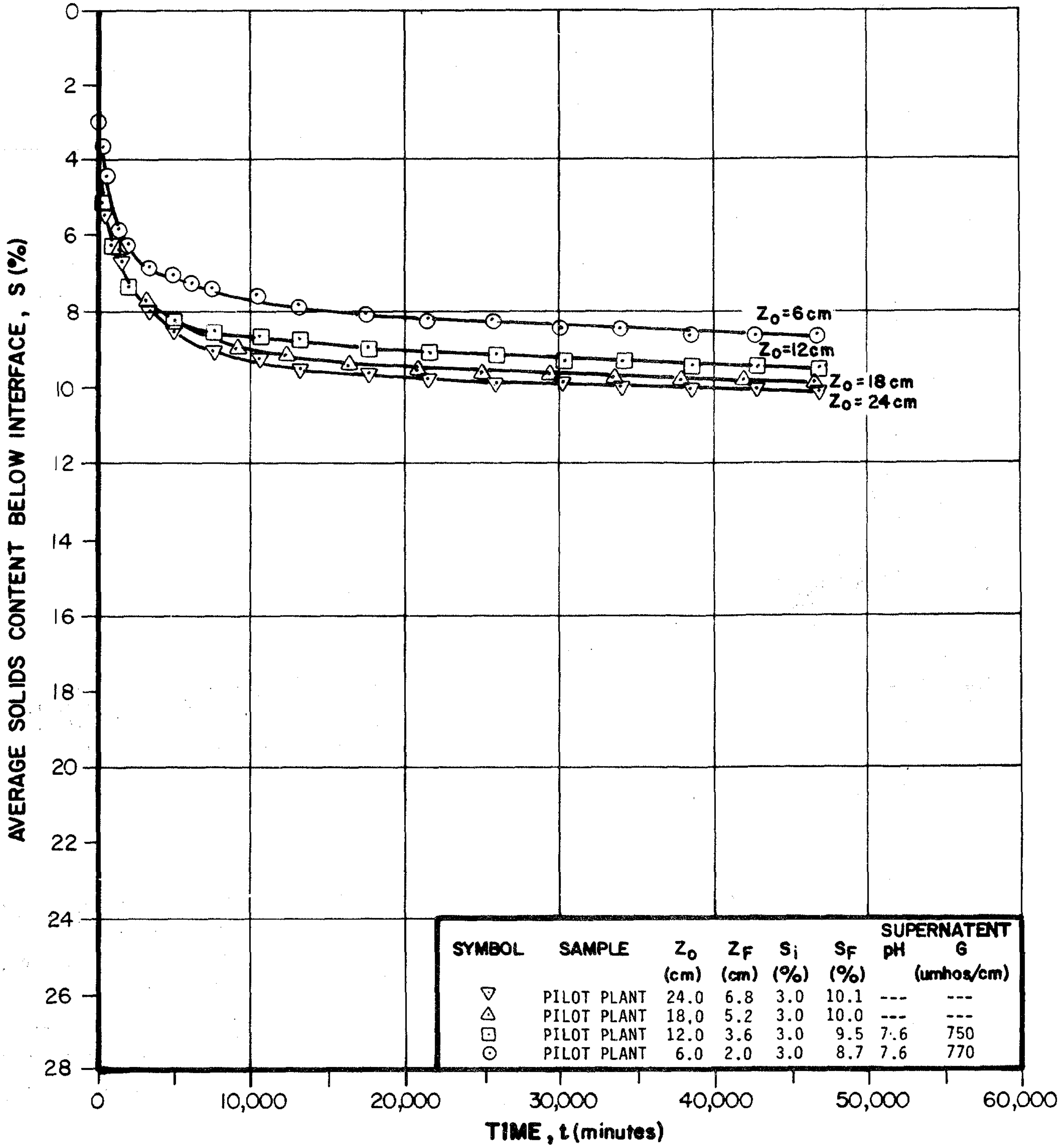
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-3



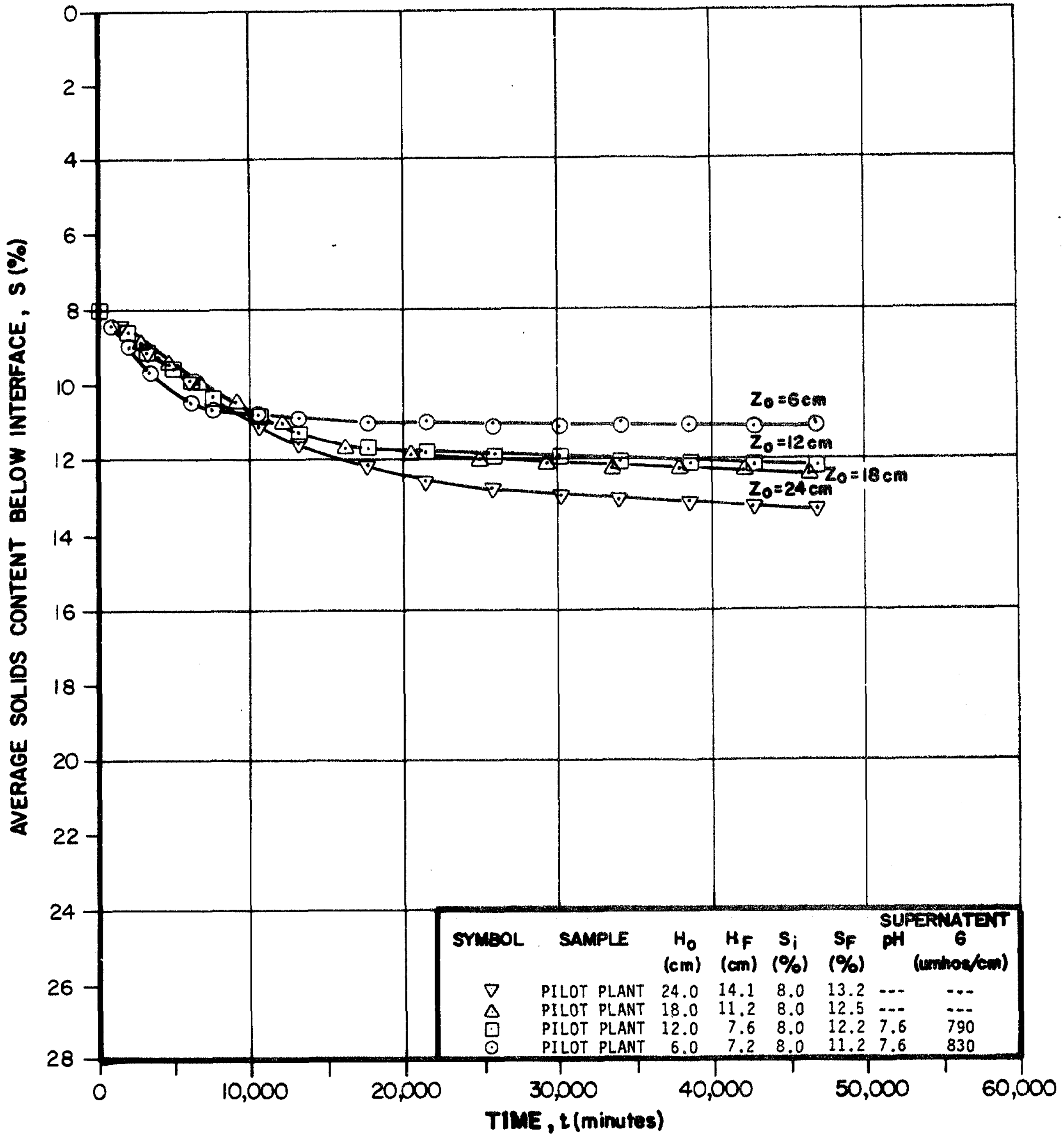
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-4



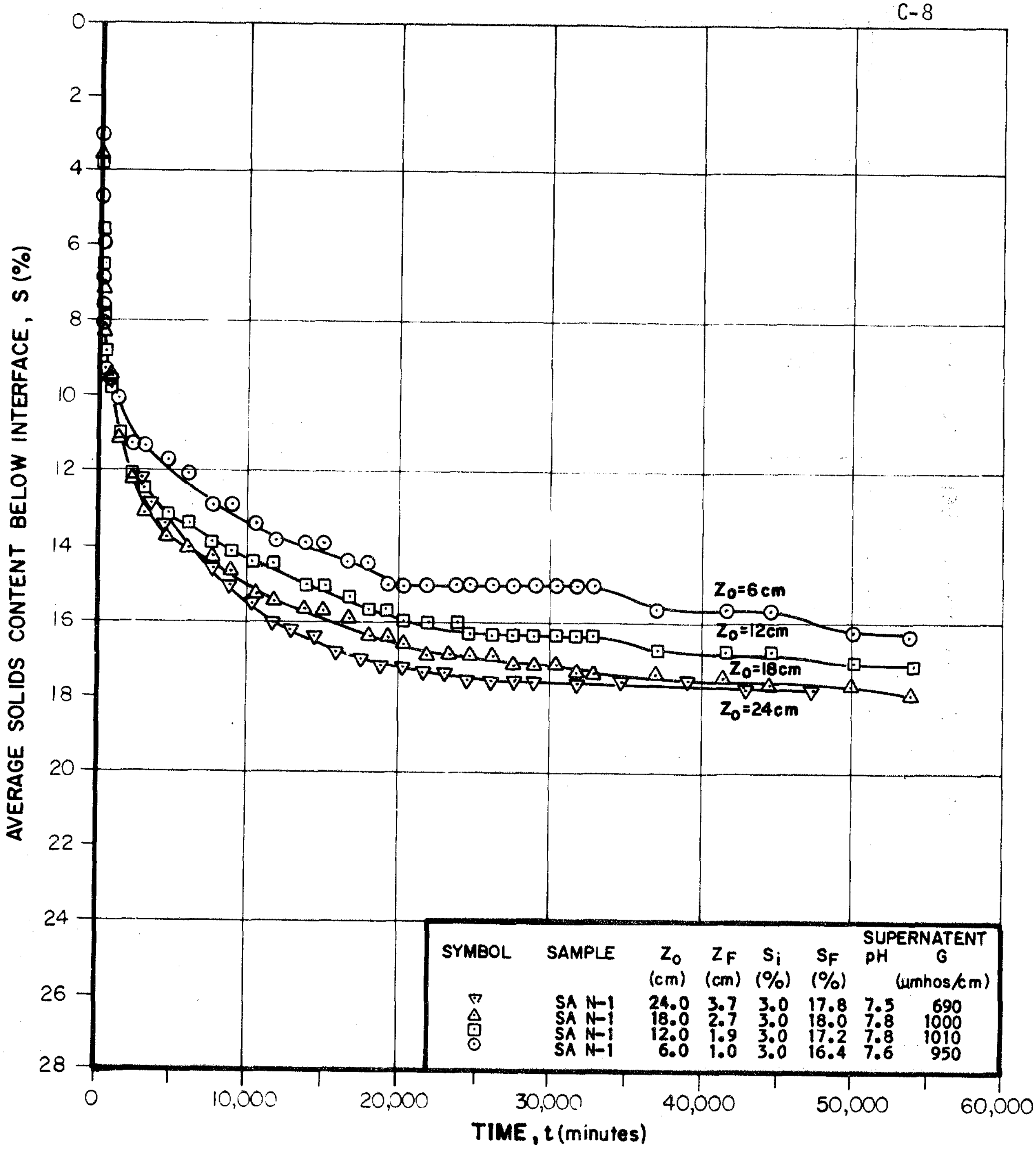
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-5

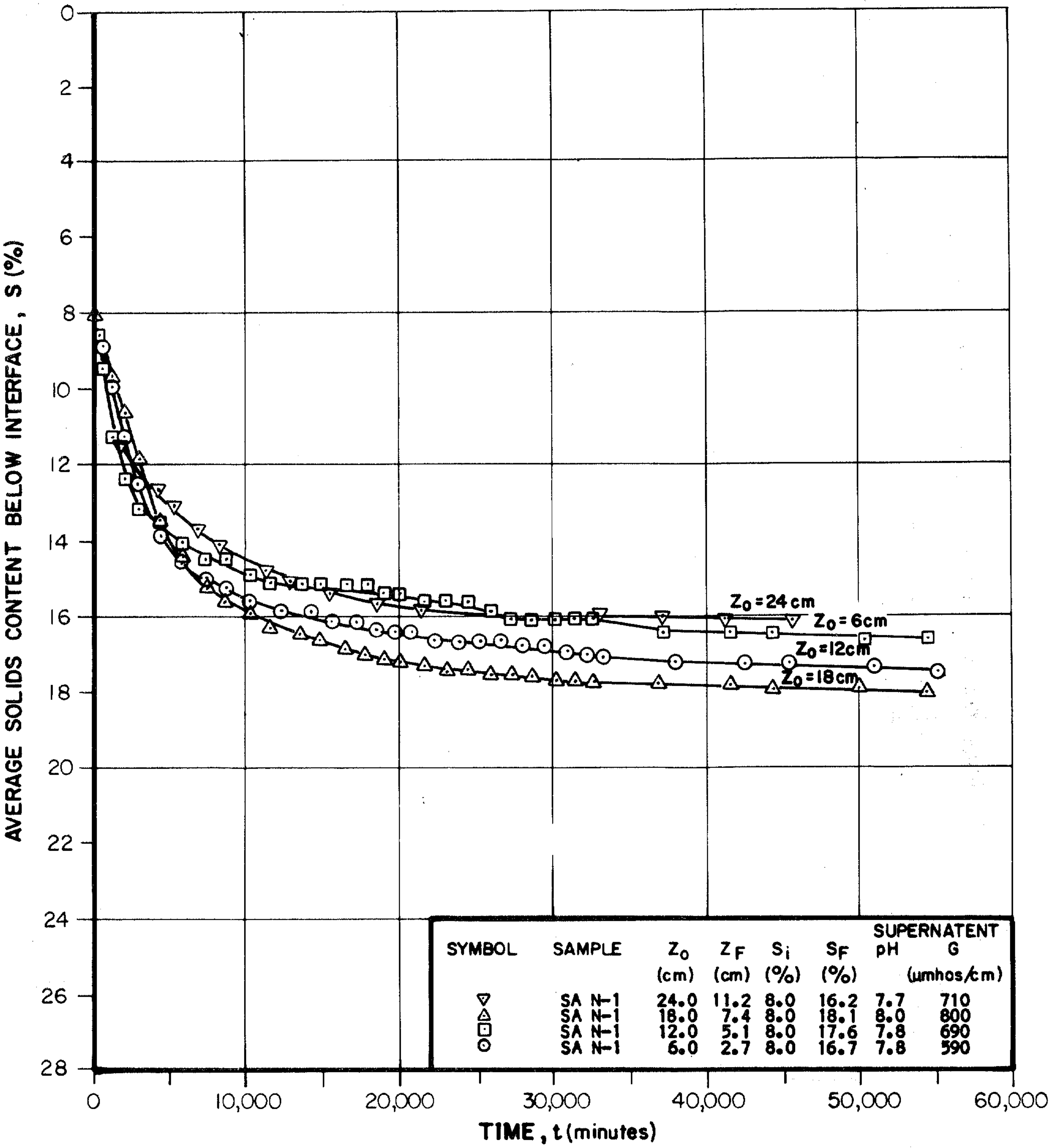


SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

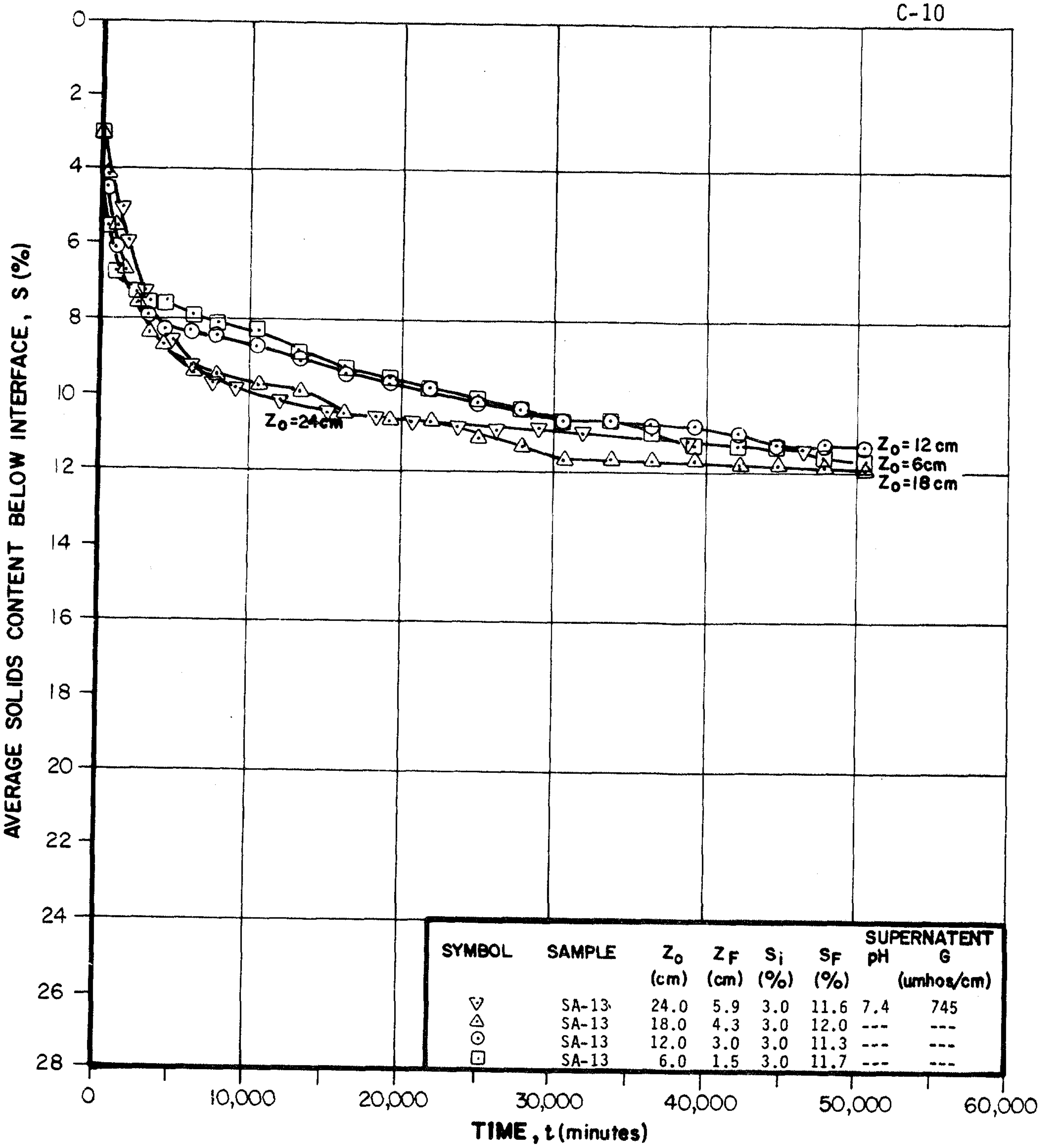
FIGURE C-6



SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

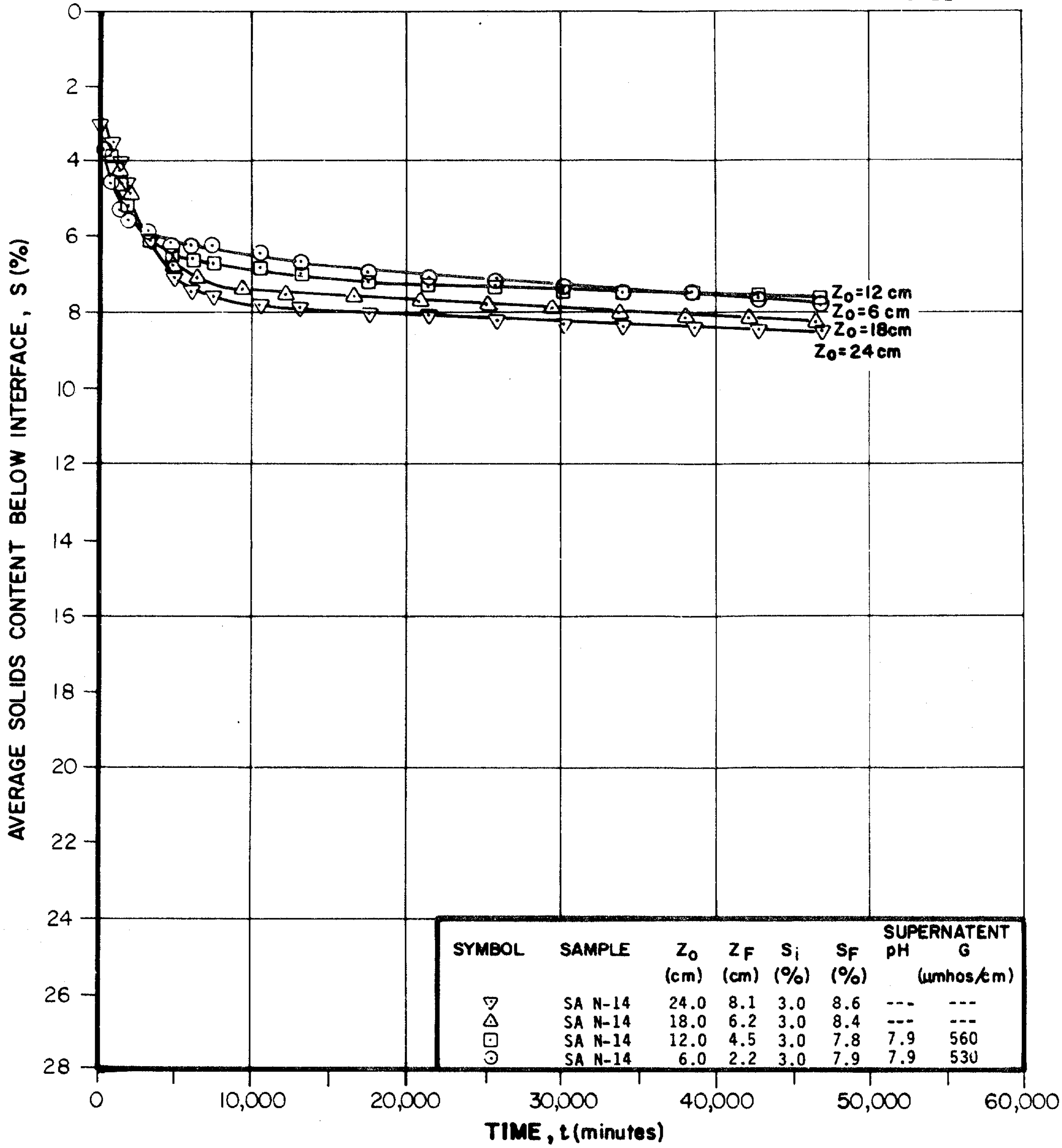


SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%



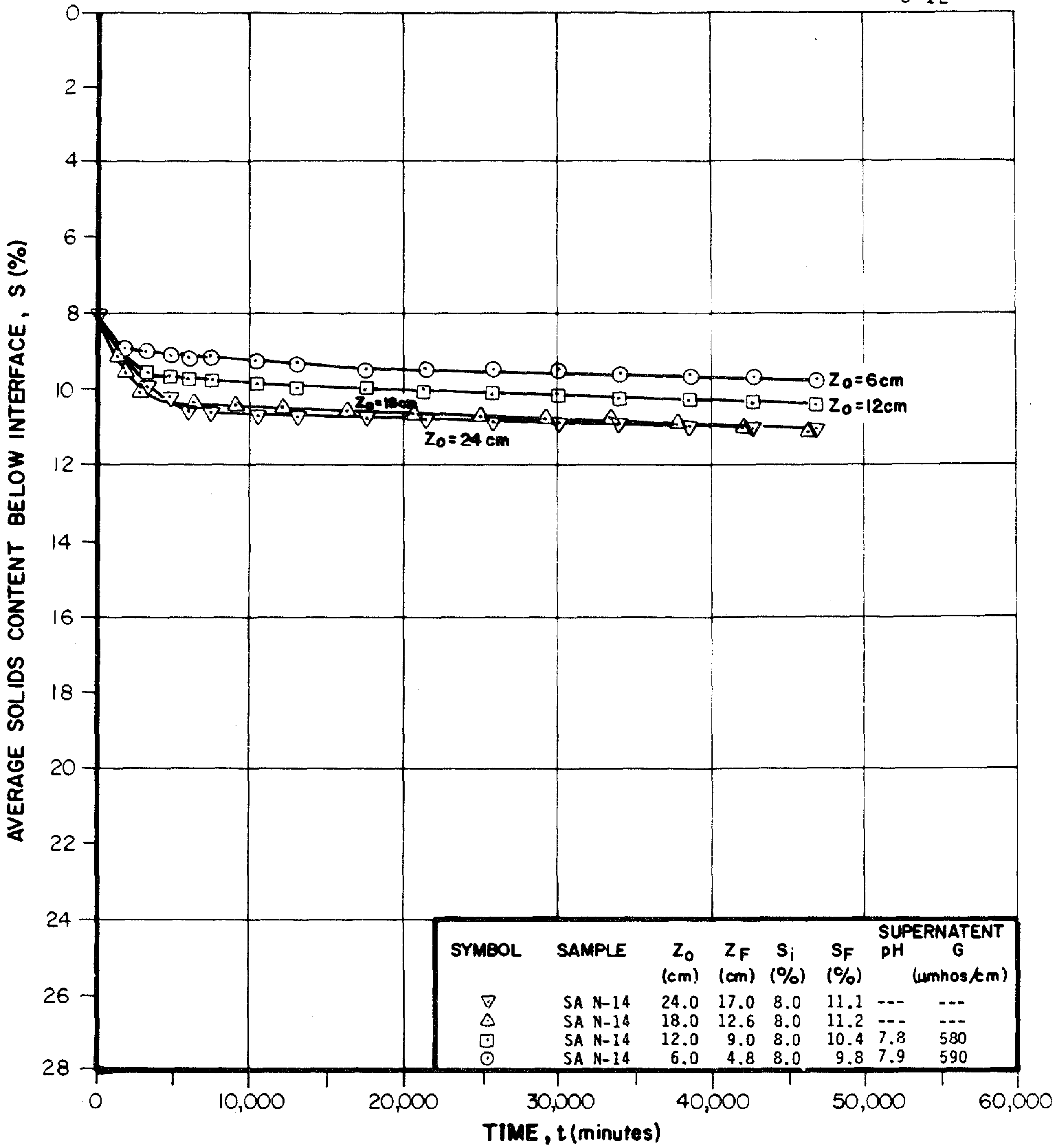
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR ESTECH-WATSON PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-9



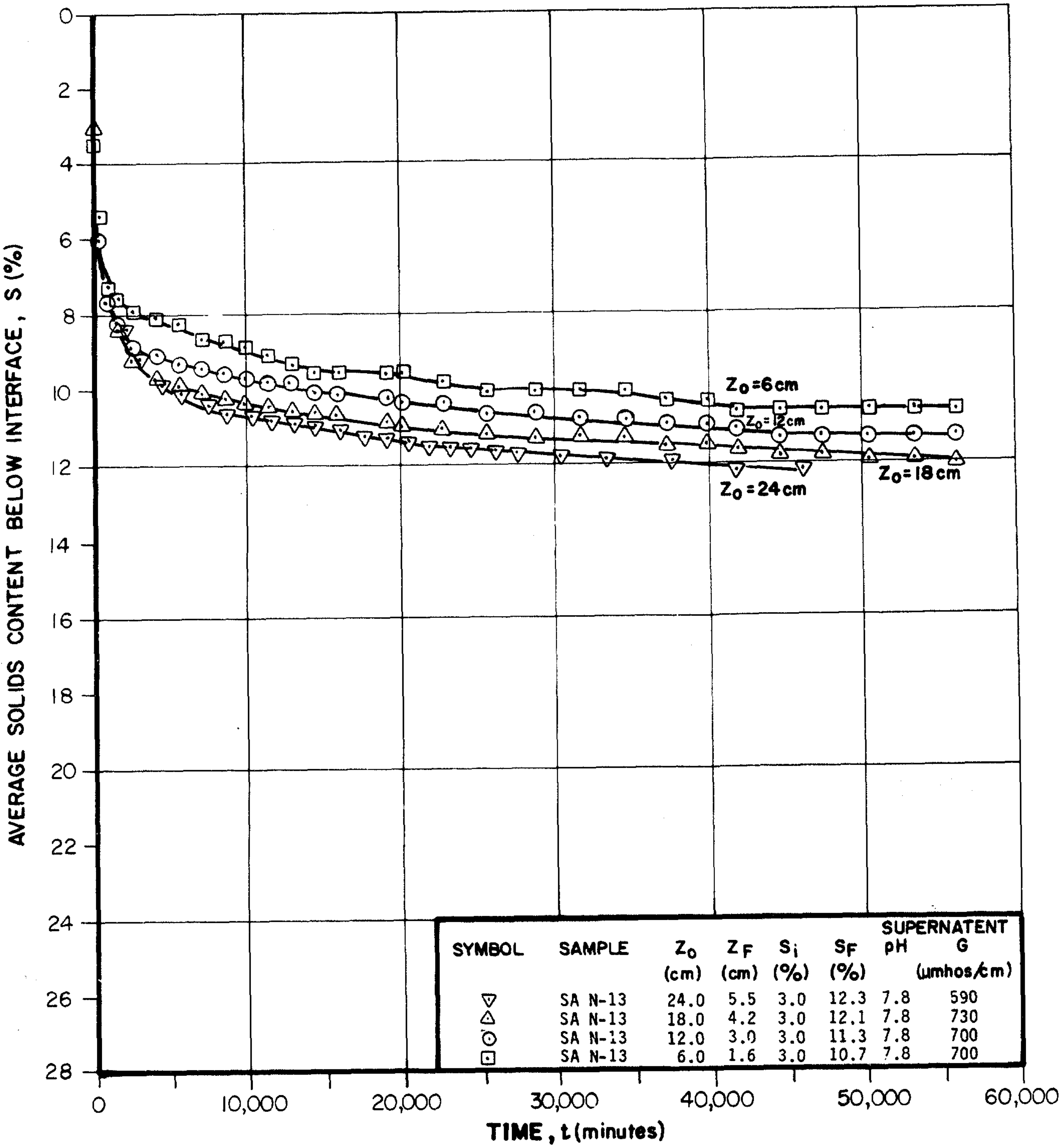
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-10



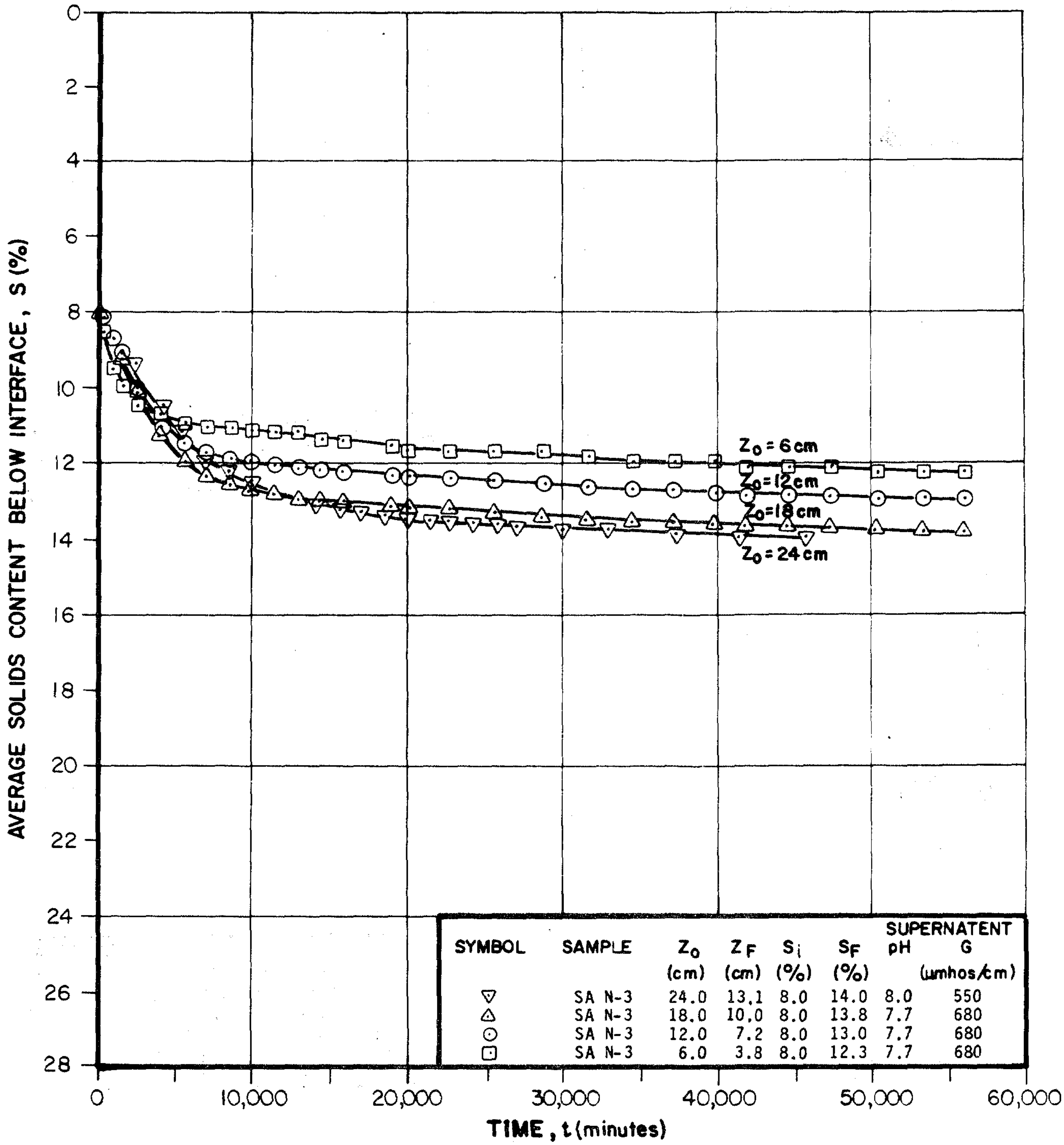
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-11



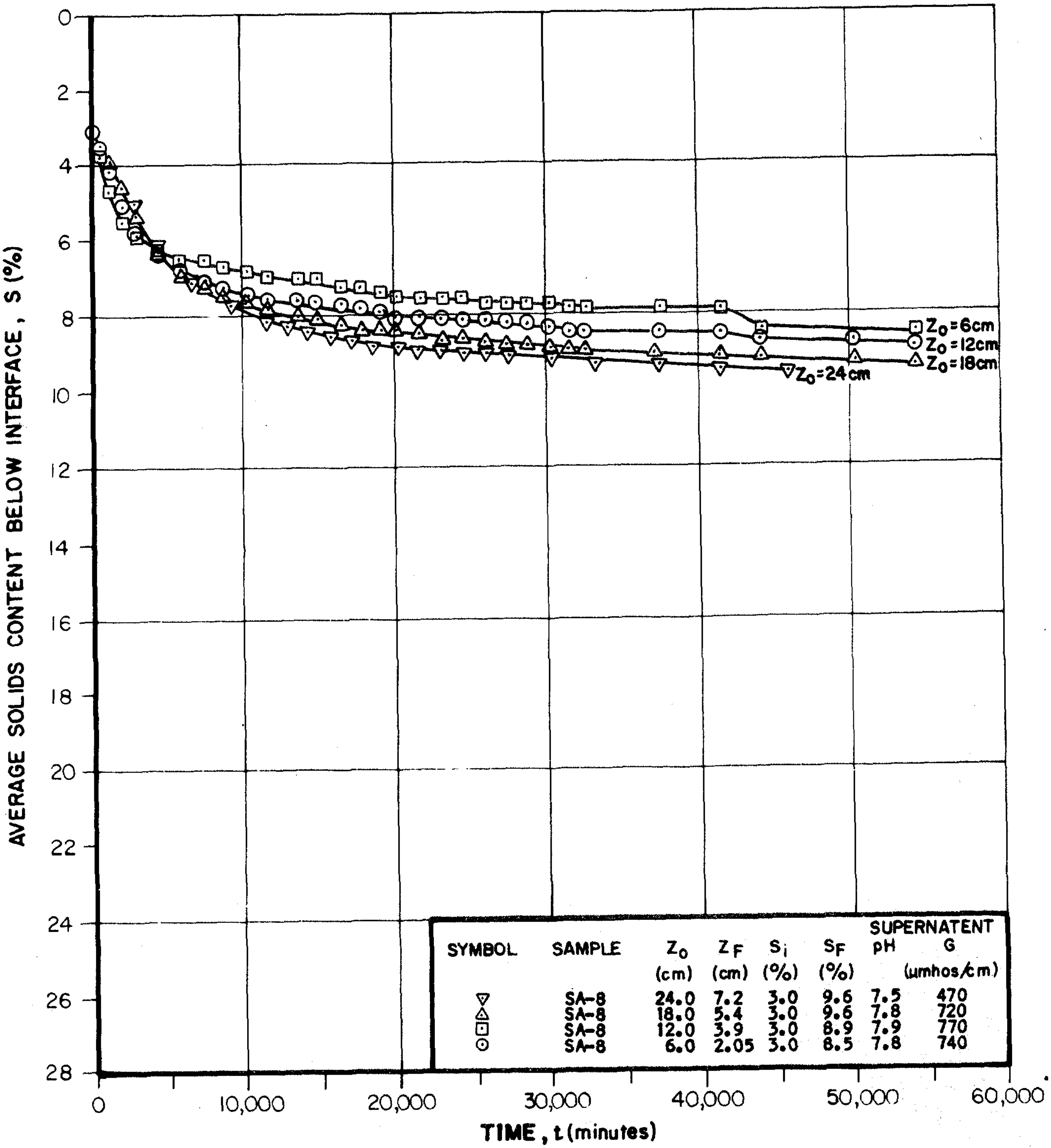
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-12

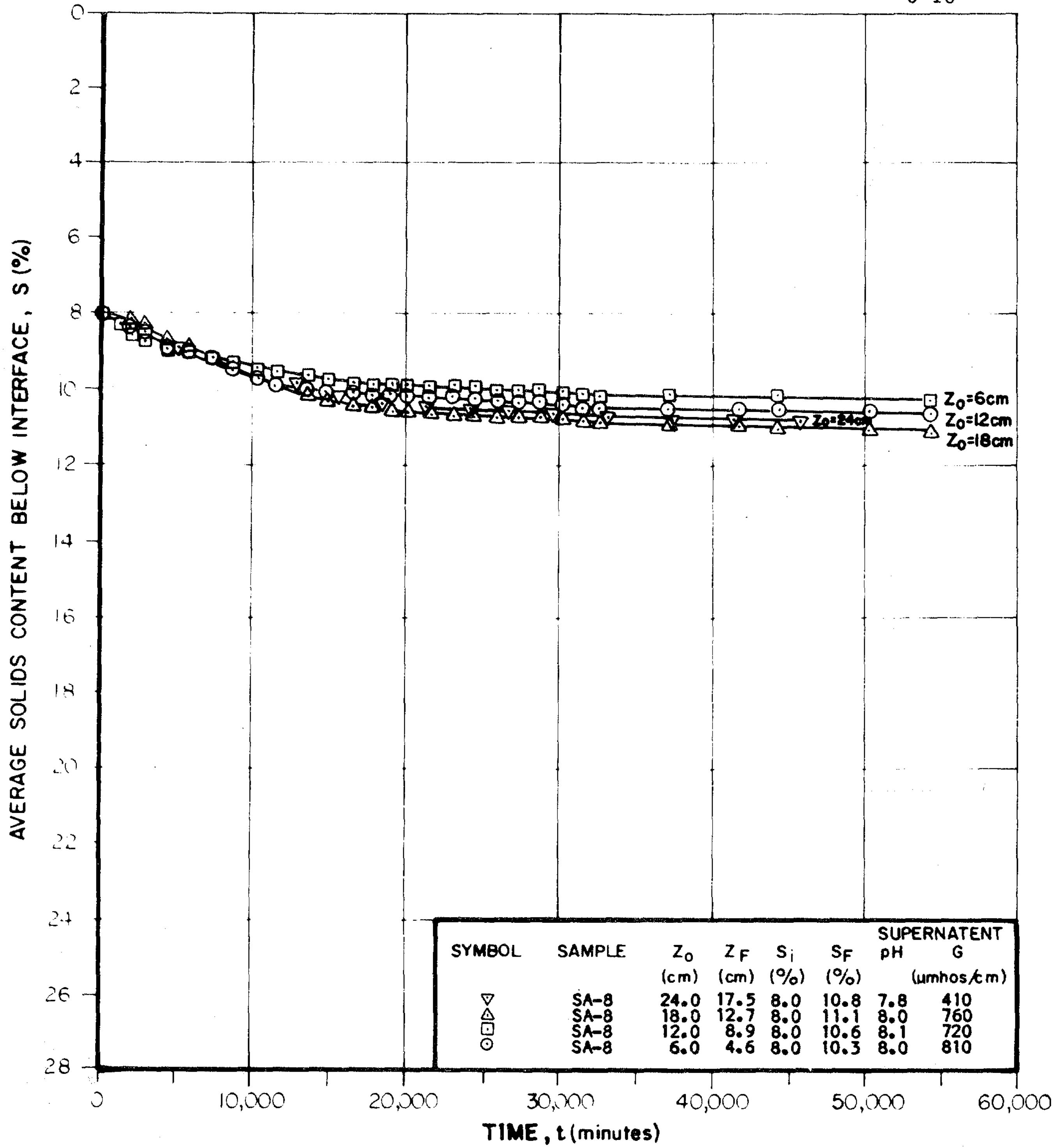


SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-13

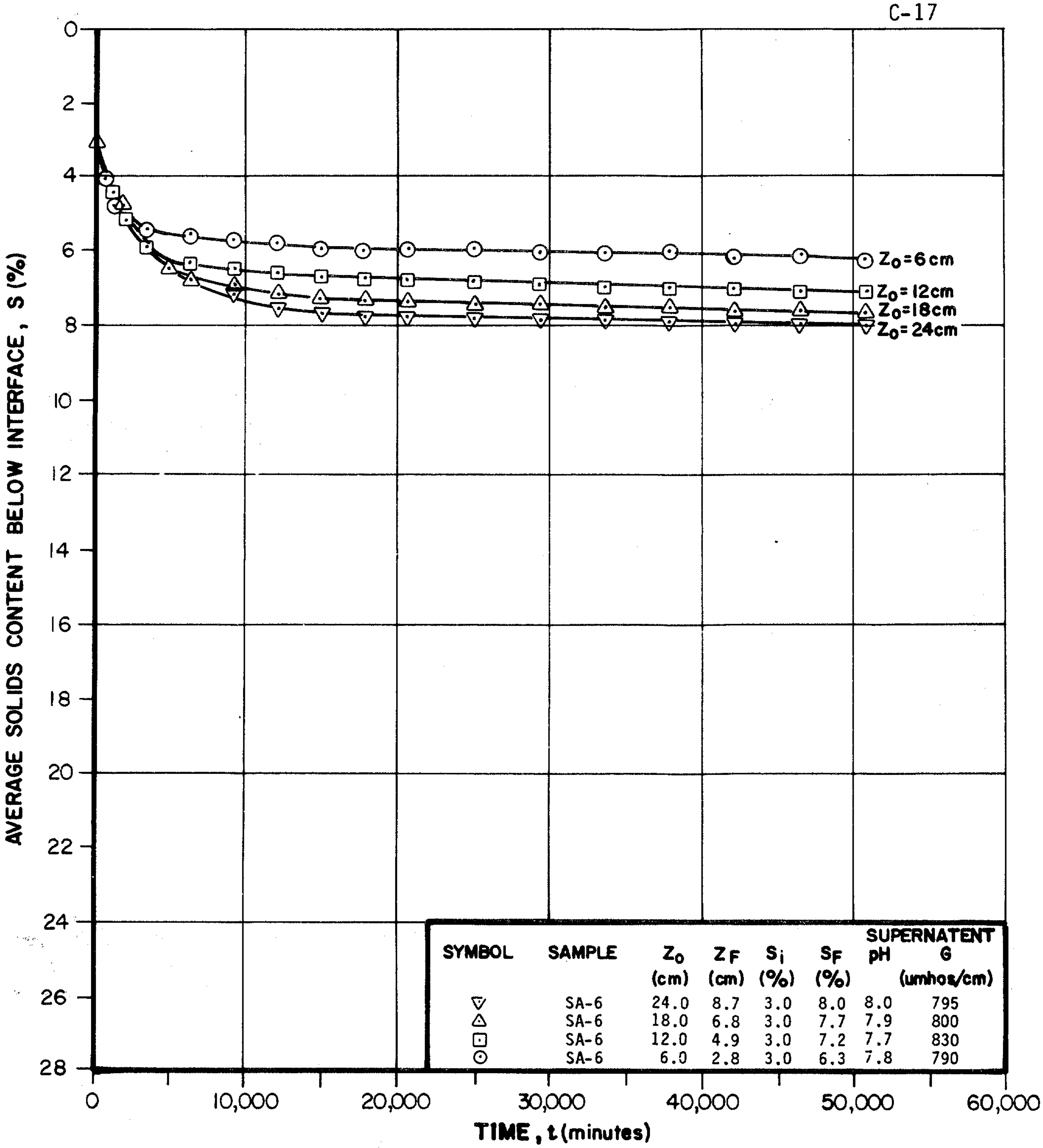


SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%



SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

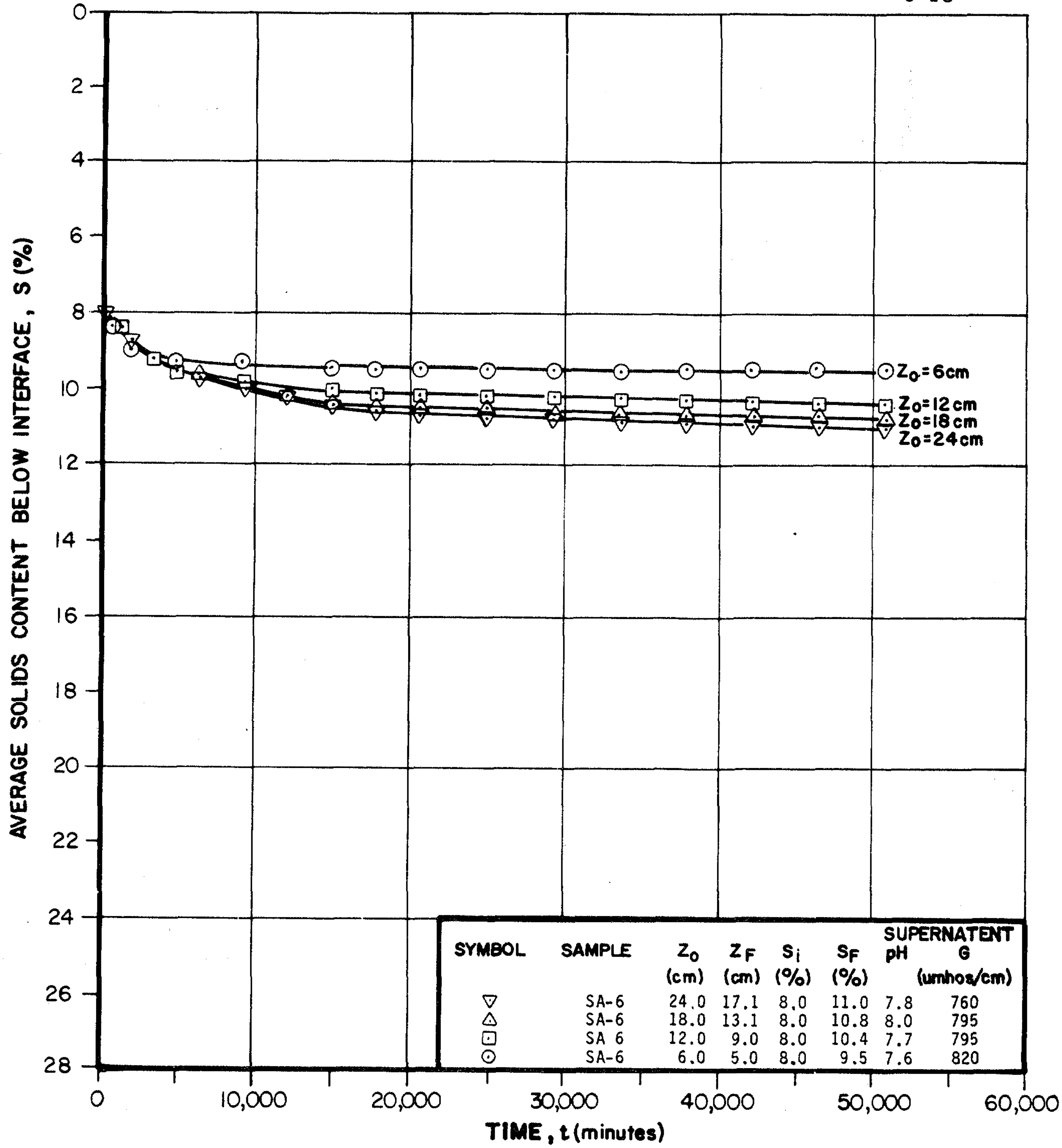
FIGURE C-15



SYMBOL	SAMPLE	Z_o (cm)	Z_F (cm)	S_i (%)	S_F (%)	SUPERNATENT pH	SUPERNATENT G (umhos/cm)
▽	SA-6	24.0	8.7	3.0	8.0	8.0	795
△	SA-6	18.0	6.8	3.0	7.7	7.9	800
⊡	SA-6	12.0	4.9	3.0	7.2	7.7	830
⊙	SA-6	6.0	2.8	3.0	6.3	7.8	790

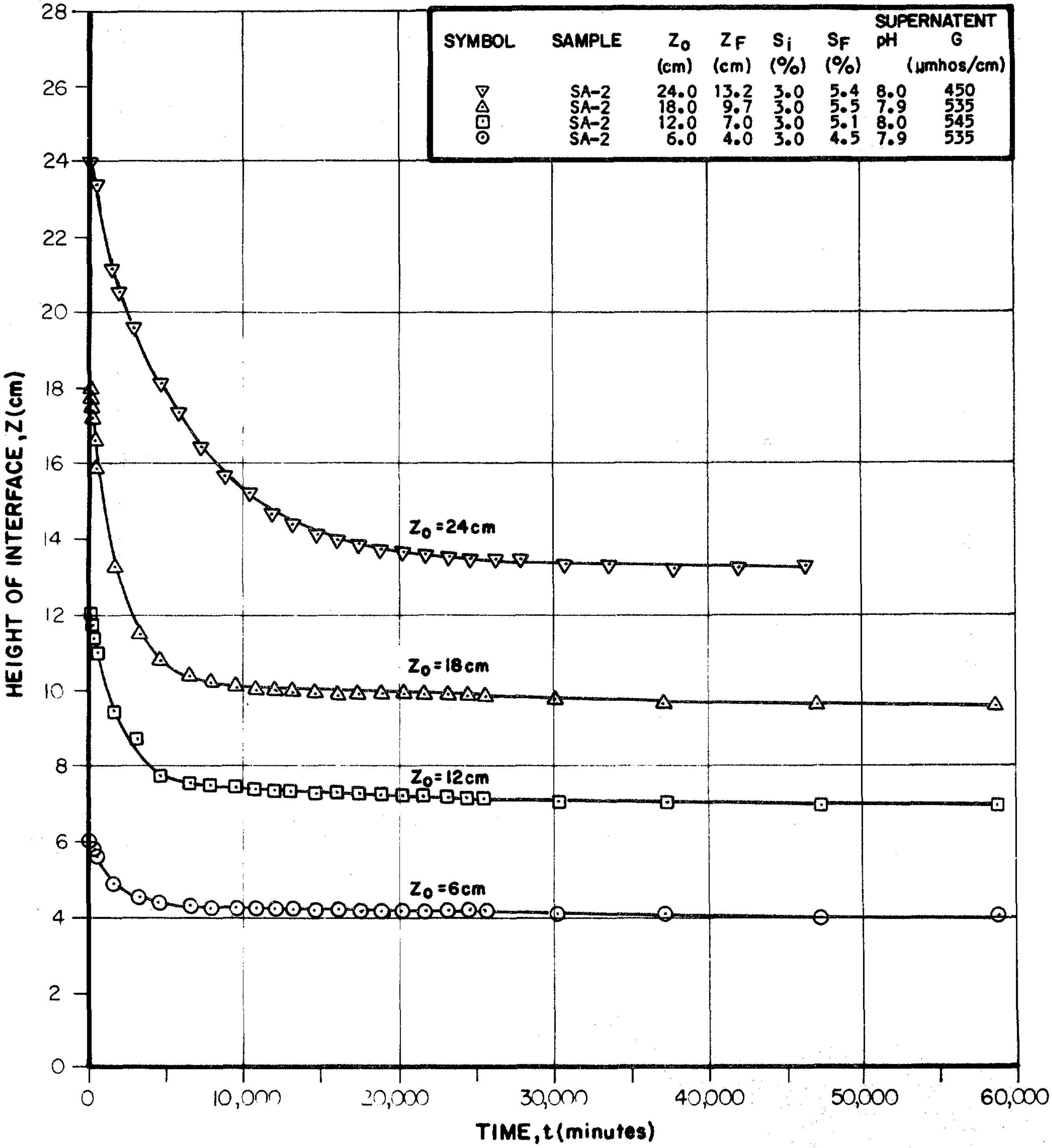
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-16



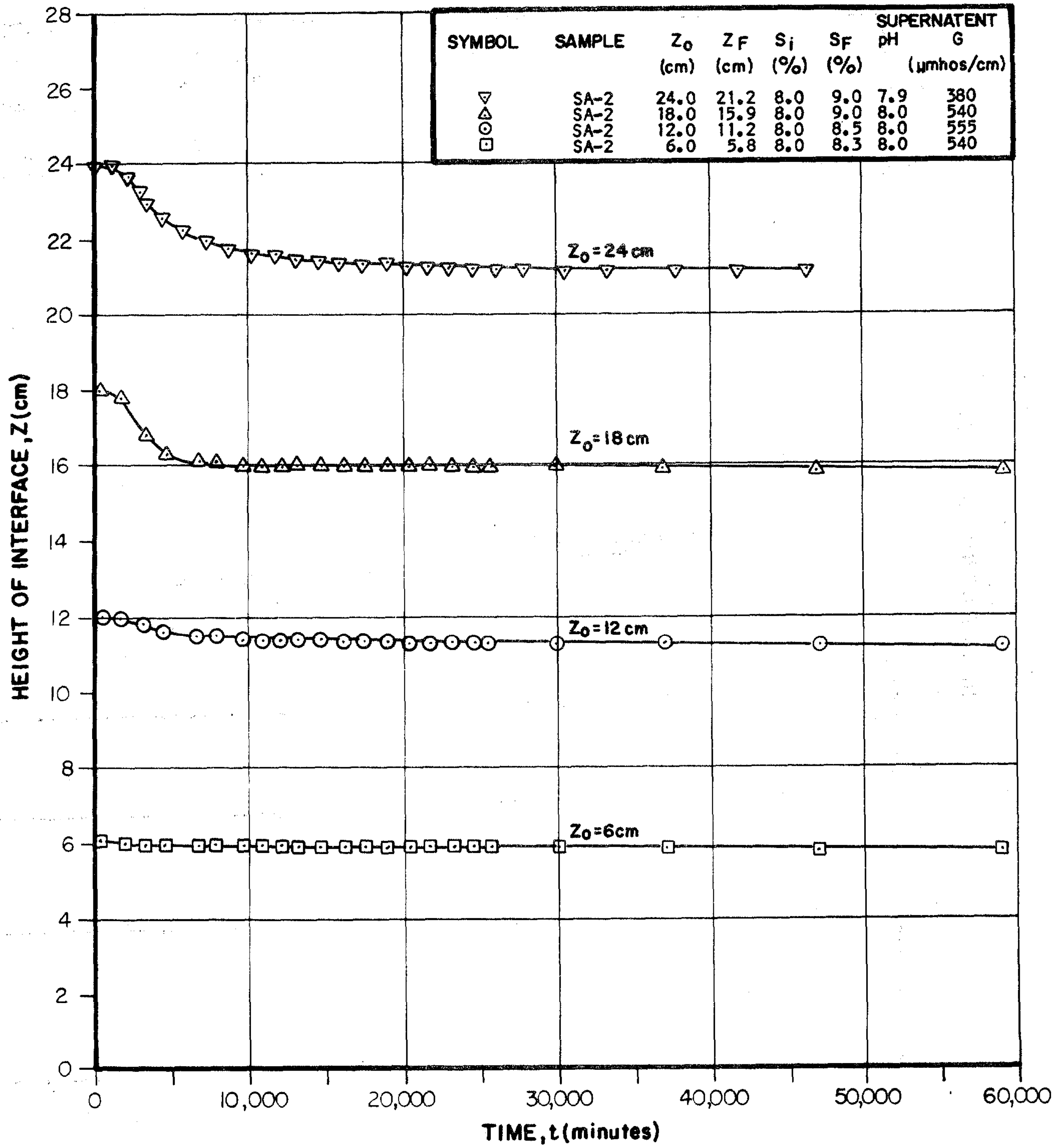
SETTLING TEST - SOLIDS CONTENT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-17

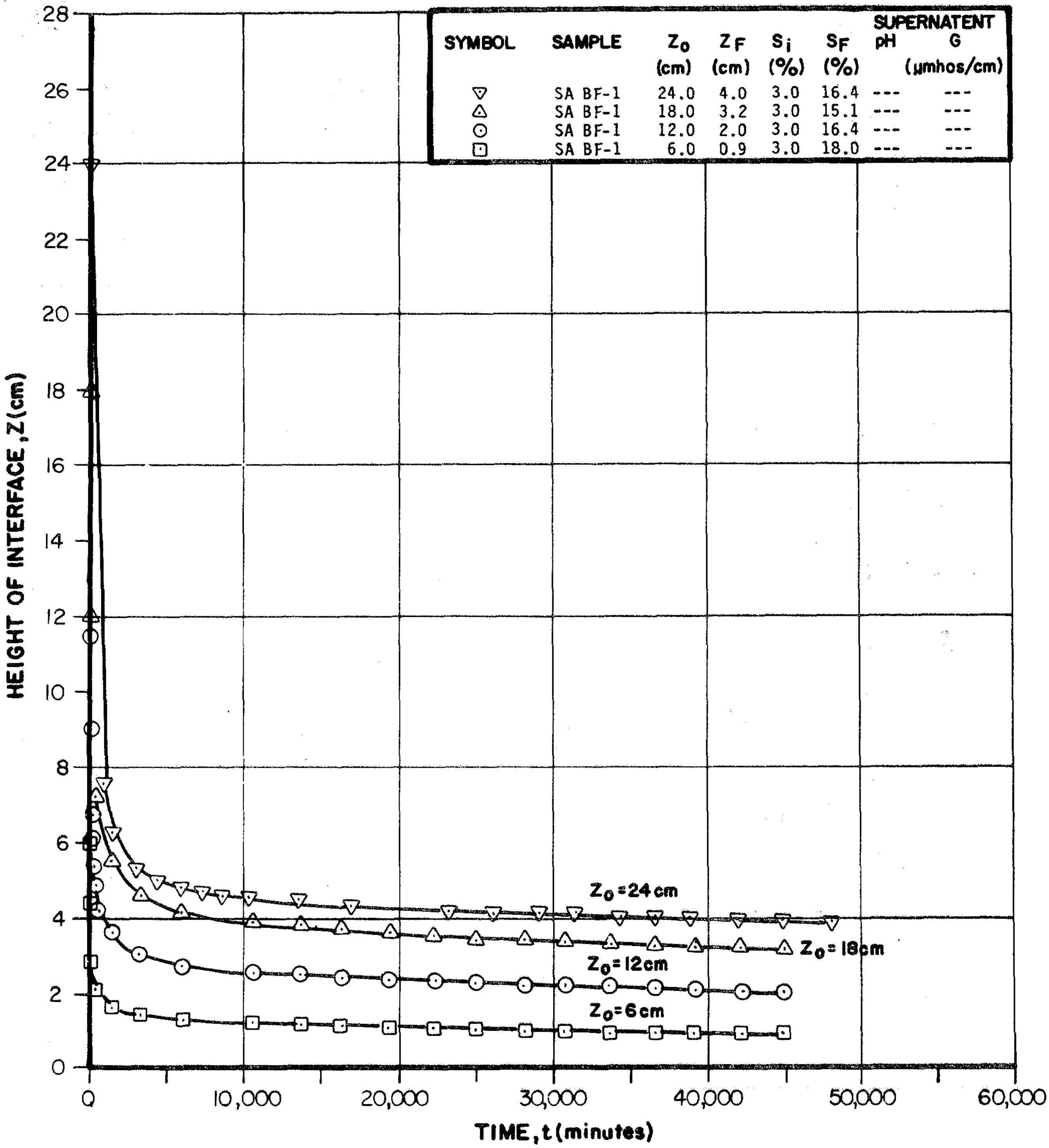


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-18

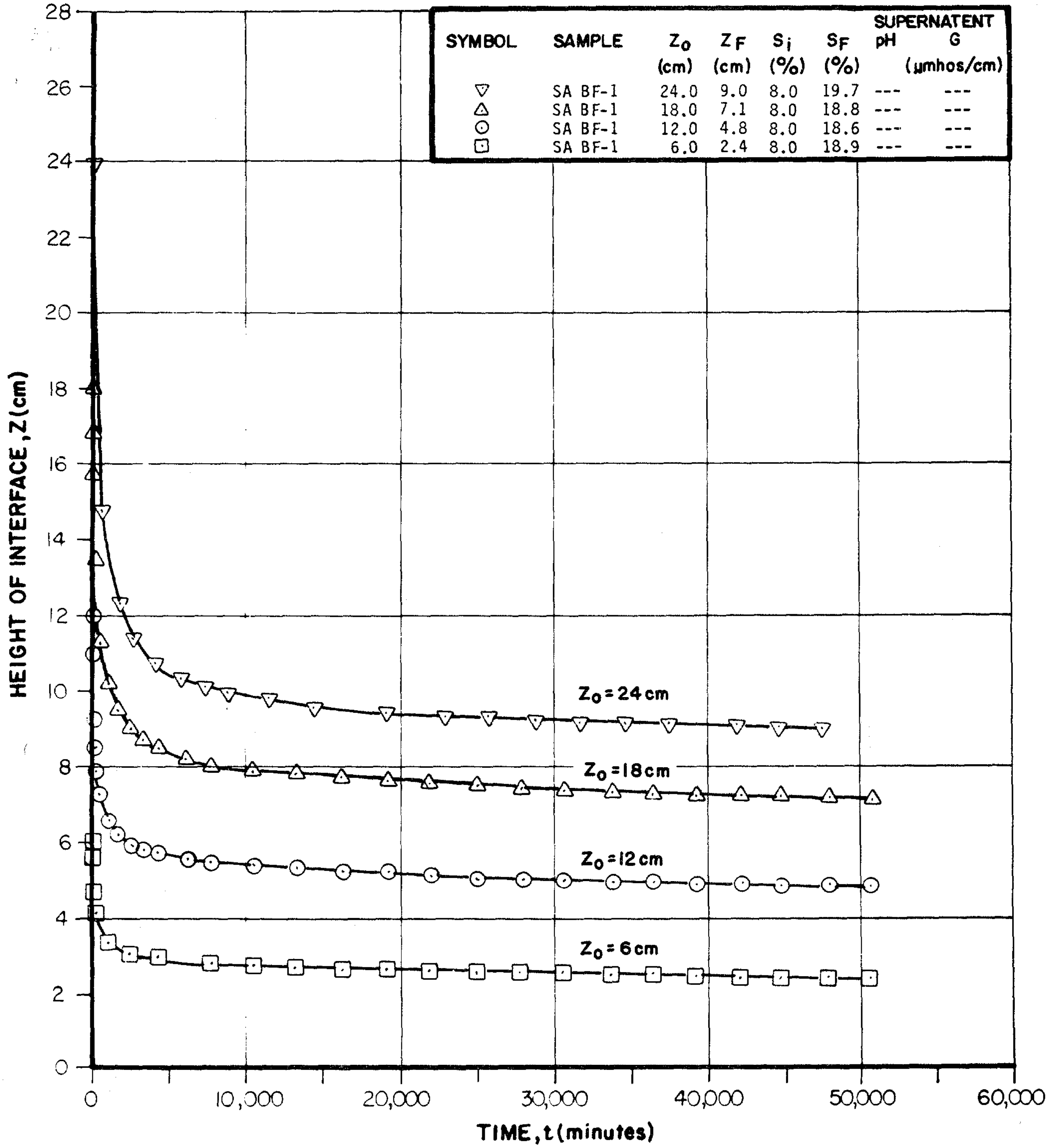


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%



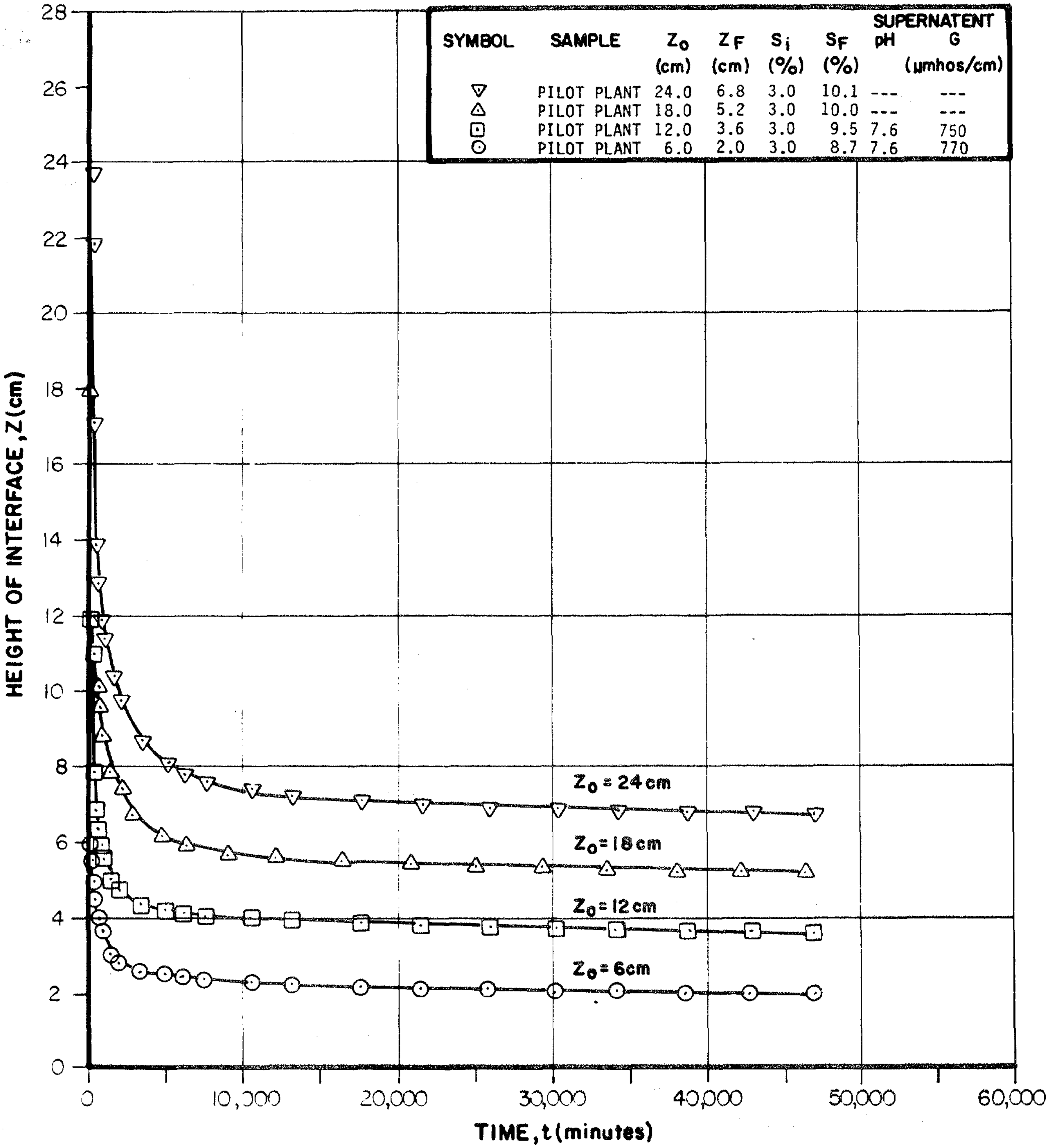
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-20



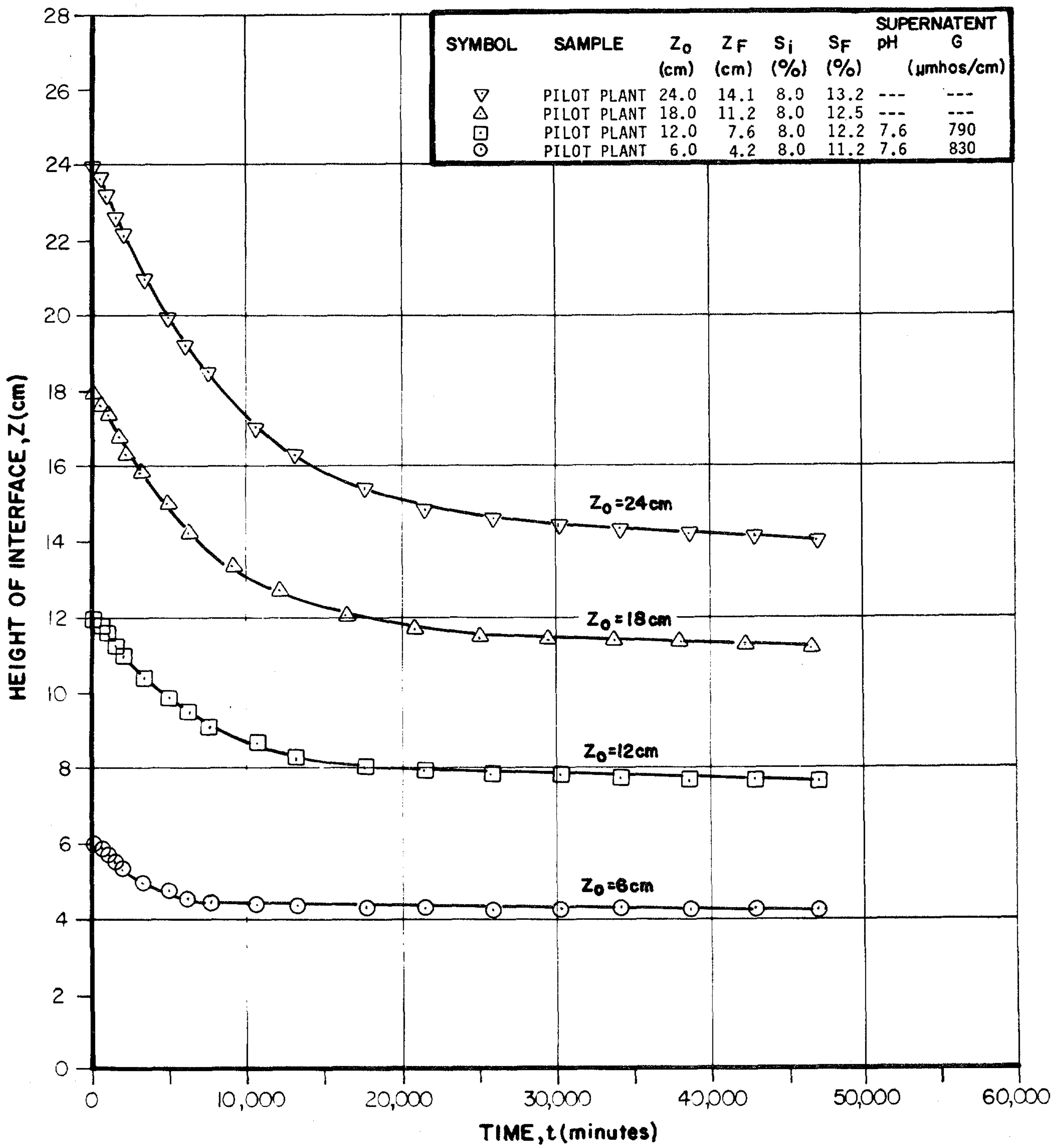
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-21



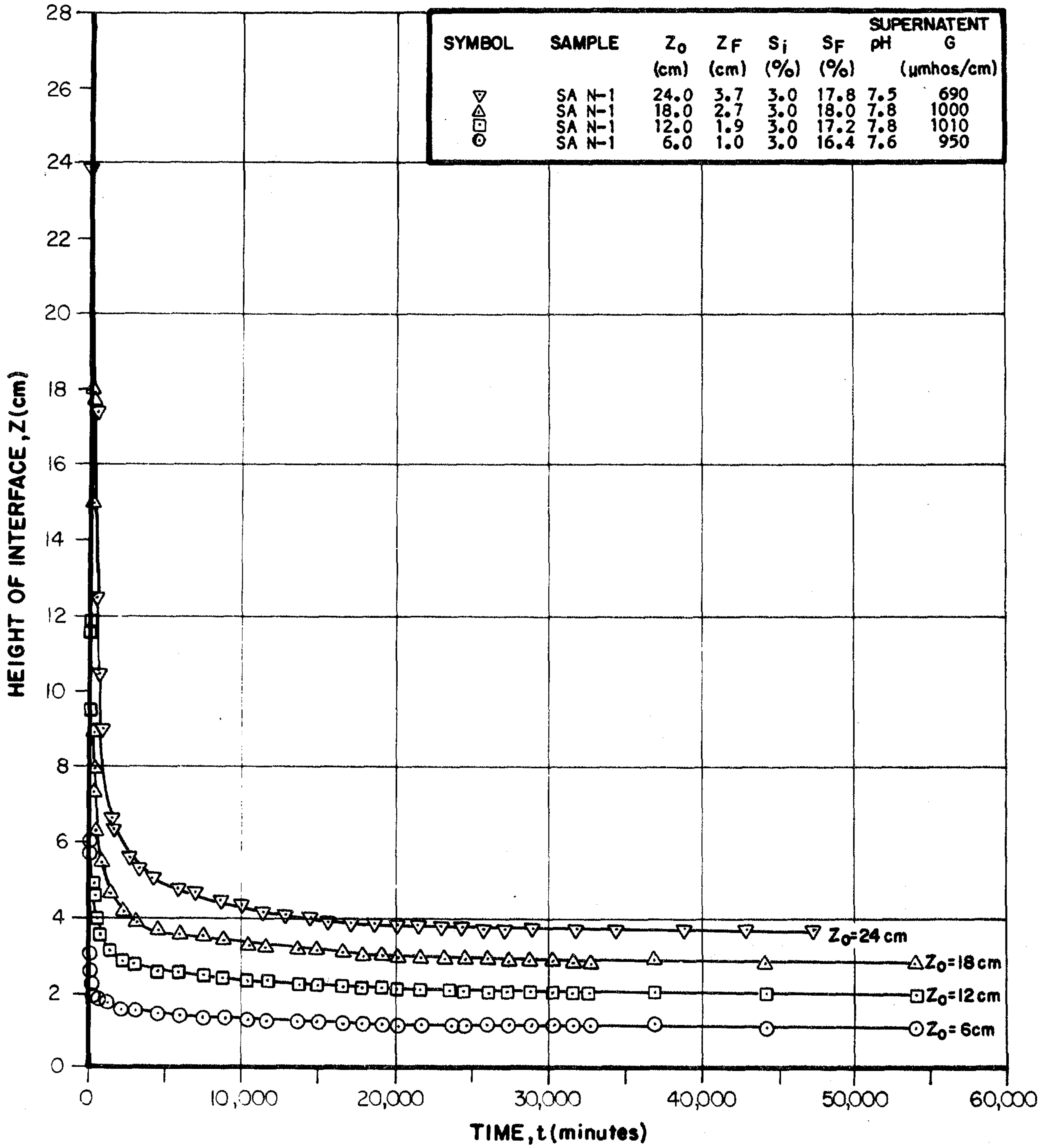
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-22



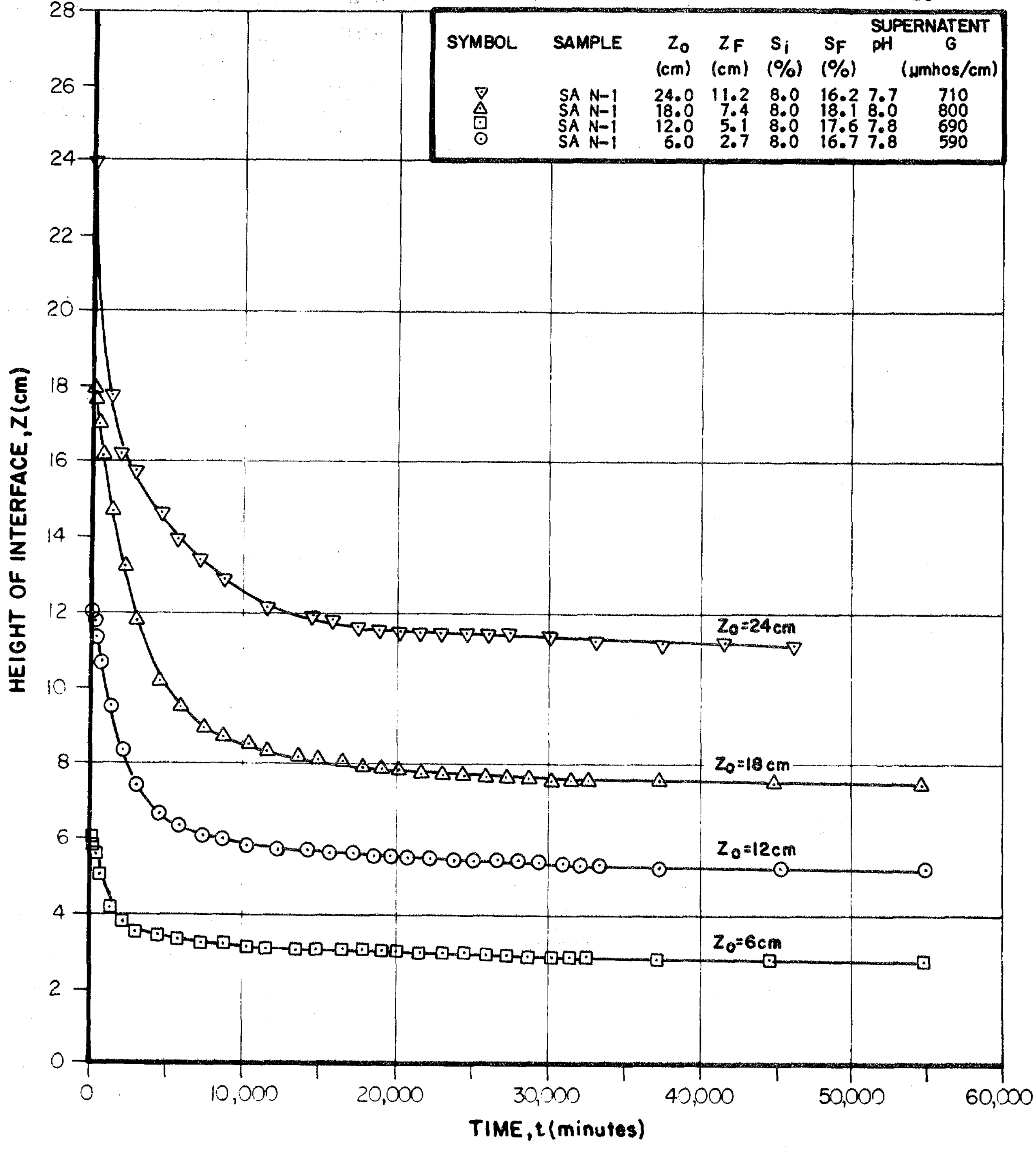
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-23



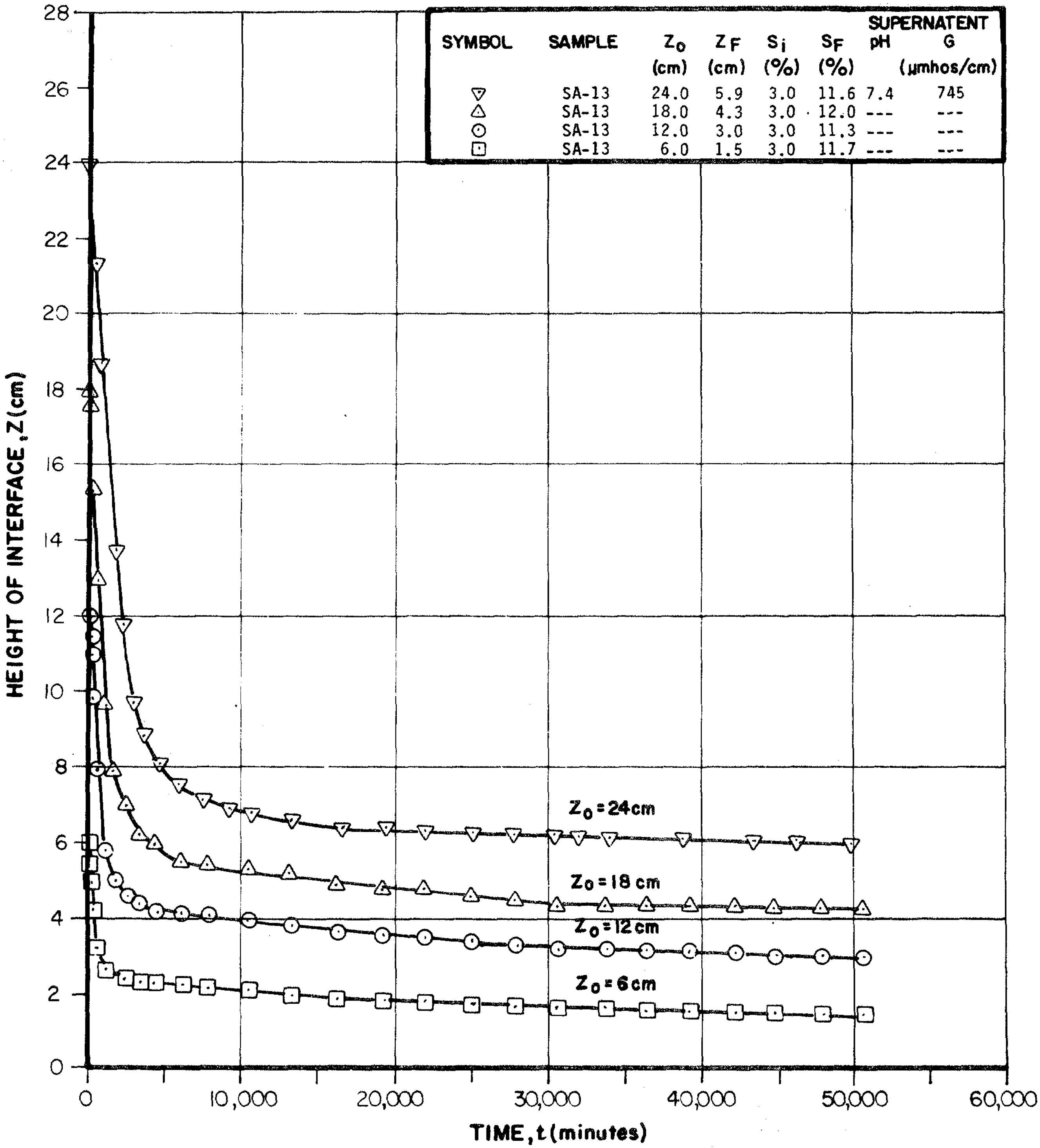
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-24



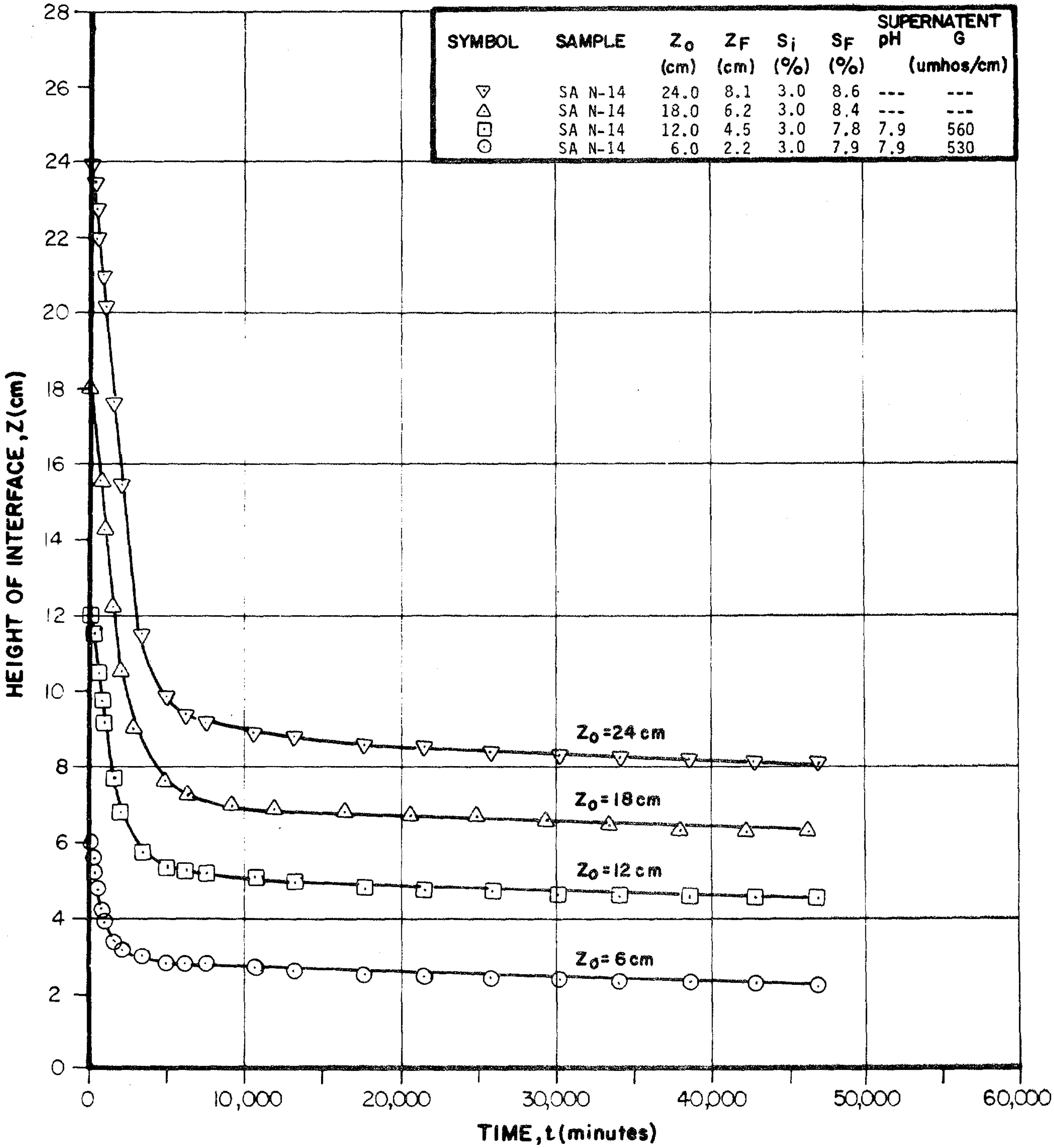
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-25



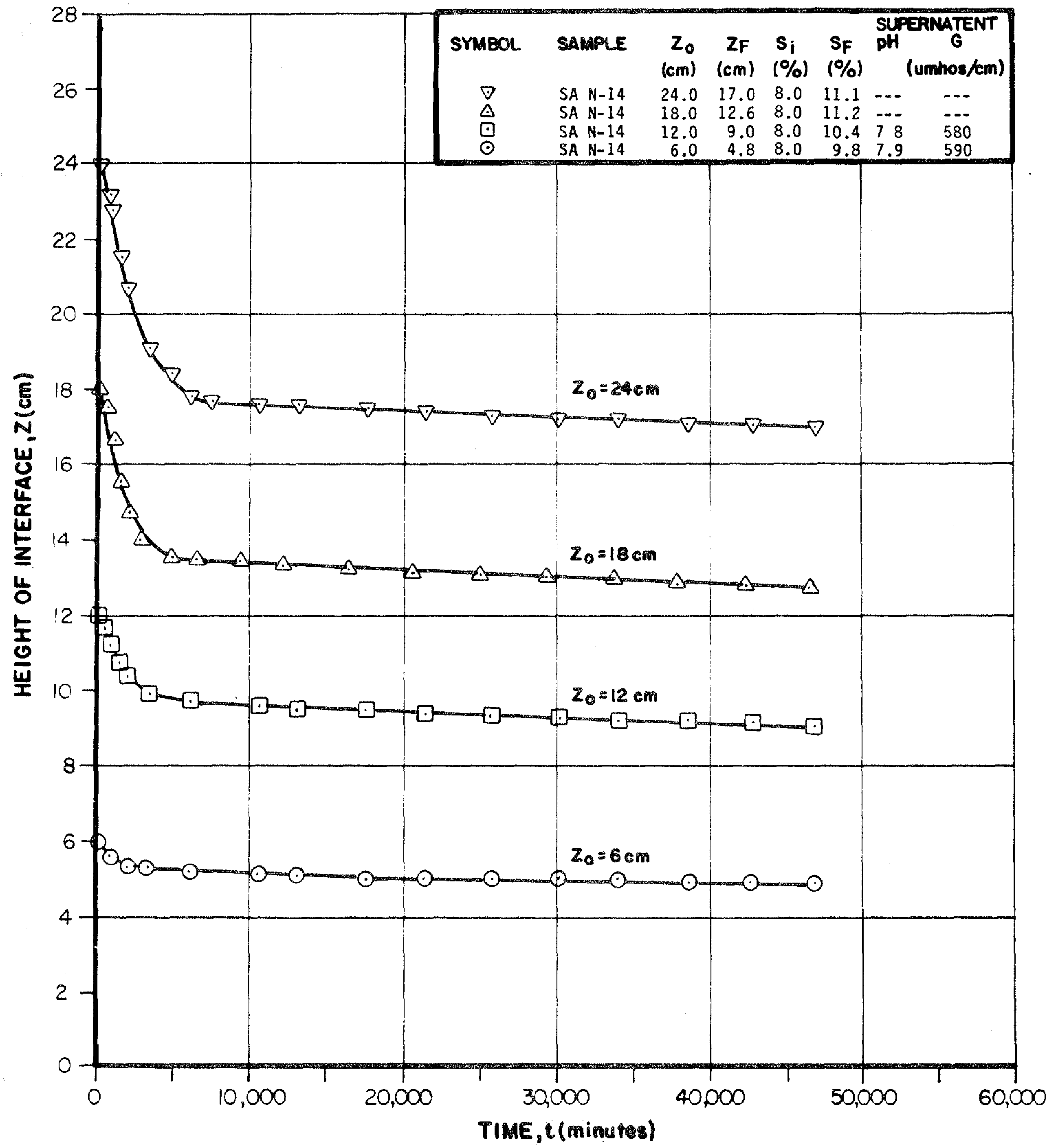
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR ESTECH-WATSON PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-26



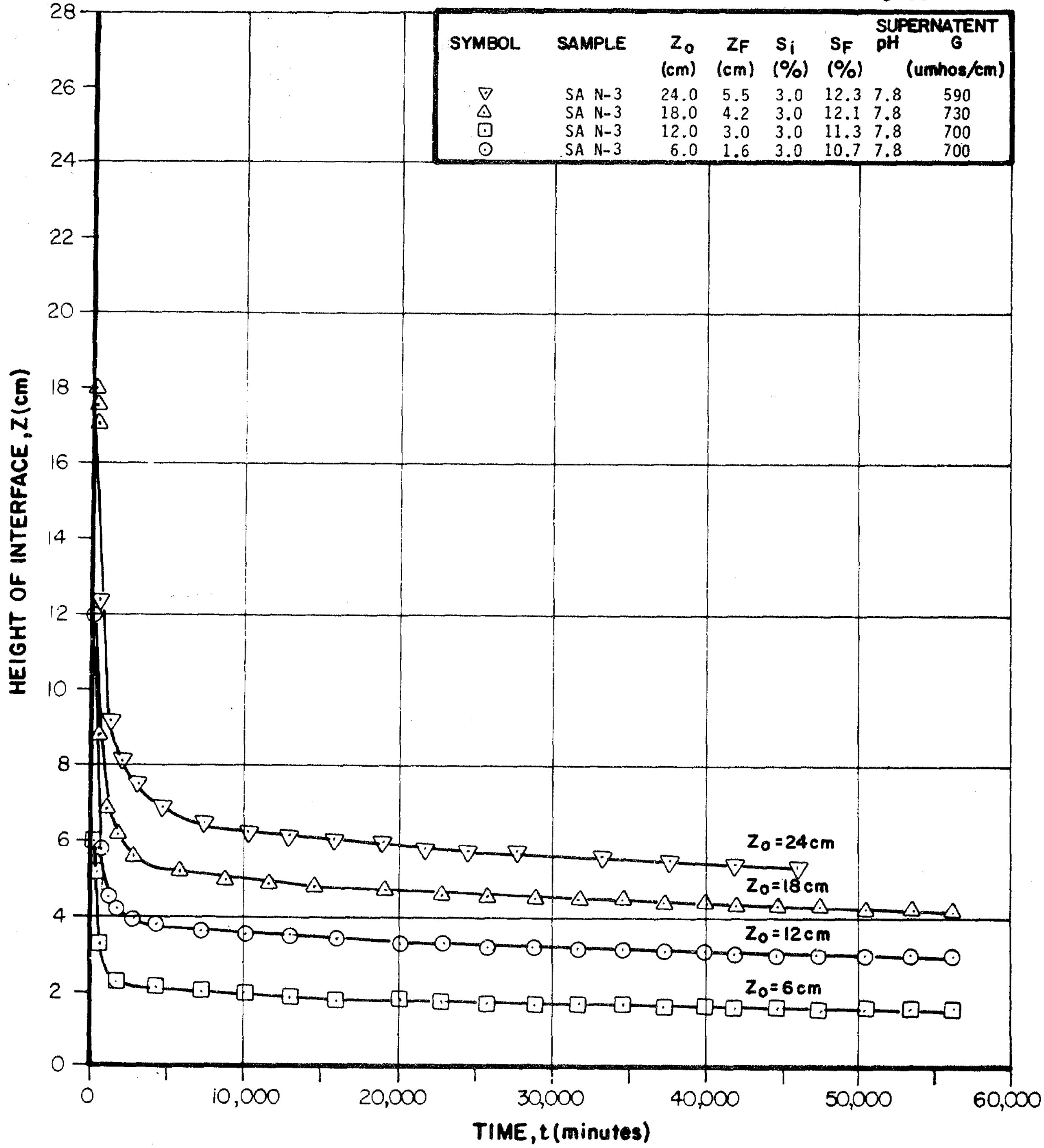
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-27



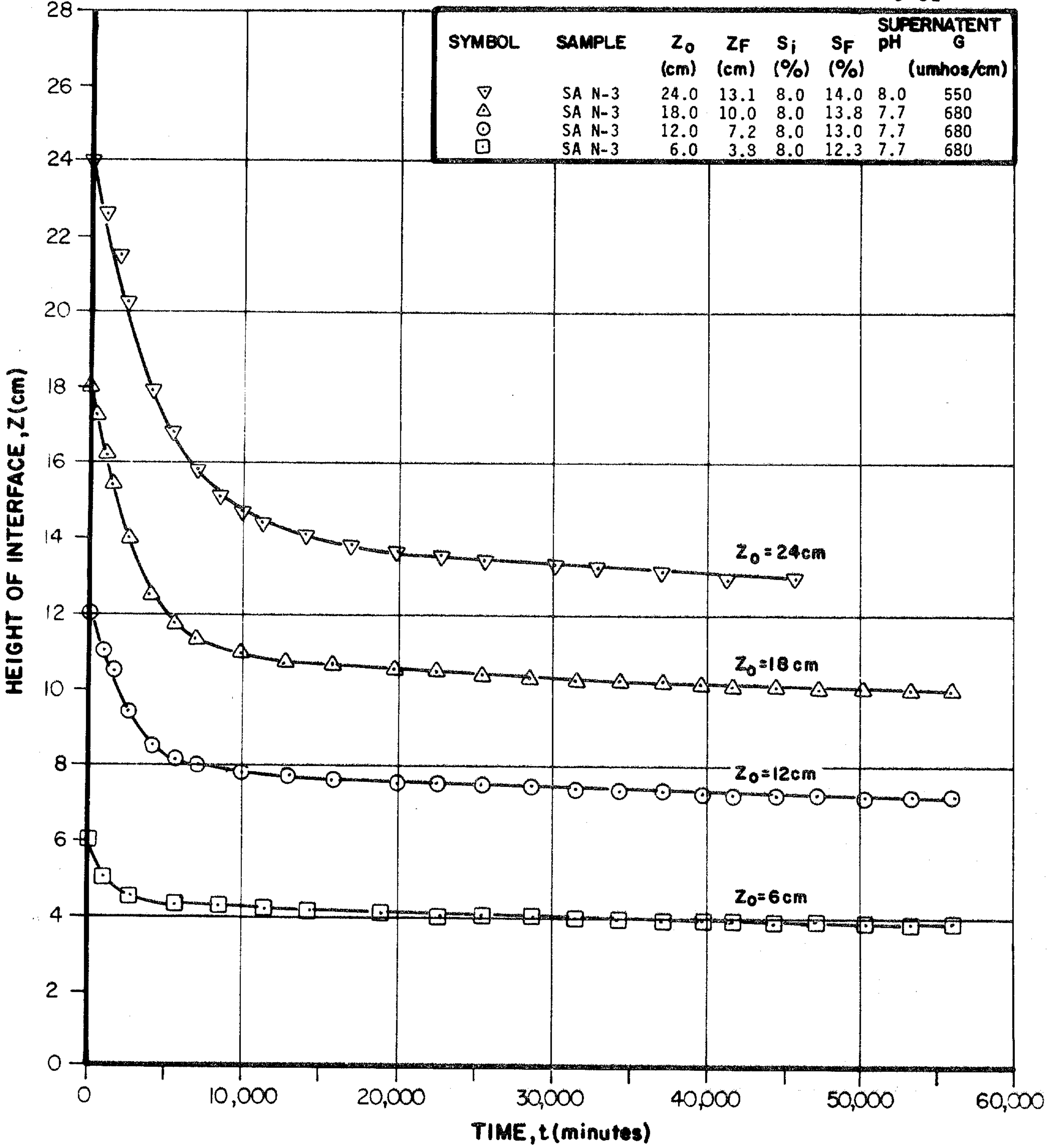
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-28



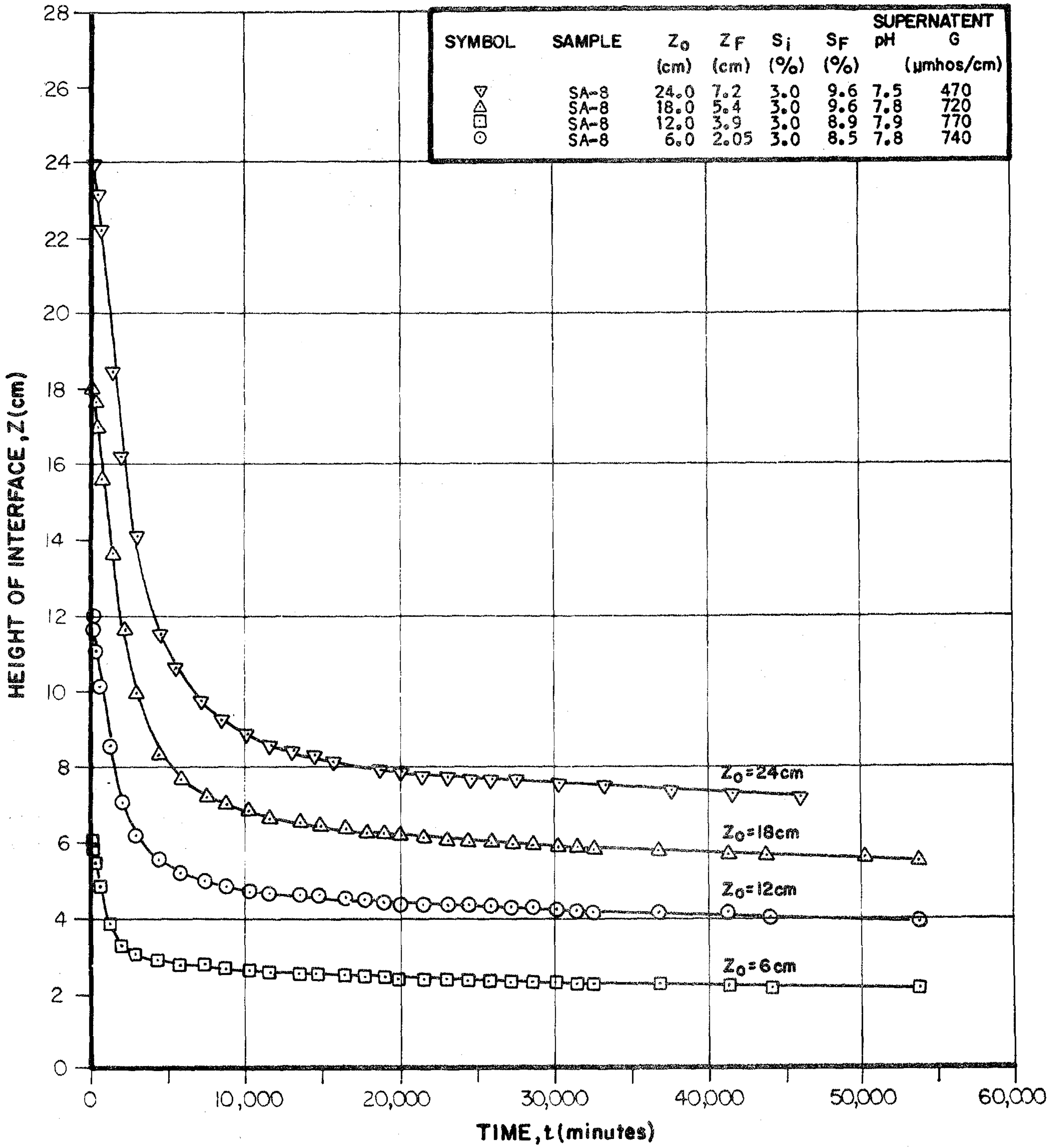
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-29



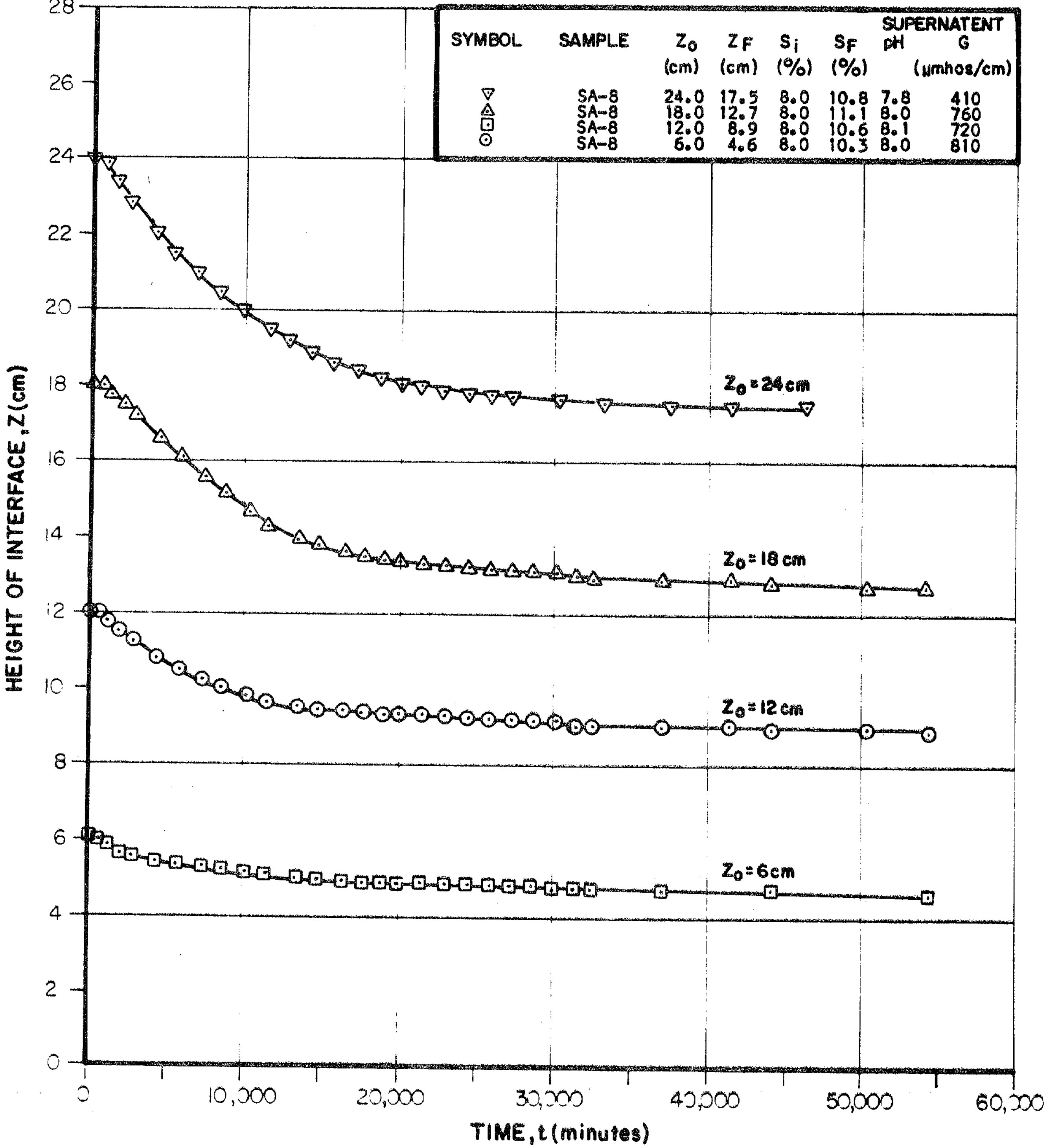
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-30

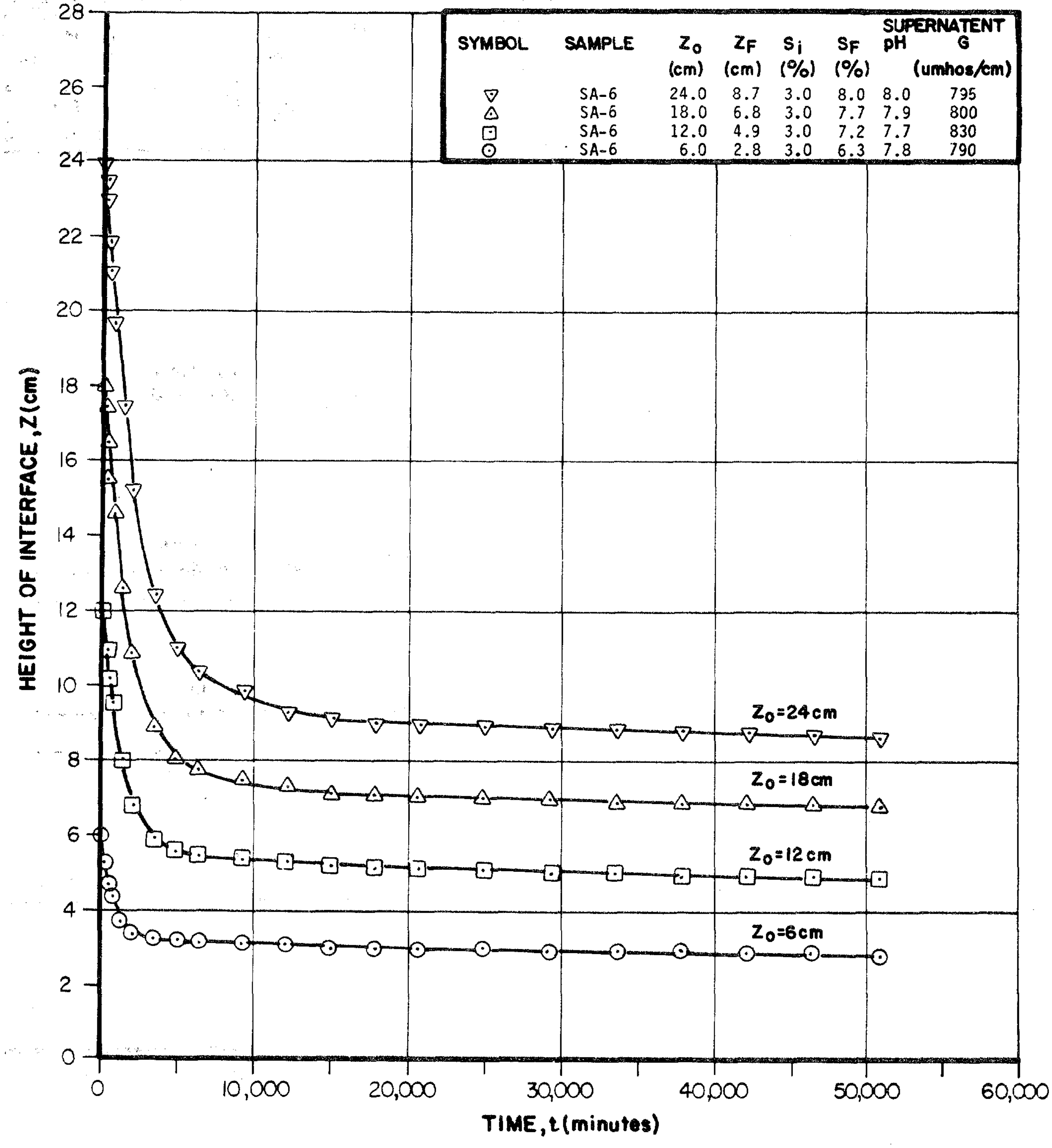


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-31

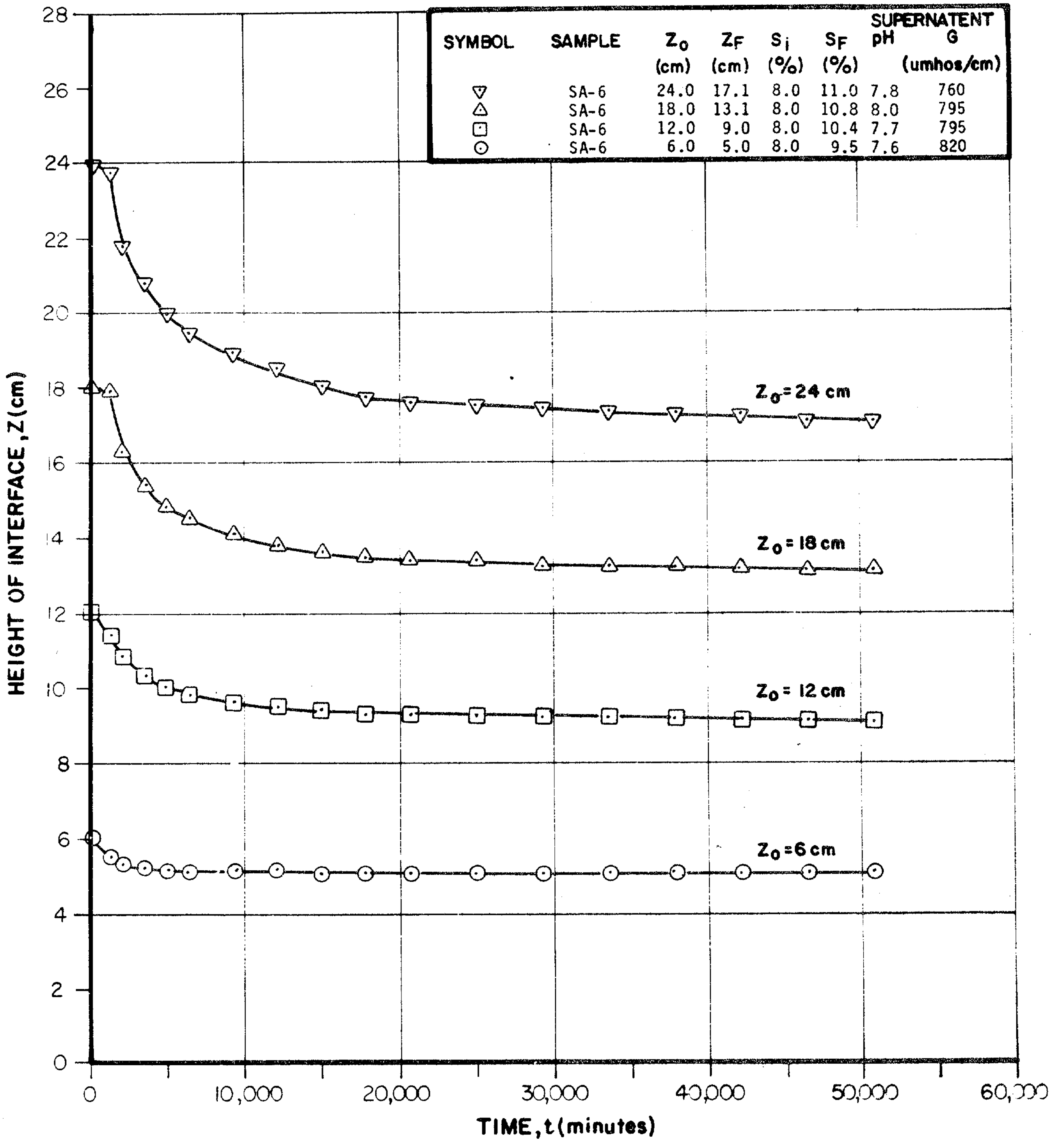


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%



SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE C-33

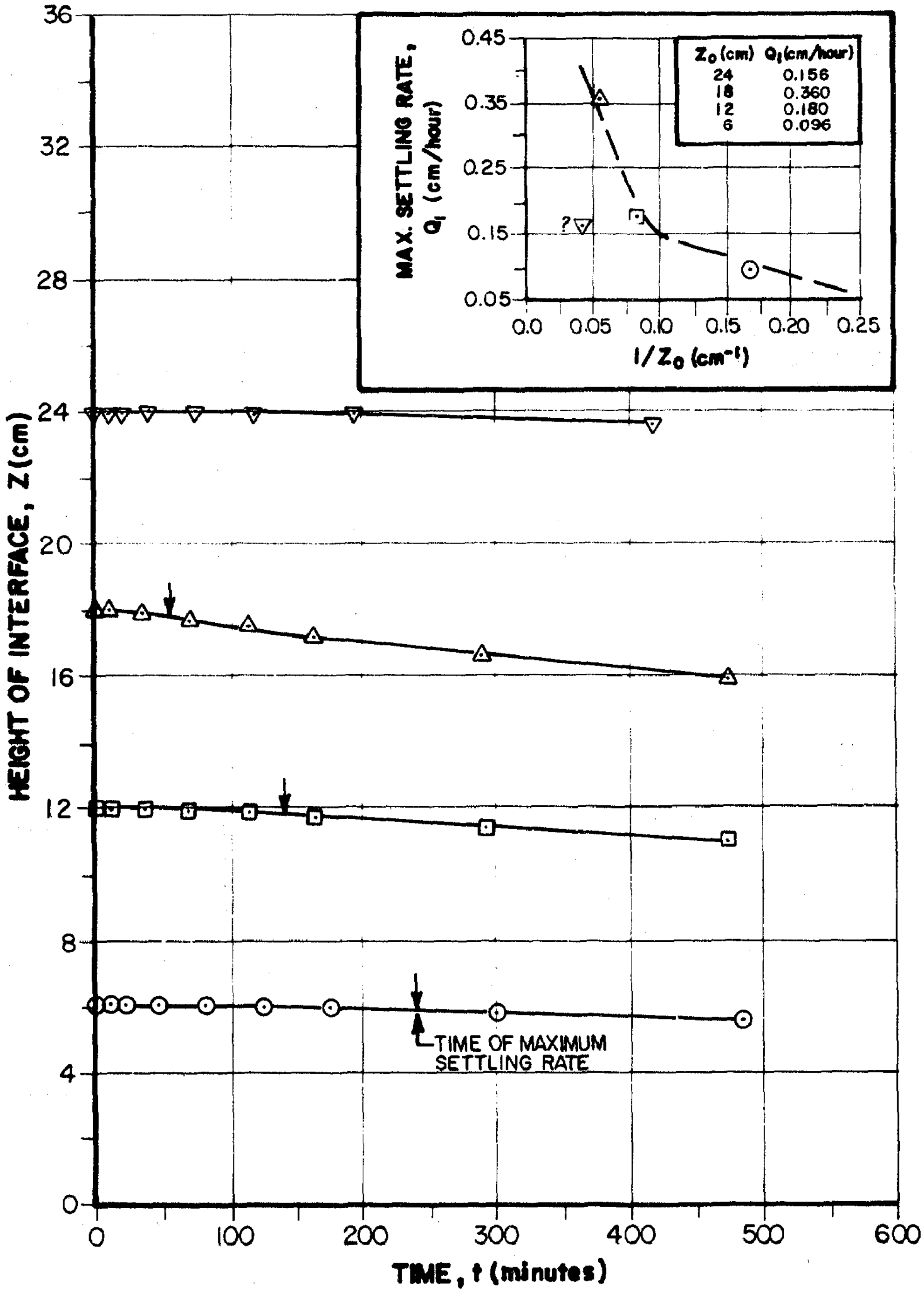


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE C-34

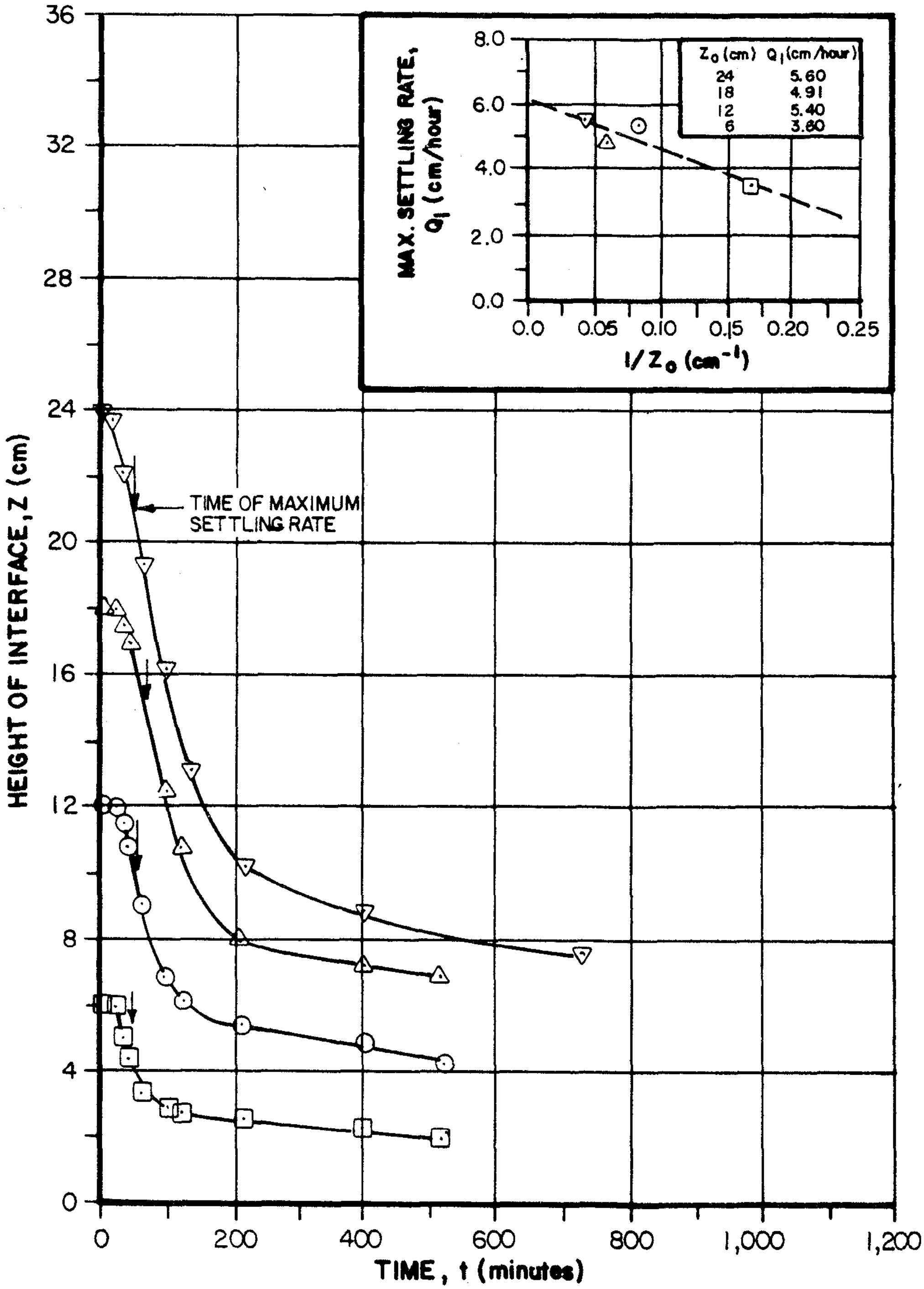
Appendix D

GRAPHICAL PLOTS OF HEIGHT OF INTERFACE VERSUS TIME FOR DETERMINATION OF MAXIMUM FIELD SETTLING RATE



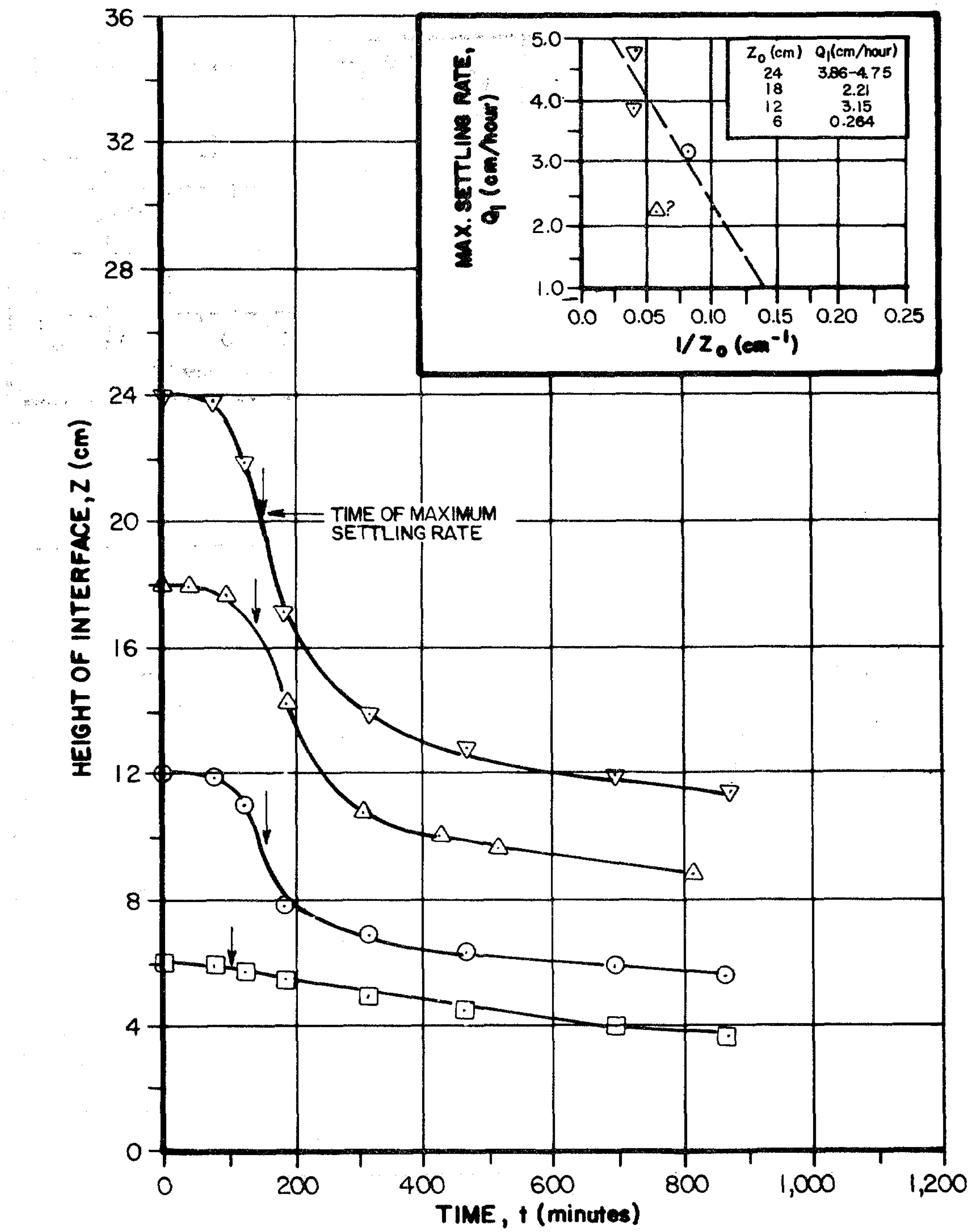
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-1



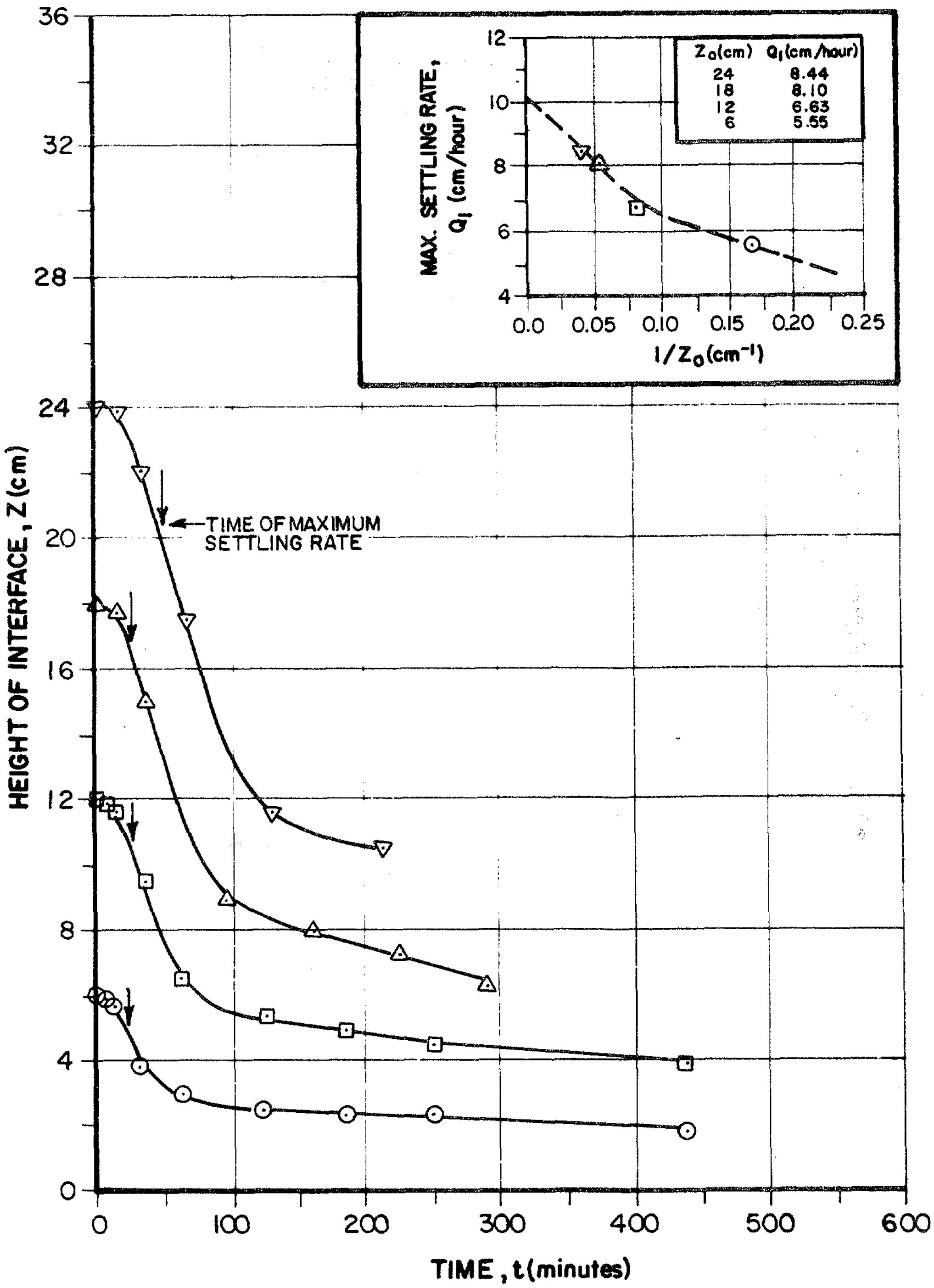
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-2



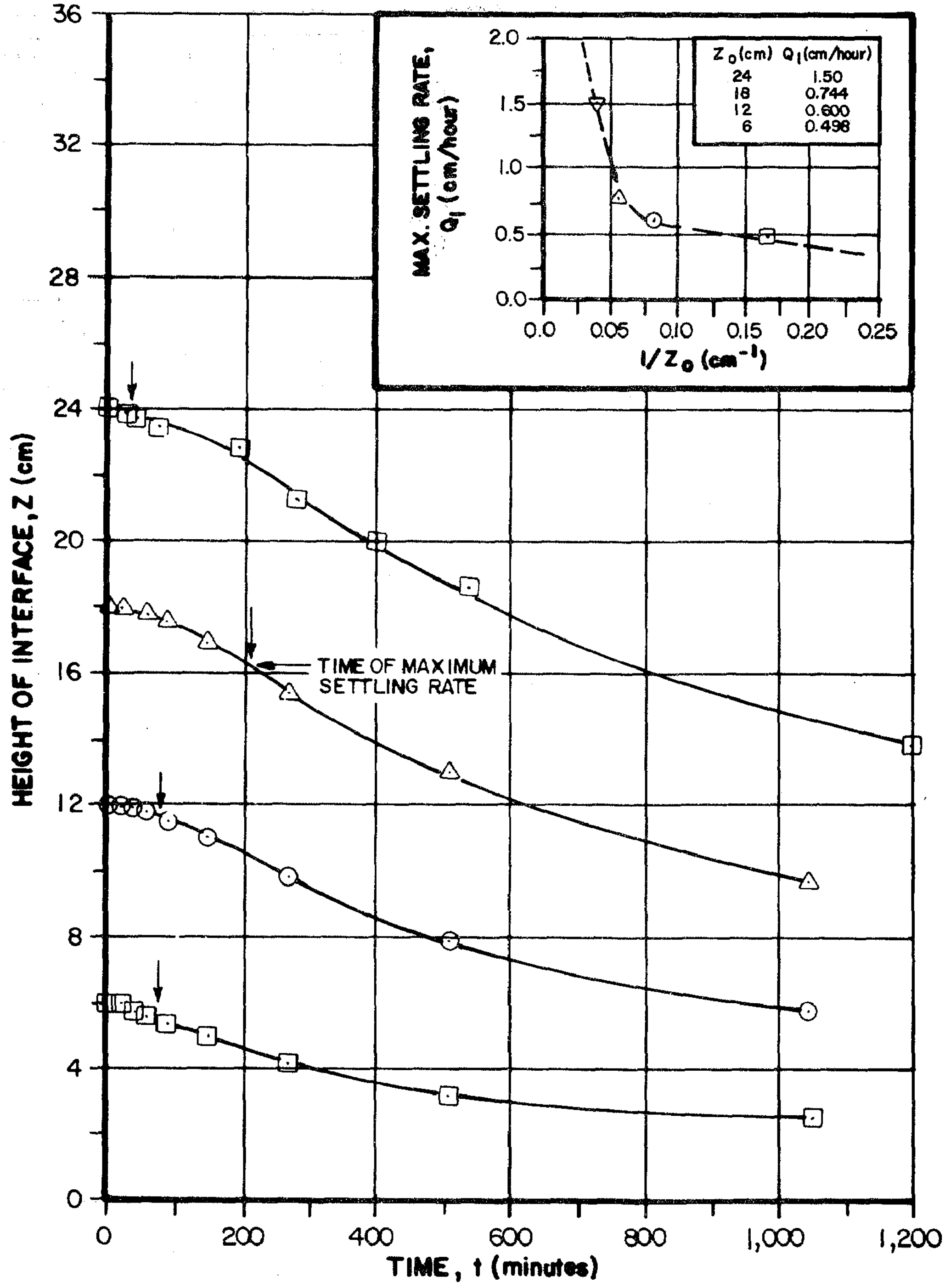
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-3



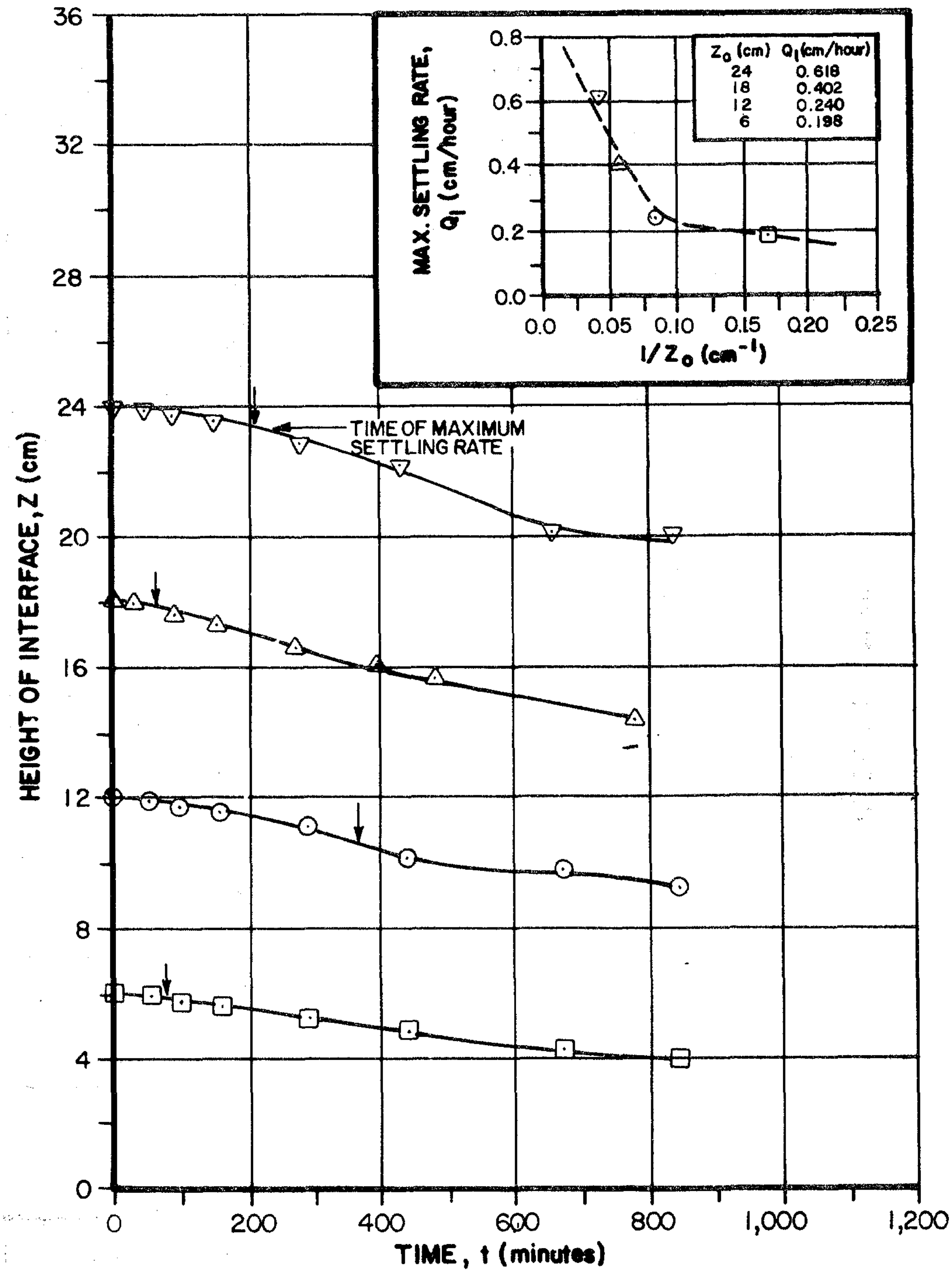
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-4



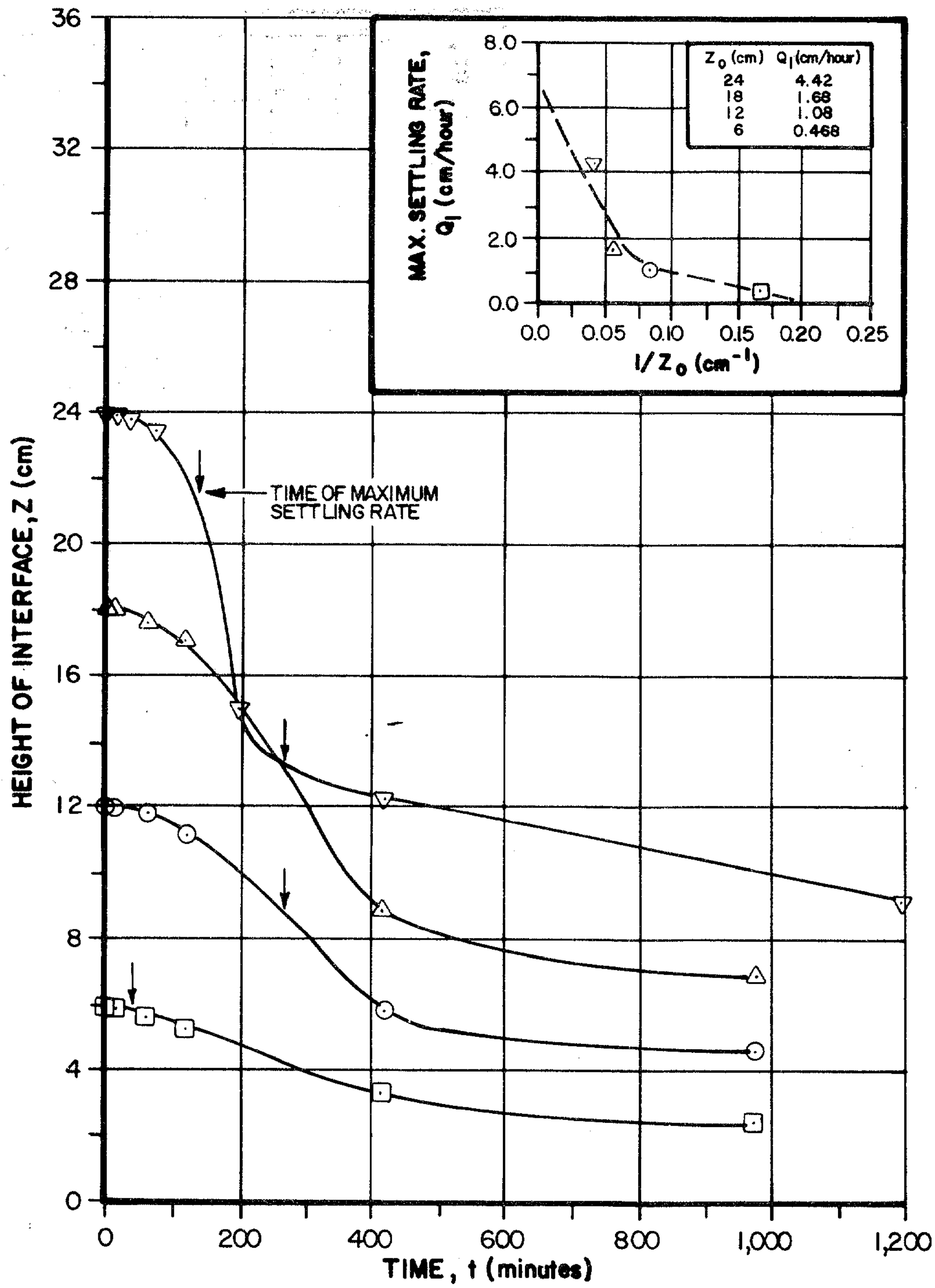
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR ESTECH-WATSON PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-5



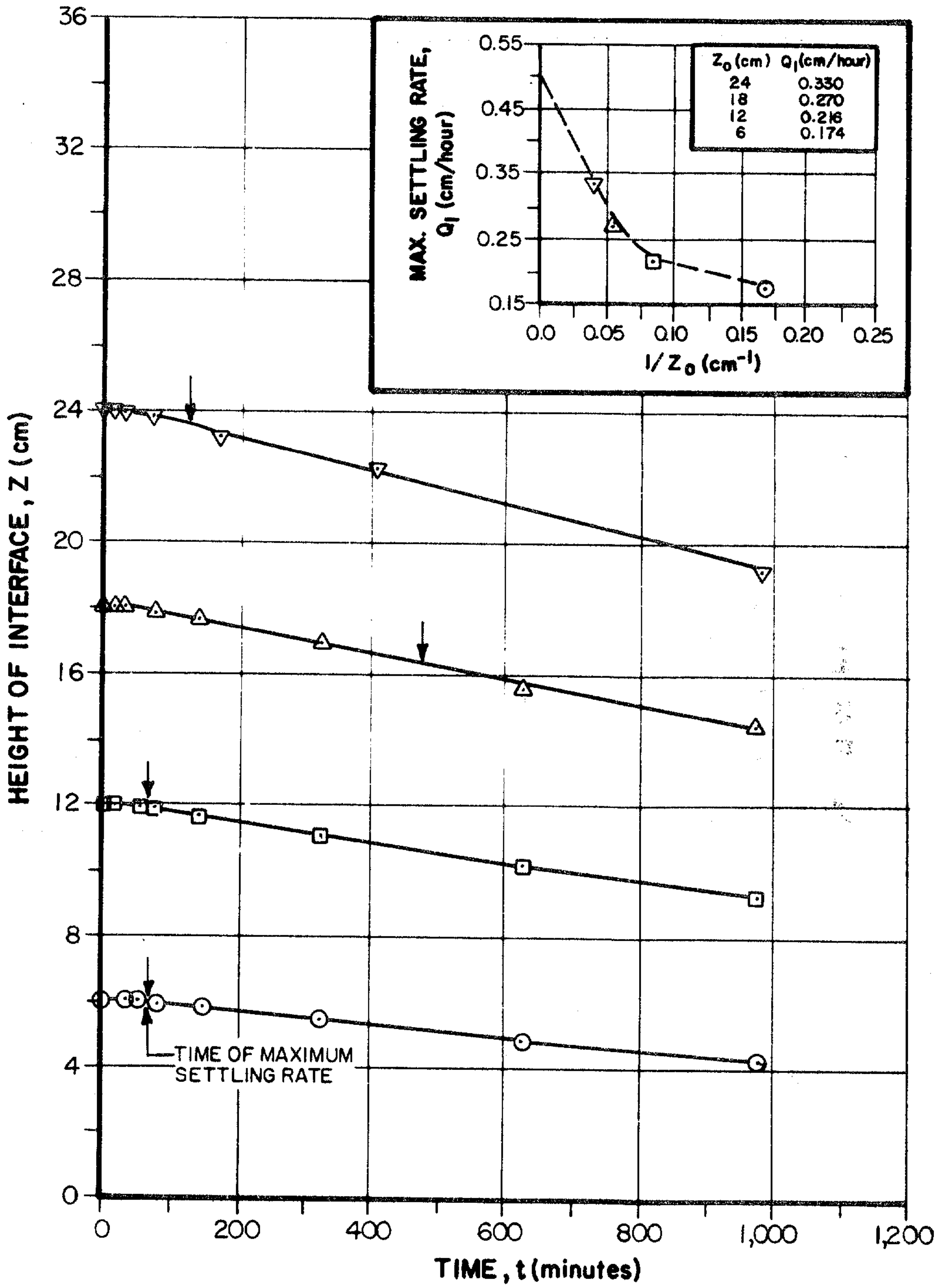
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-6



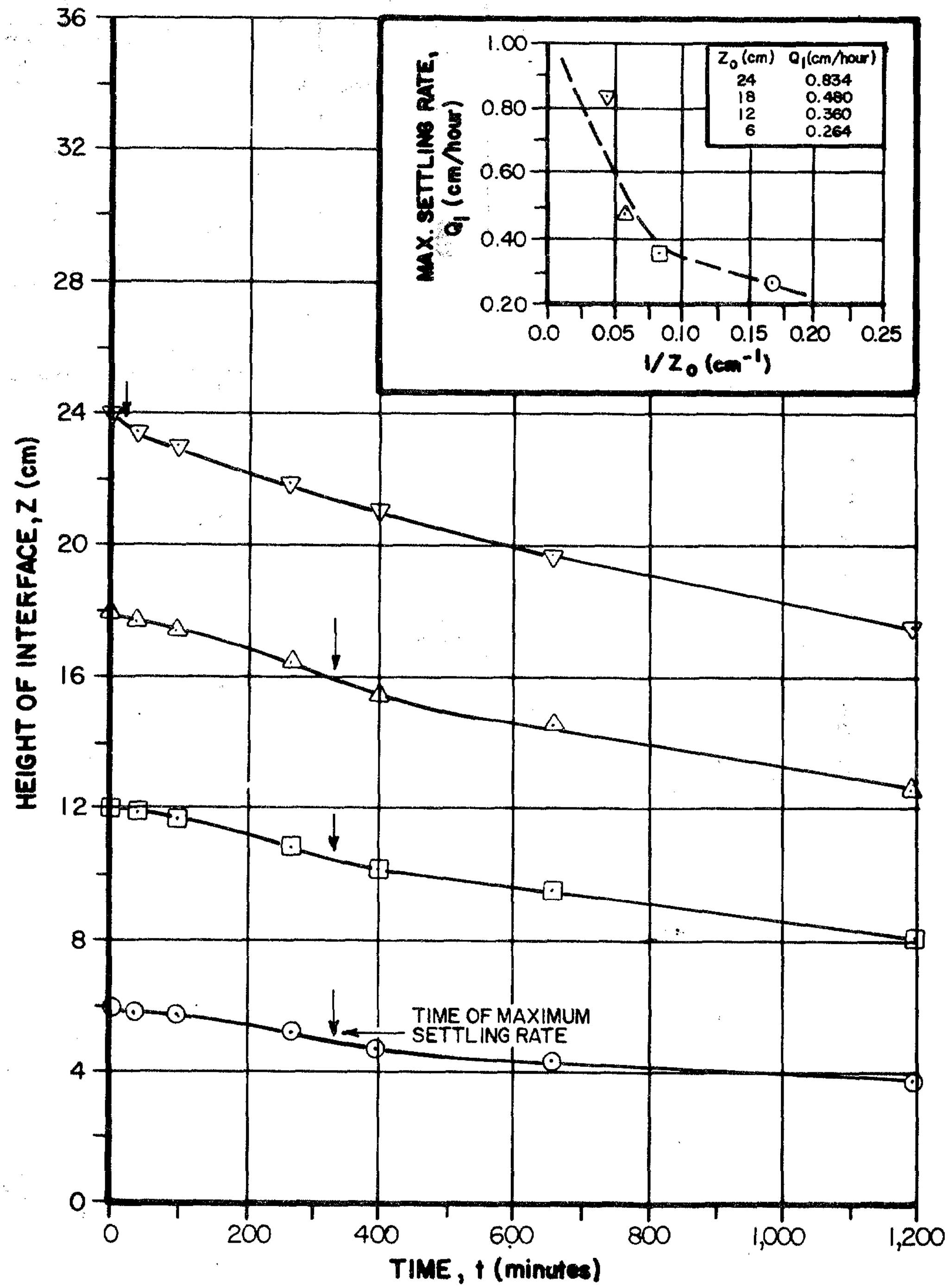
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-7



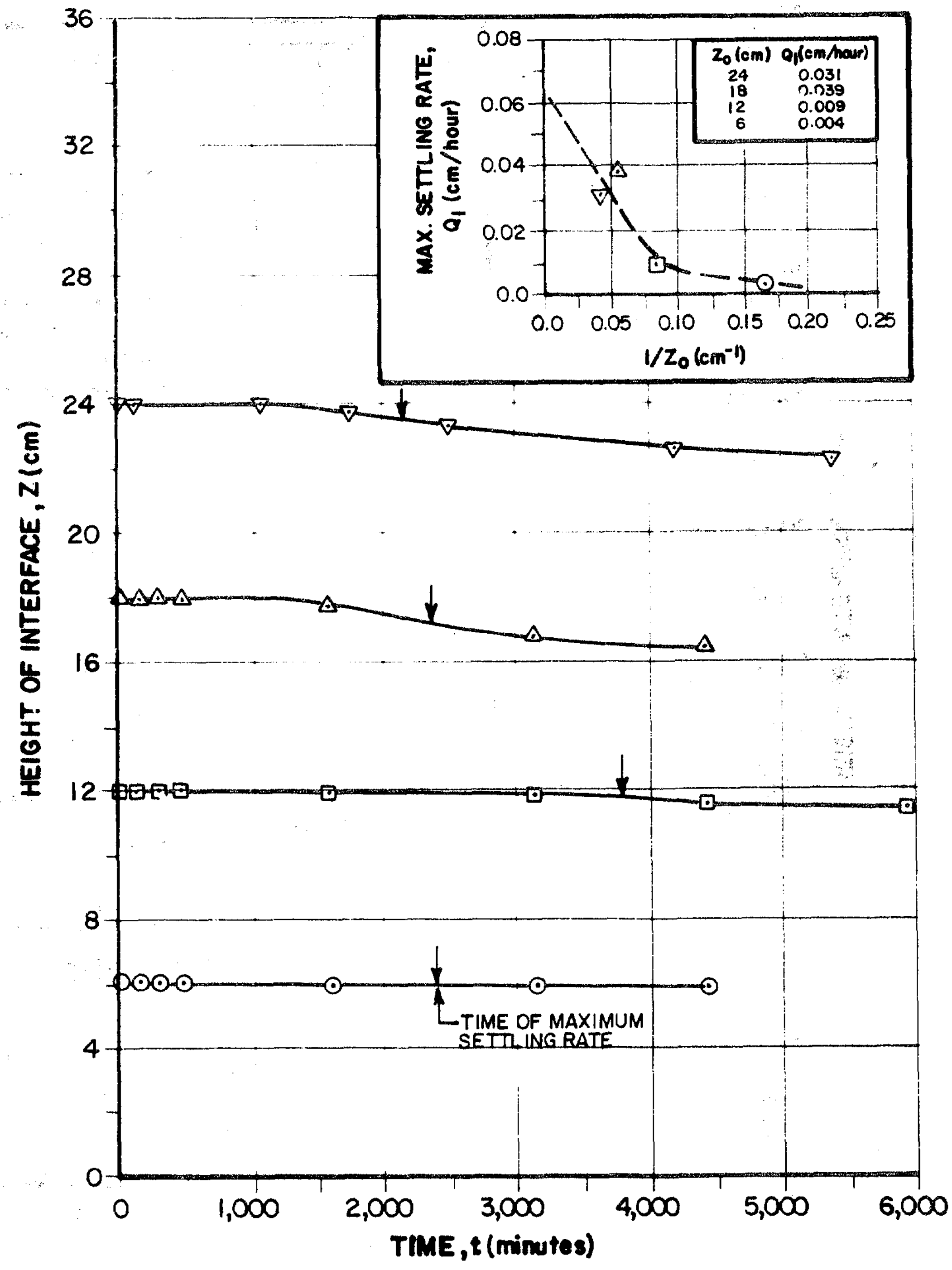
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-8



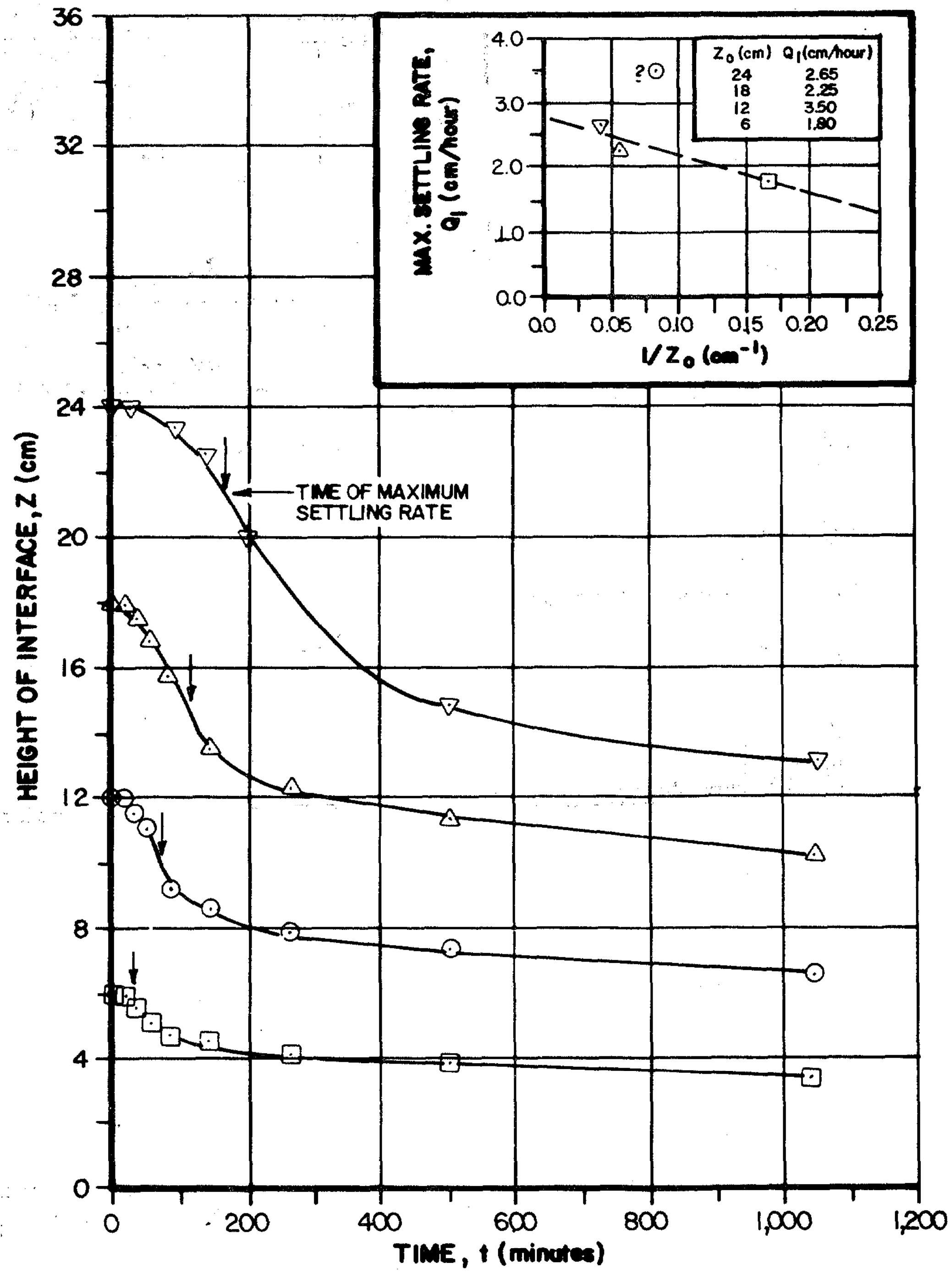
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE D-9



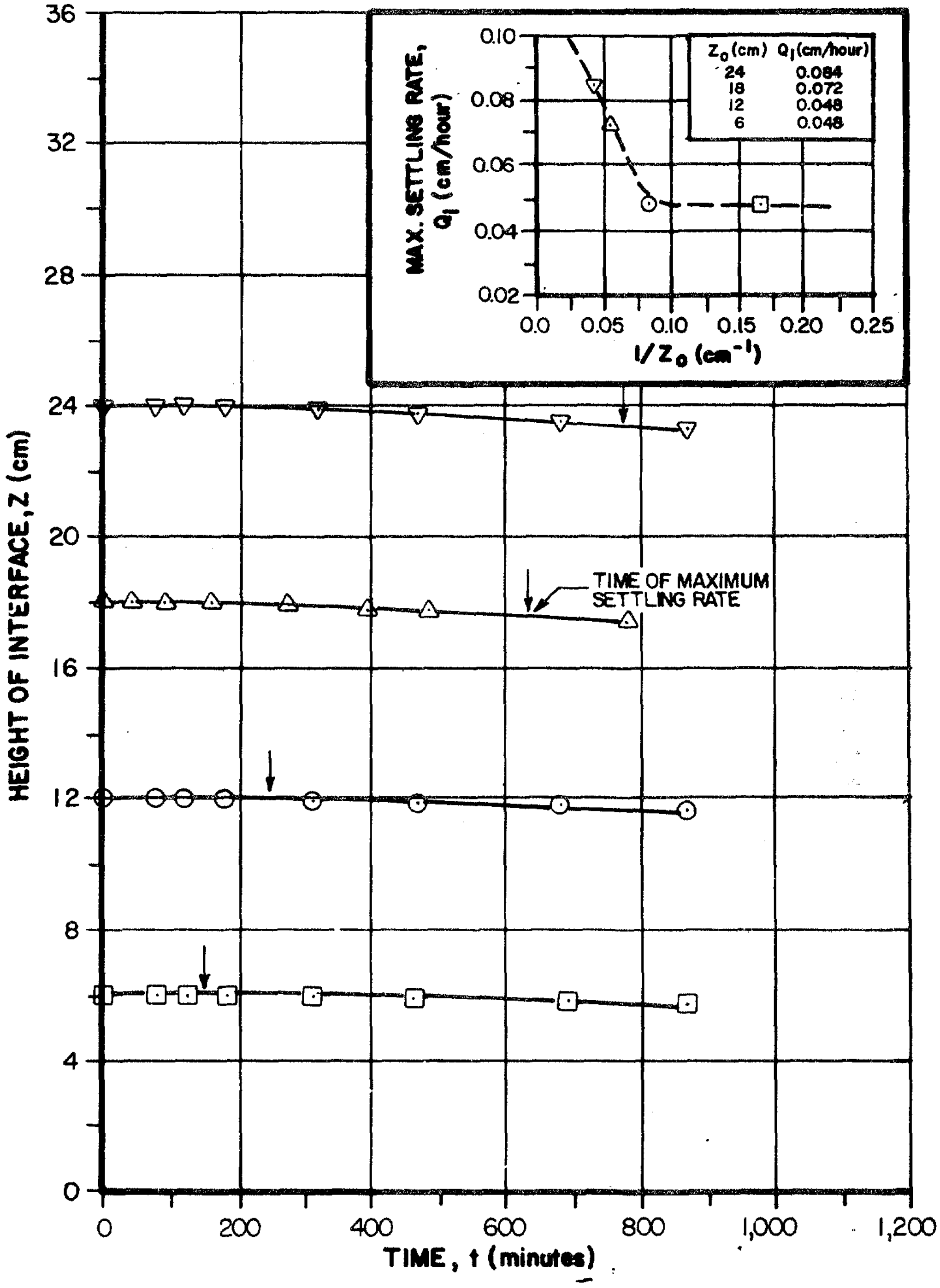
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-10



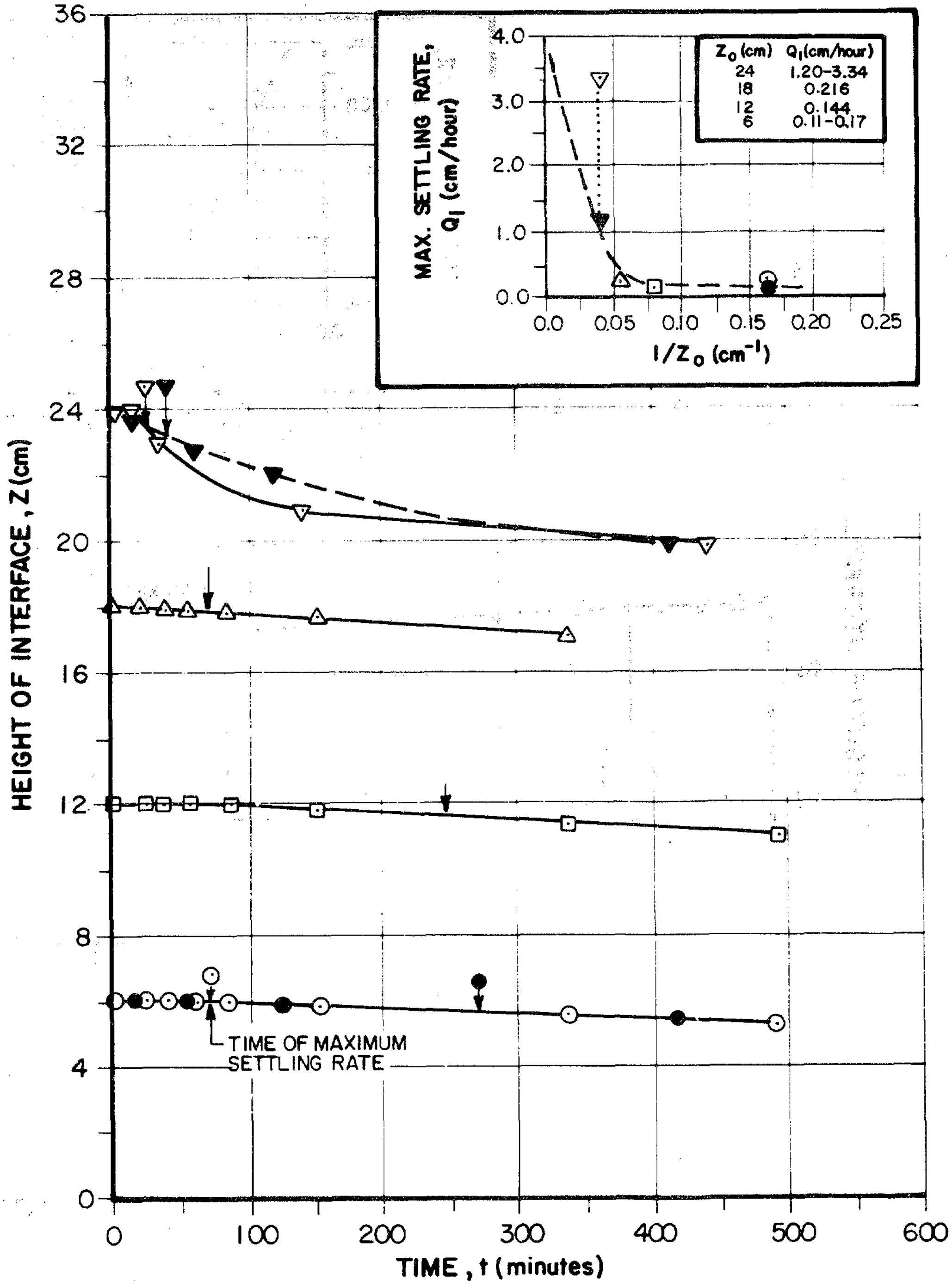
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-11



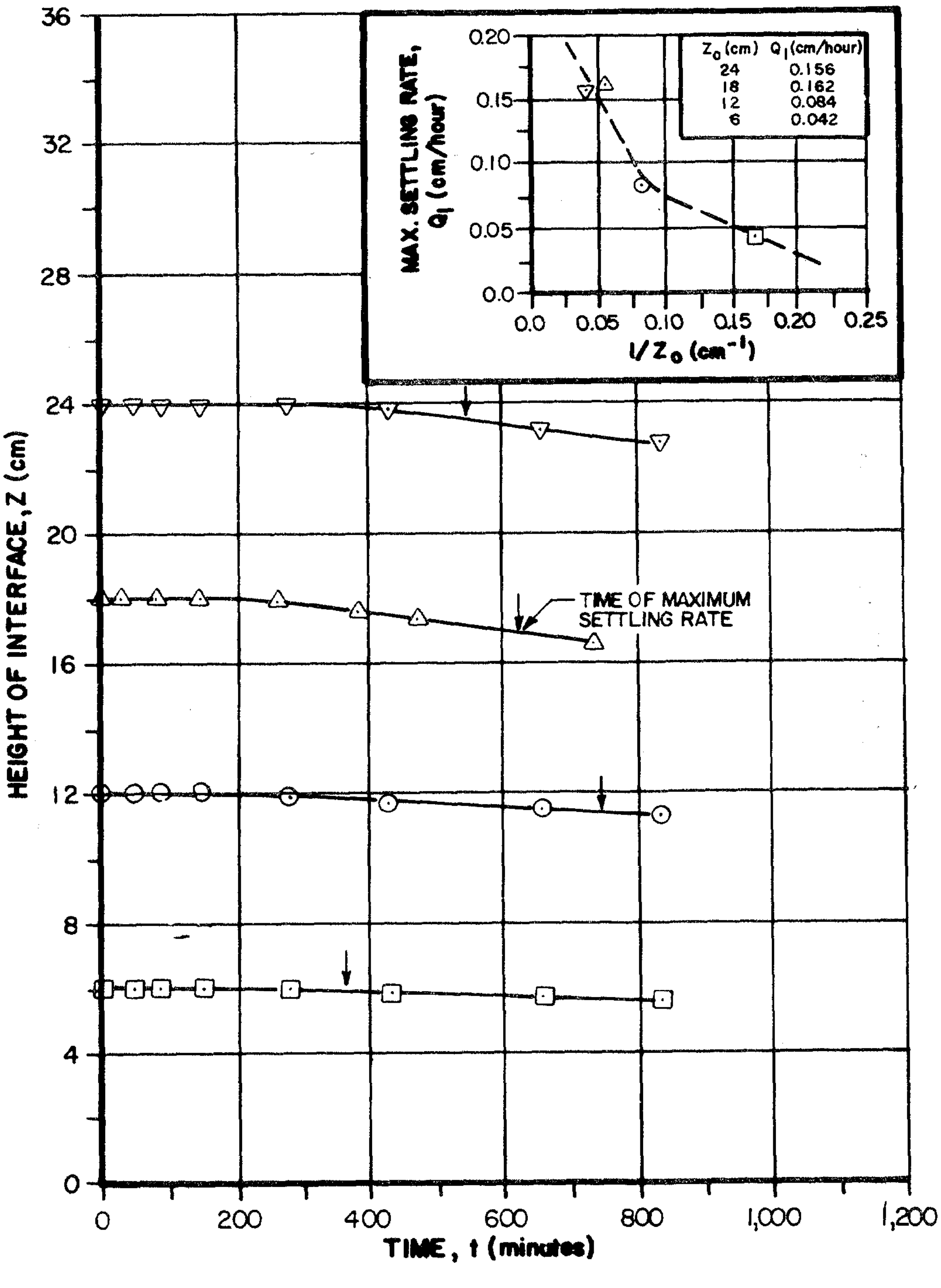
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-12



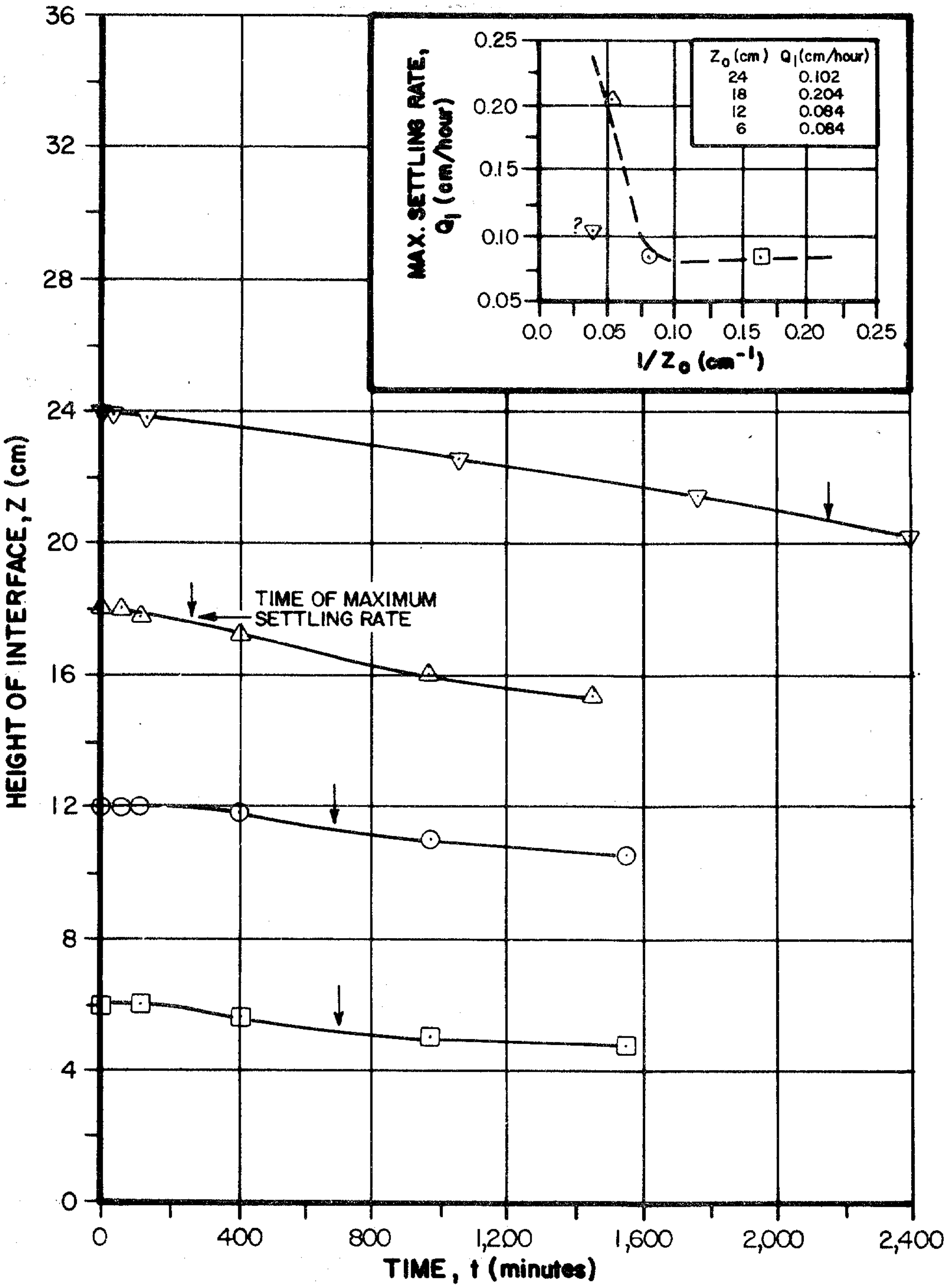
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR CF MINING- HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-13



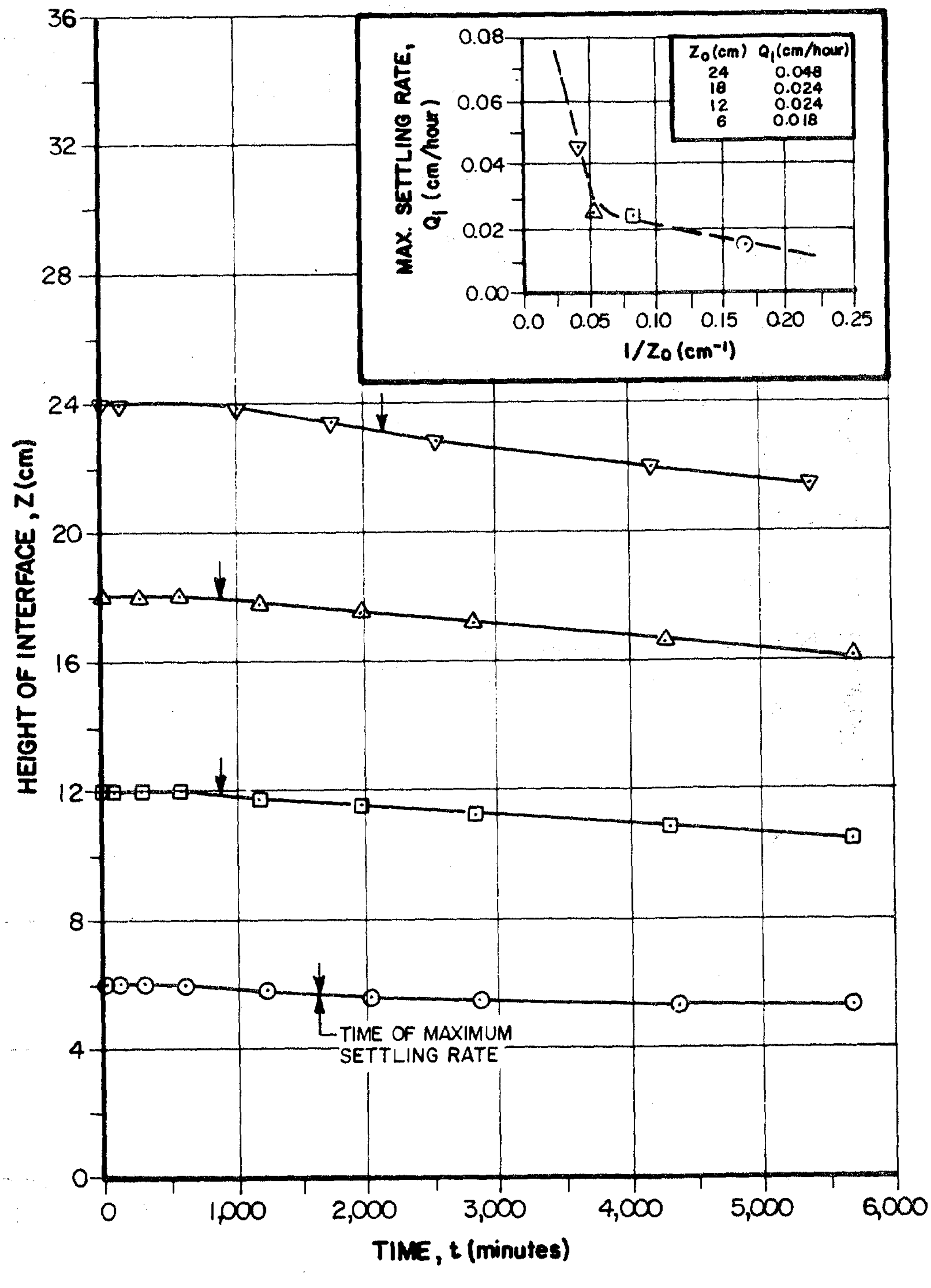
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-14



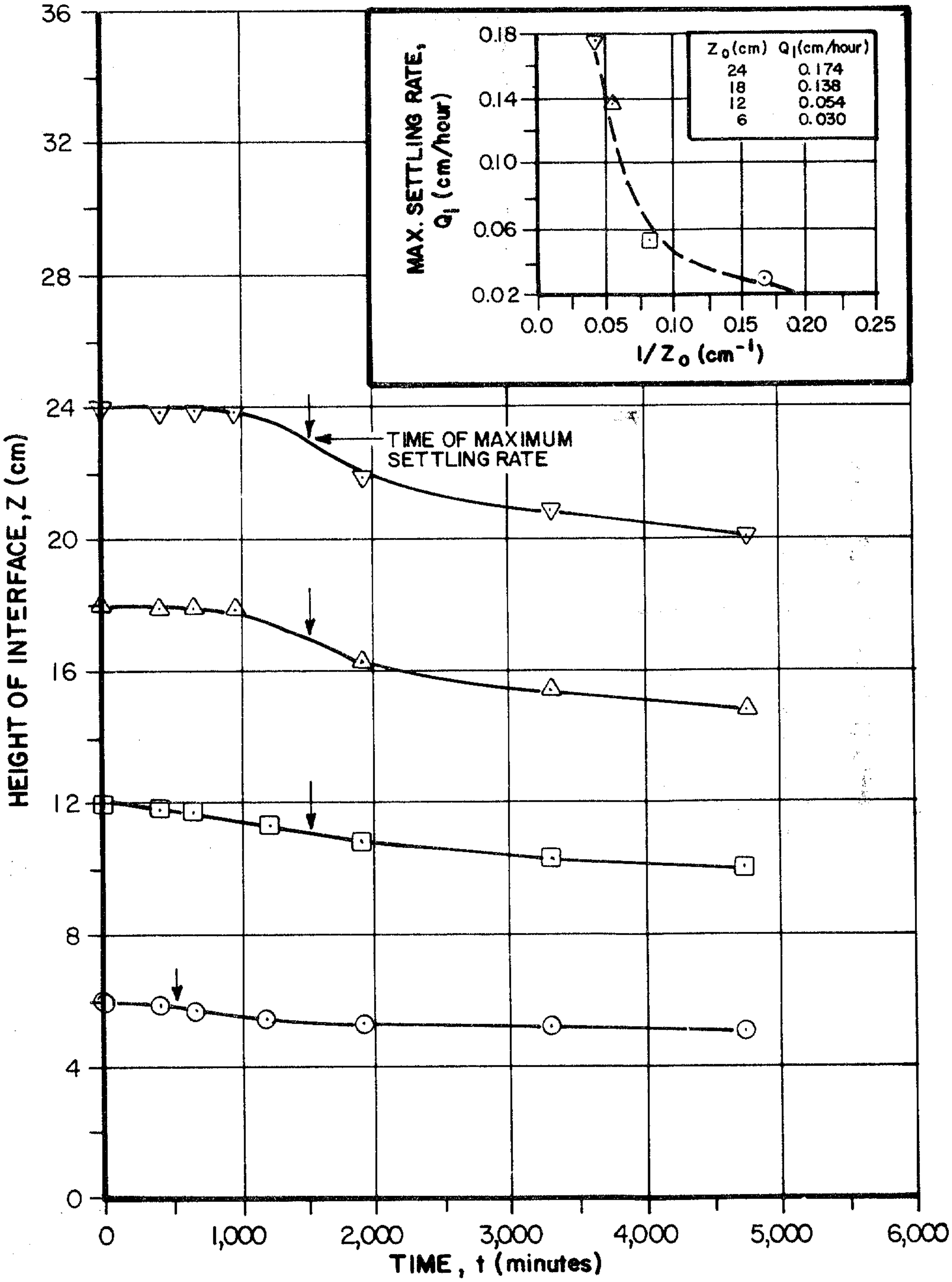
SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-15



SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-16

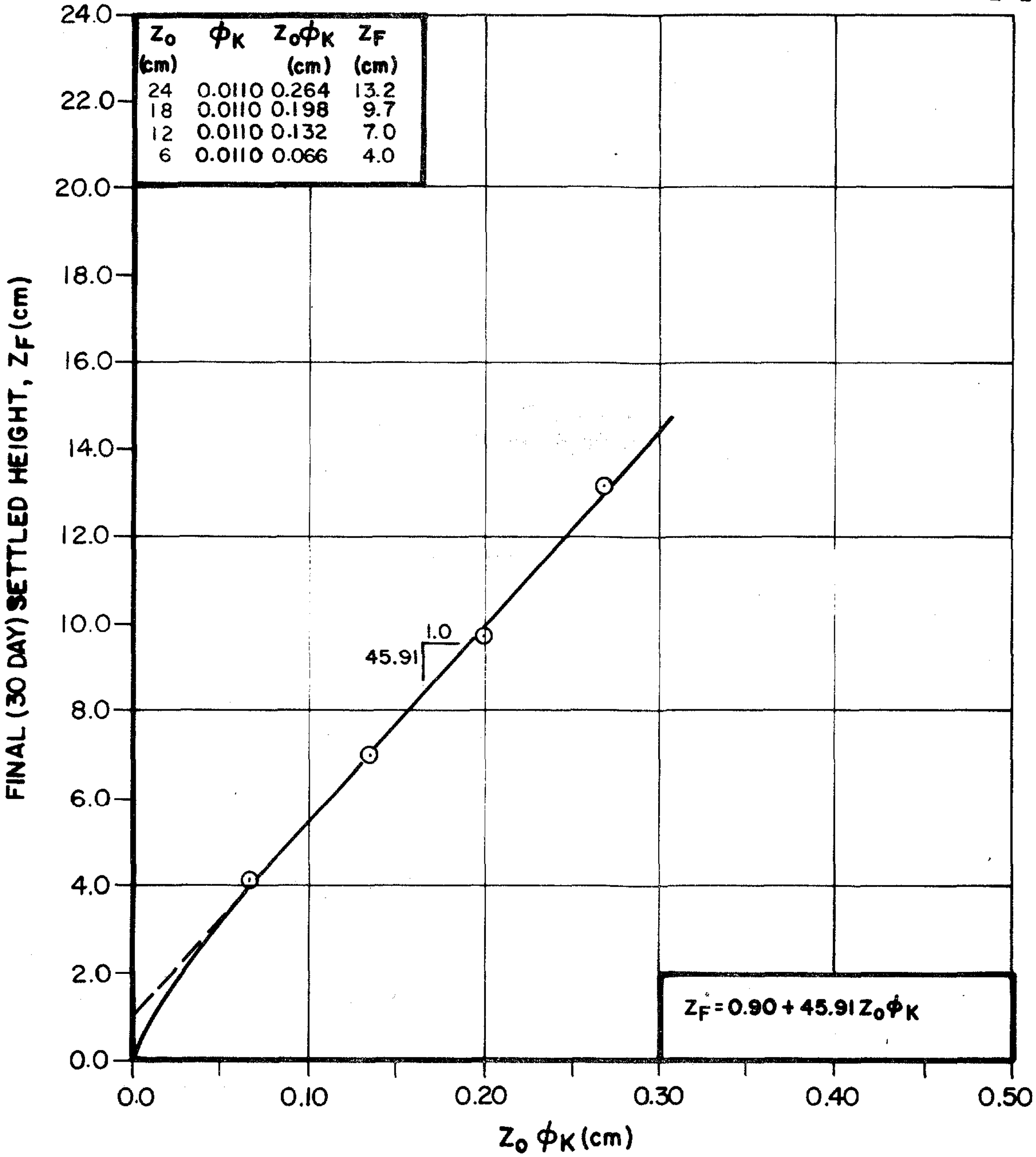


SETTLING TEST - HEIGHT VS. TIME FOR VARIOUS INITIAL SAMPLE HEIGHTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE D-17

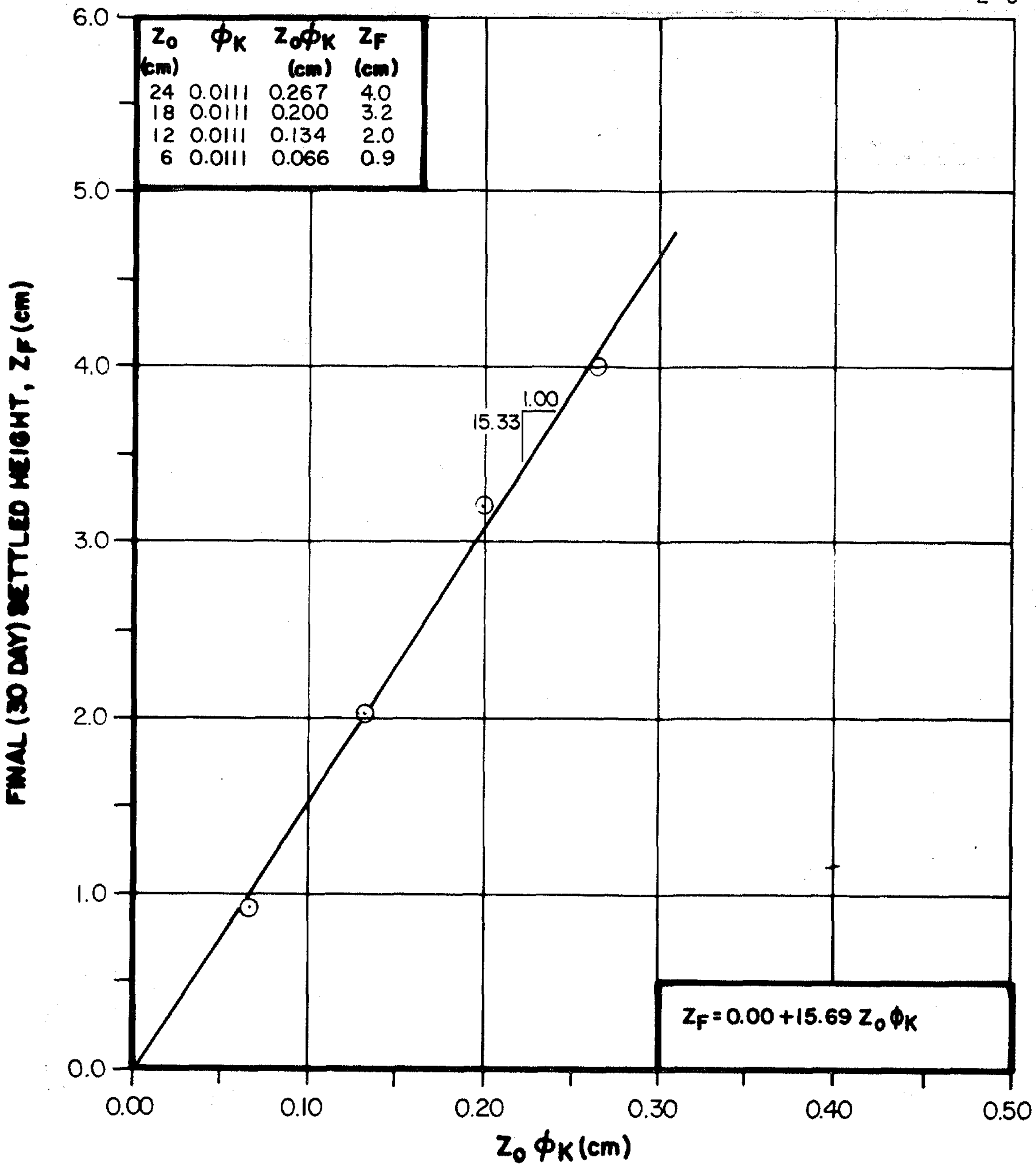
Appendix E

GRAPHICAL PLOTS OF FINAL SETTLED HEIGHT VERSUS HEIGHT OF CLAY SOLIDS FOR DETERMINATION OF FLOC VOLUME CONCENTRATION



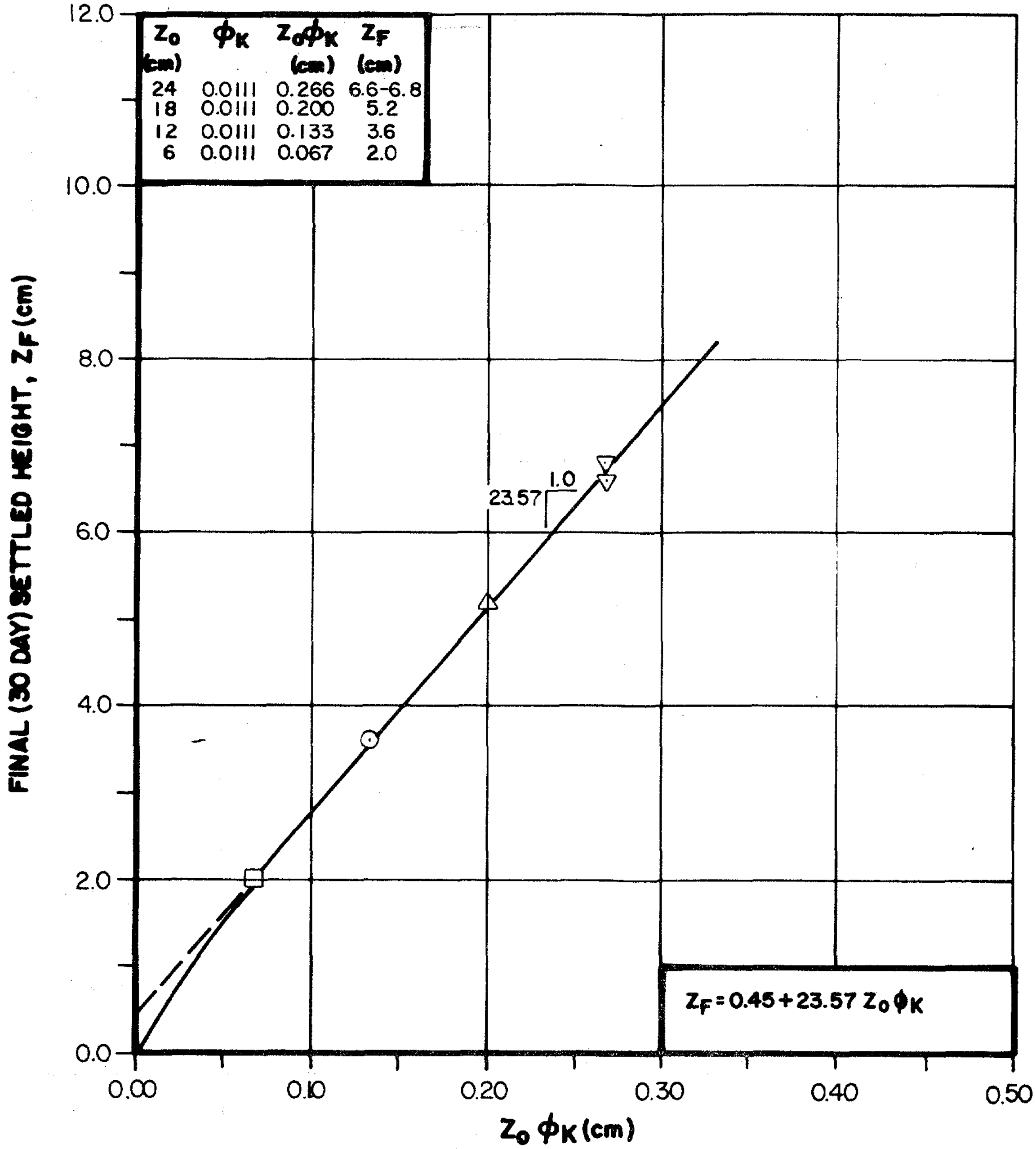
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-1



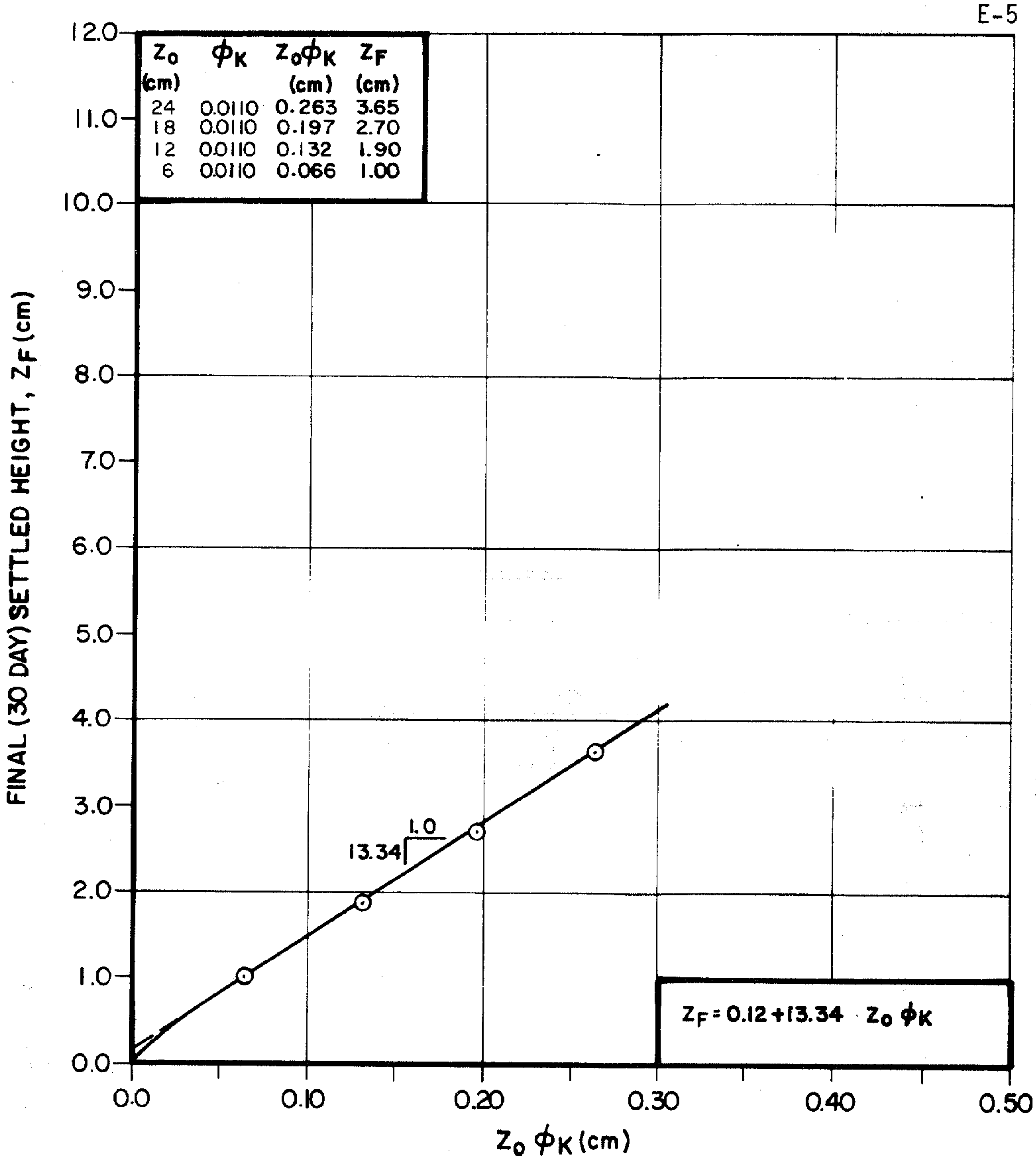
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR AMAX BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-2



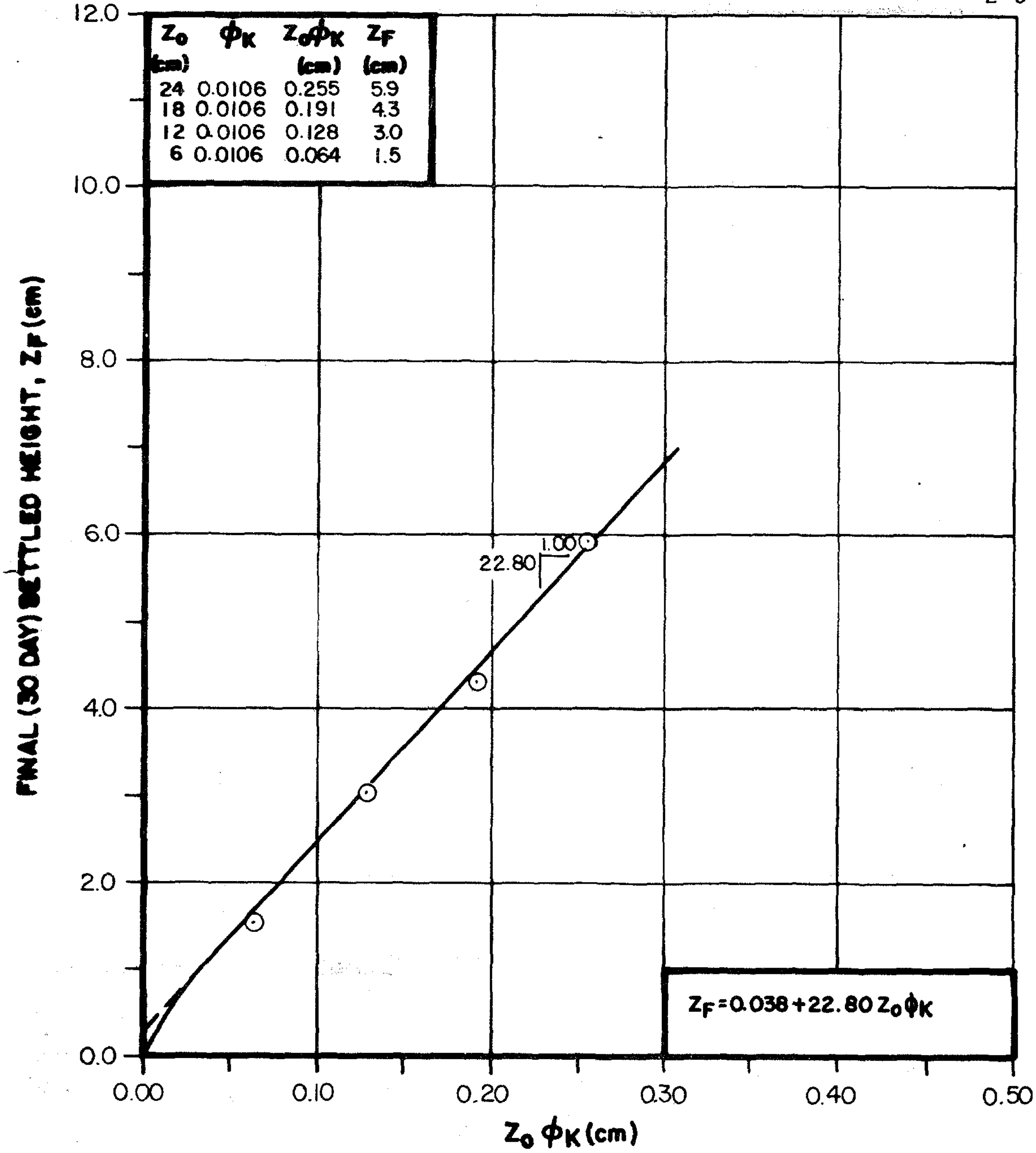
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-3



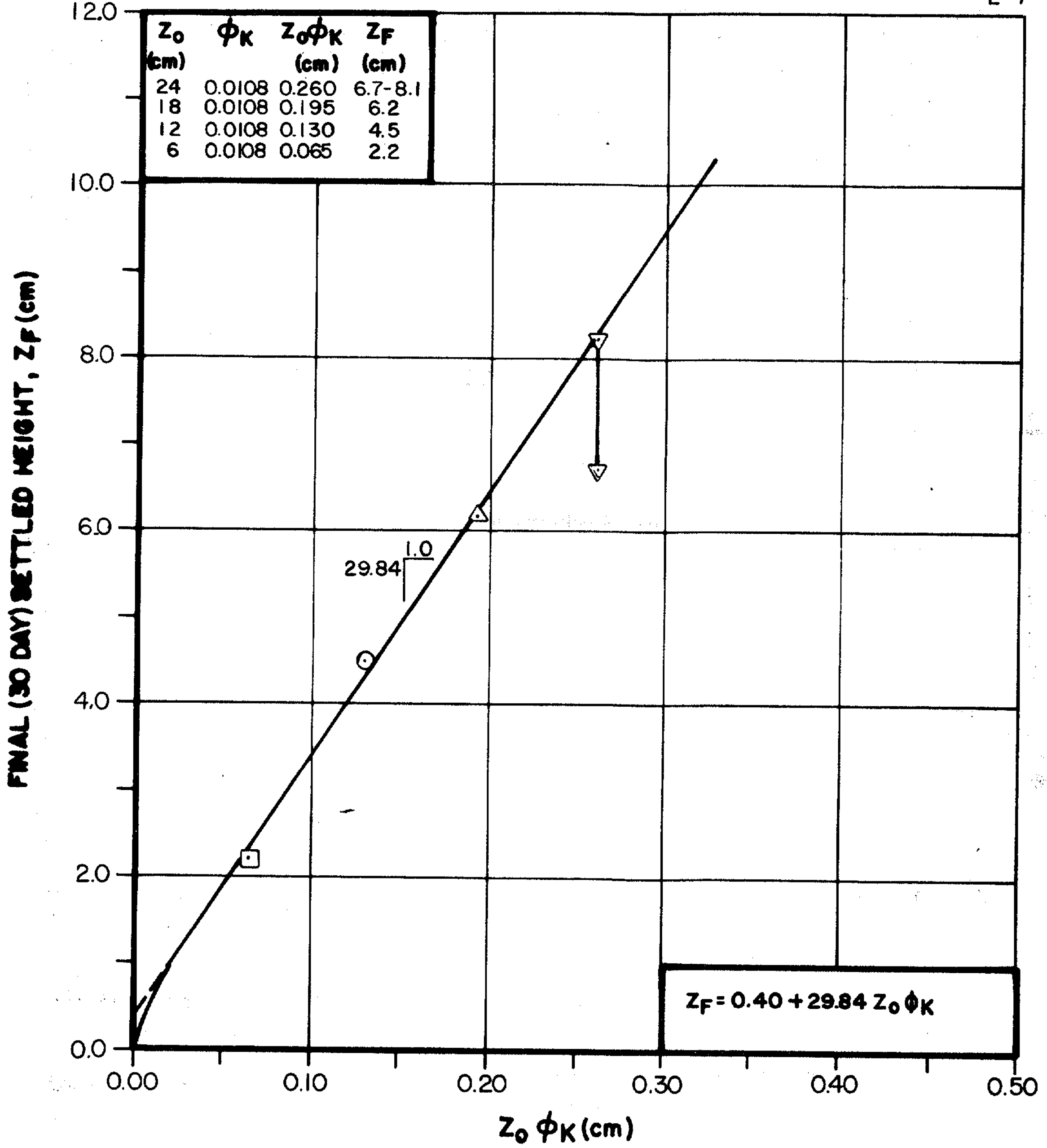
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-4



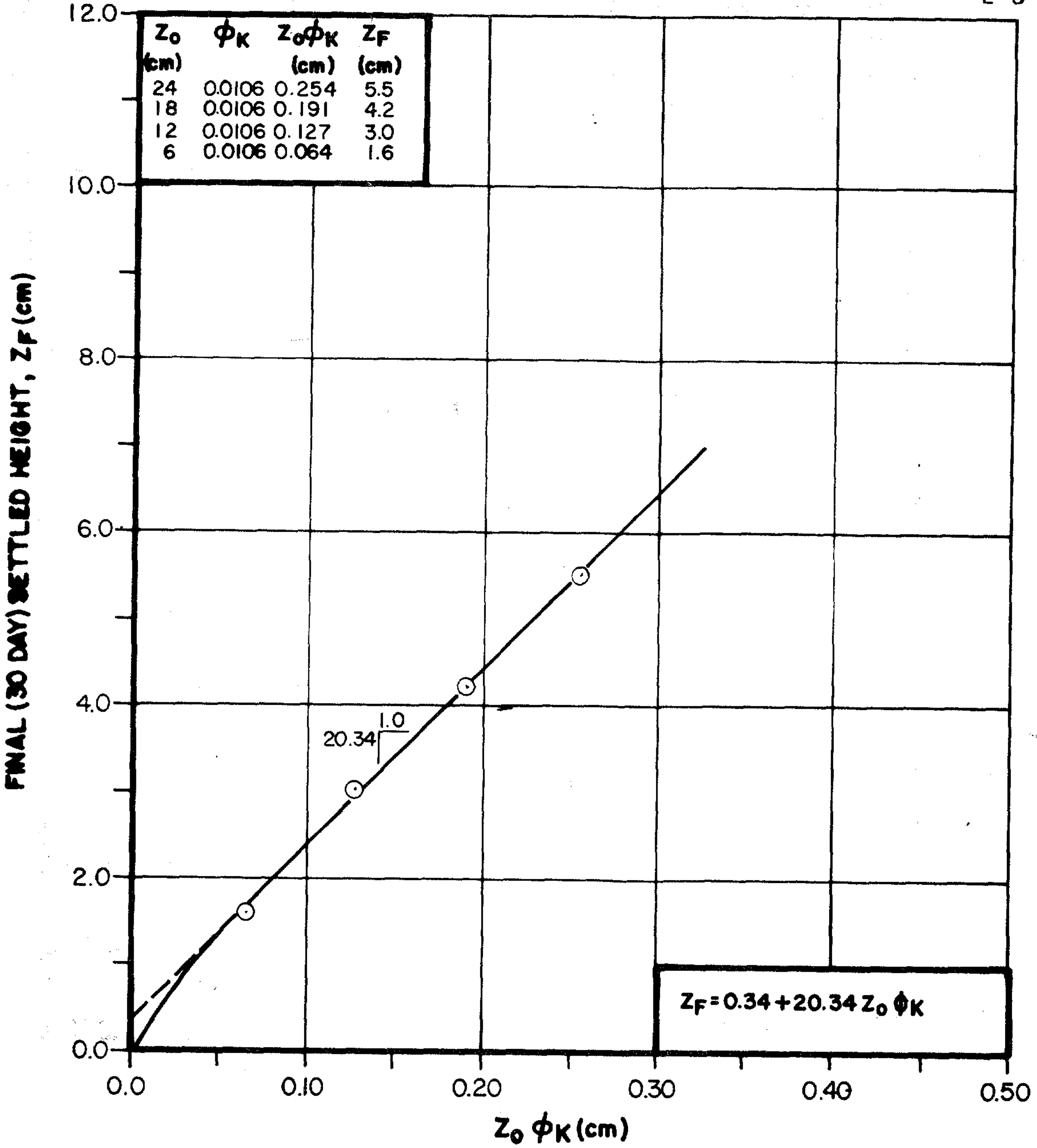
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR ESTECH-WATSON PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-5



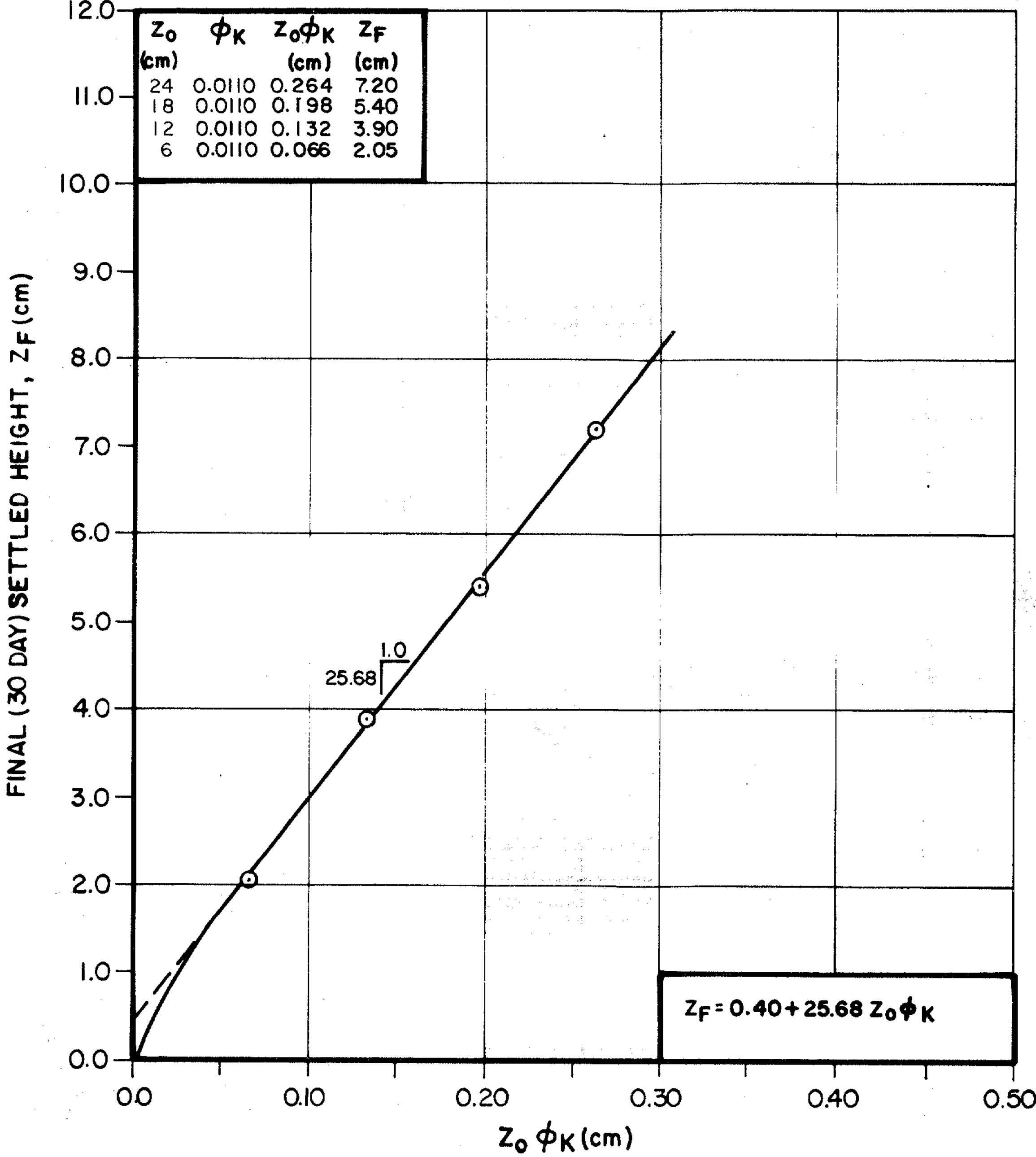
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-6



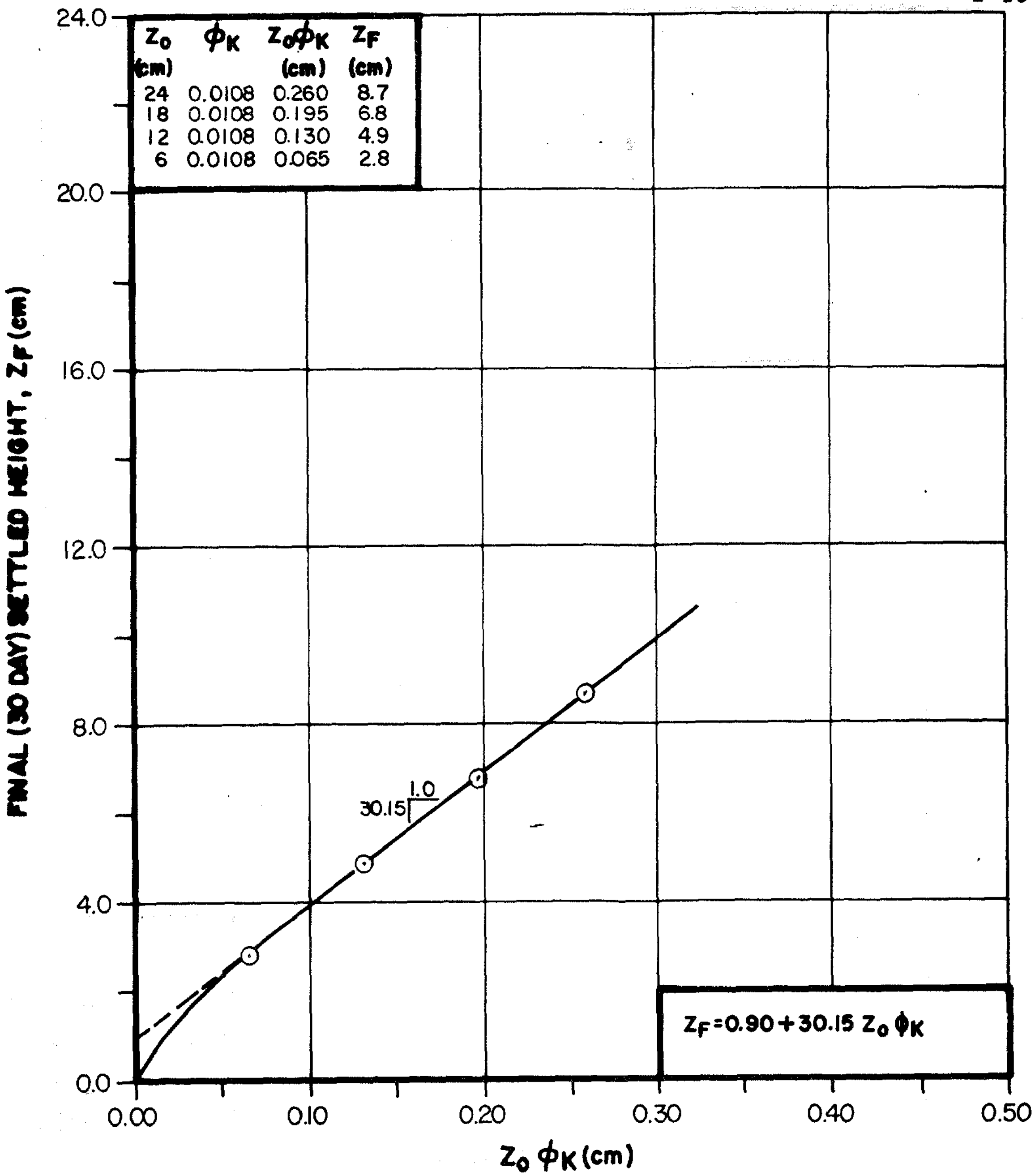
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-7



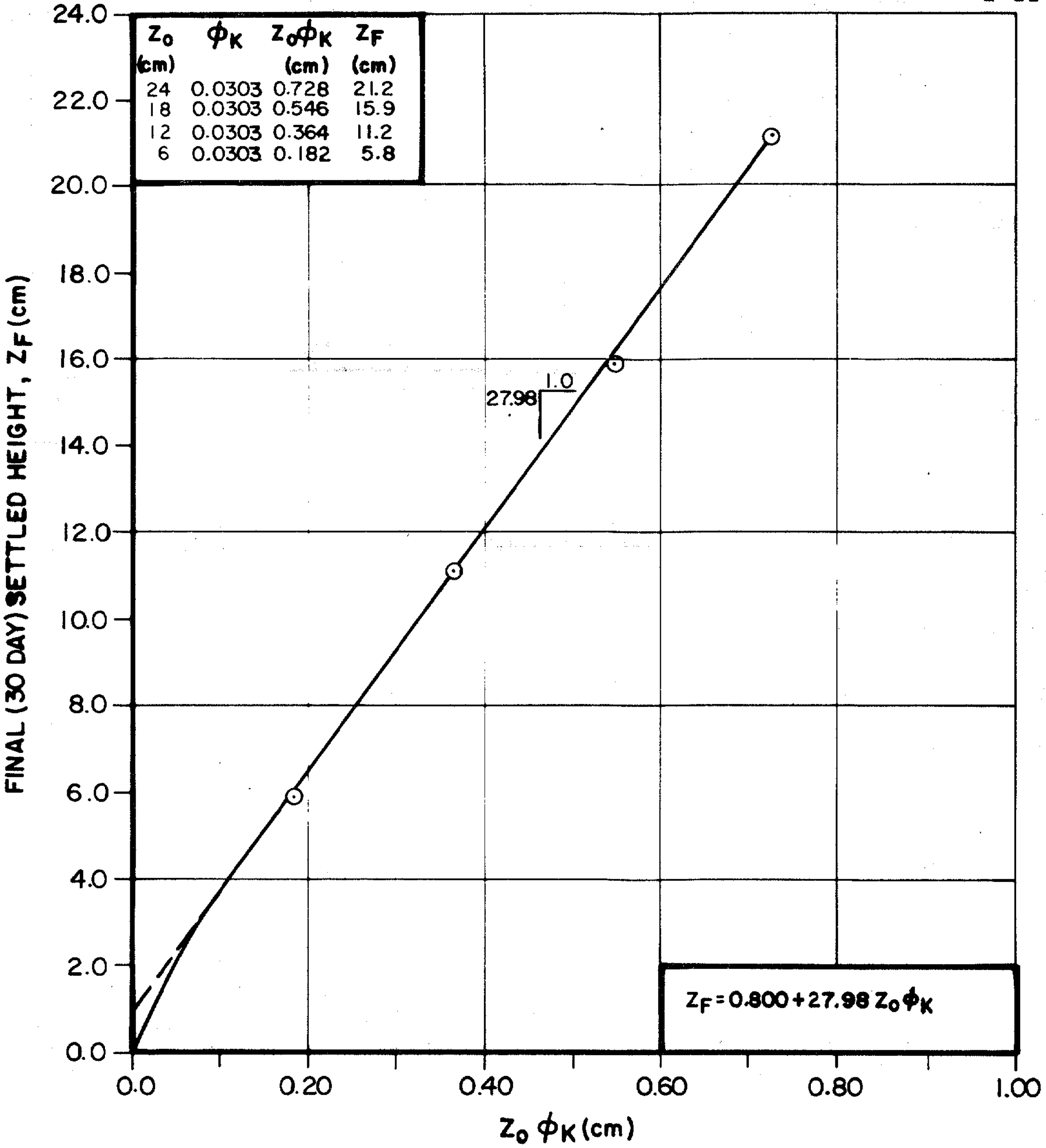
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

FIGURE E-8



FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 3%

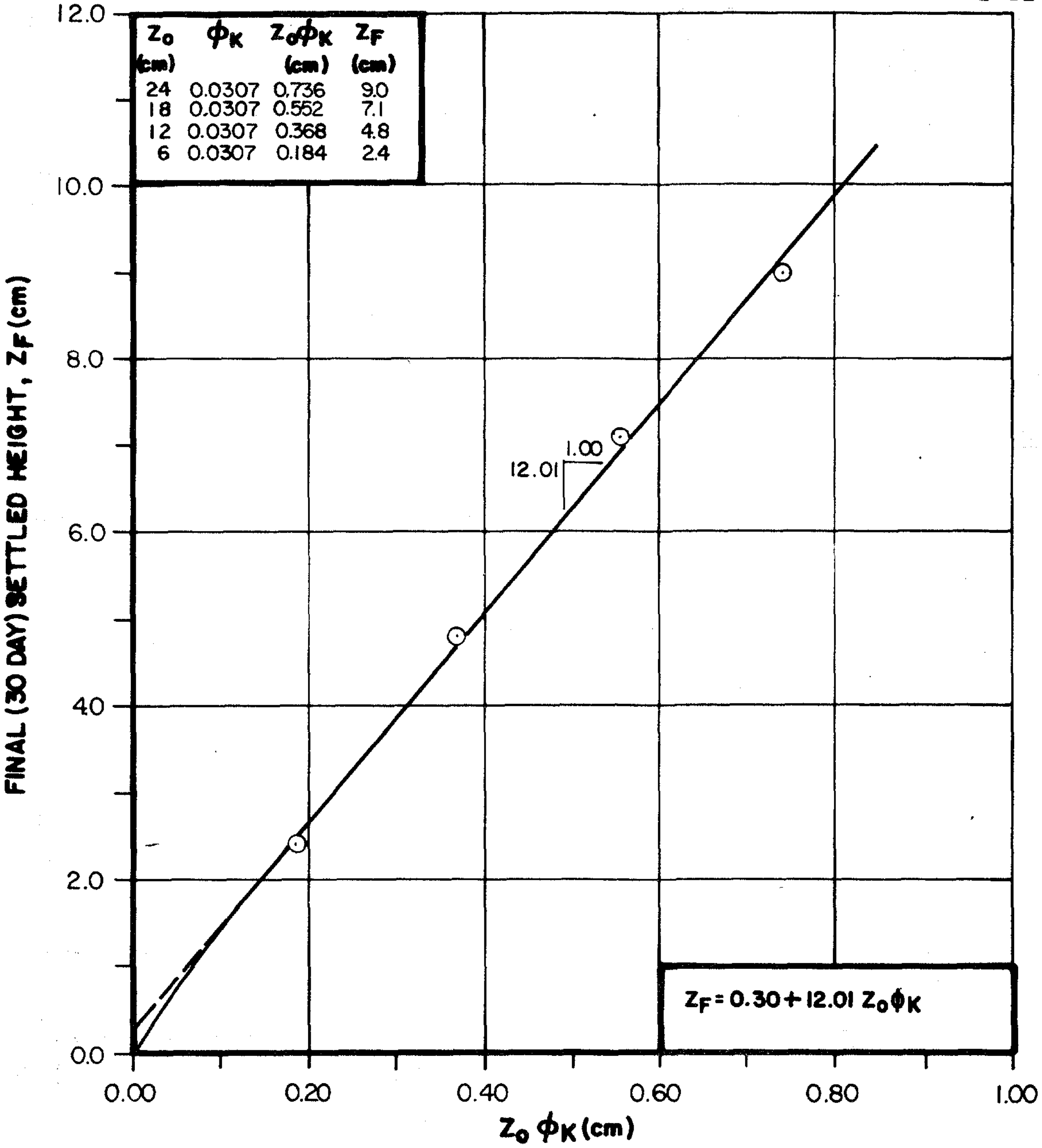
FIGURE E-9



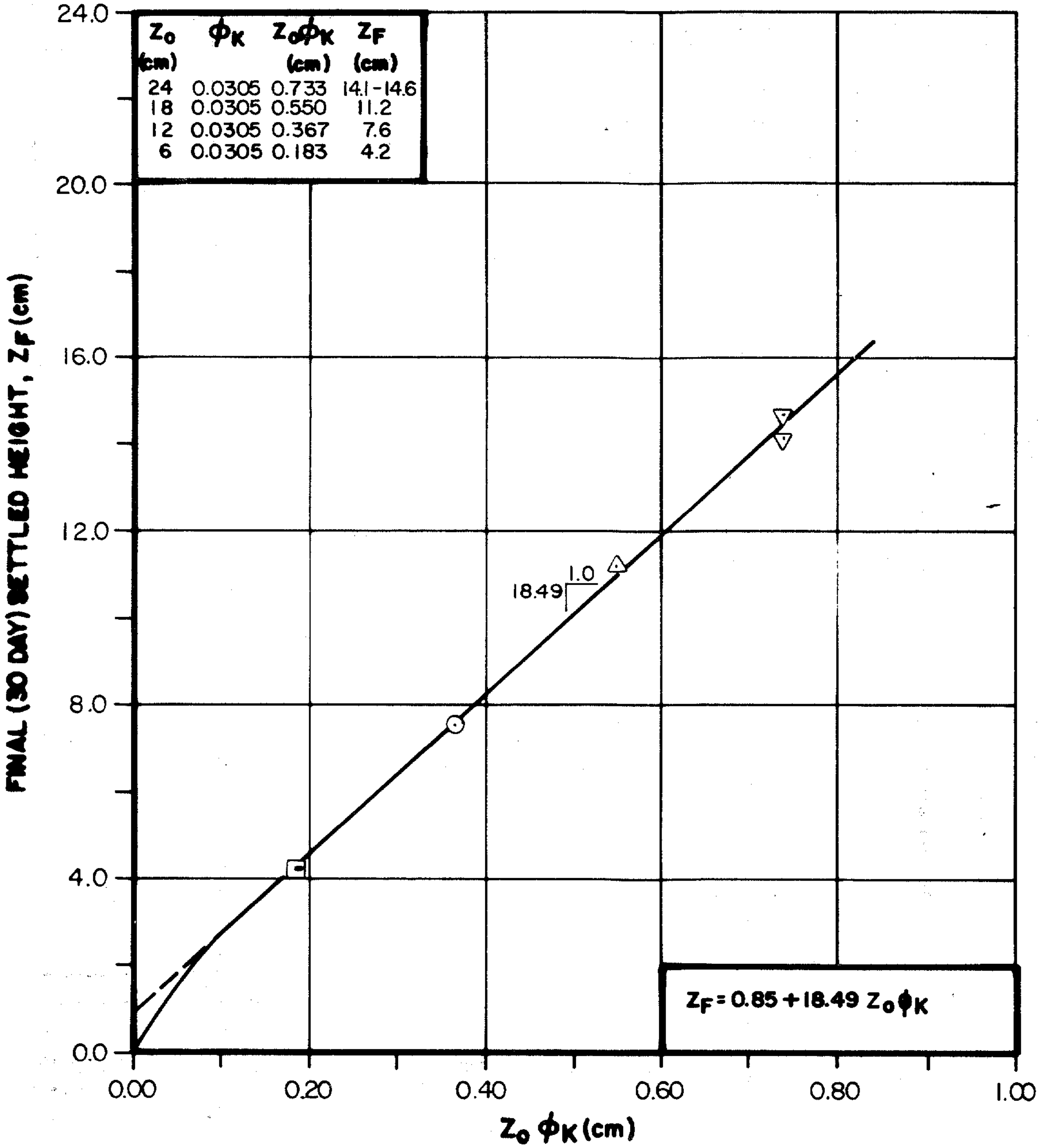
Z_0 (cm)	ϕ_K	$Z_0\phi_K$ (cm)	Z_F (cm)
24	0.0303	0.728	21.2
18	0.0303	0.546	15.9
12	0.0303	0.364	11.2
6	0.0303	0.182	5.8

FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-10

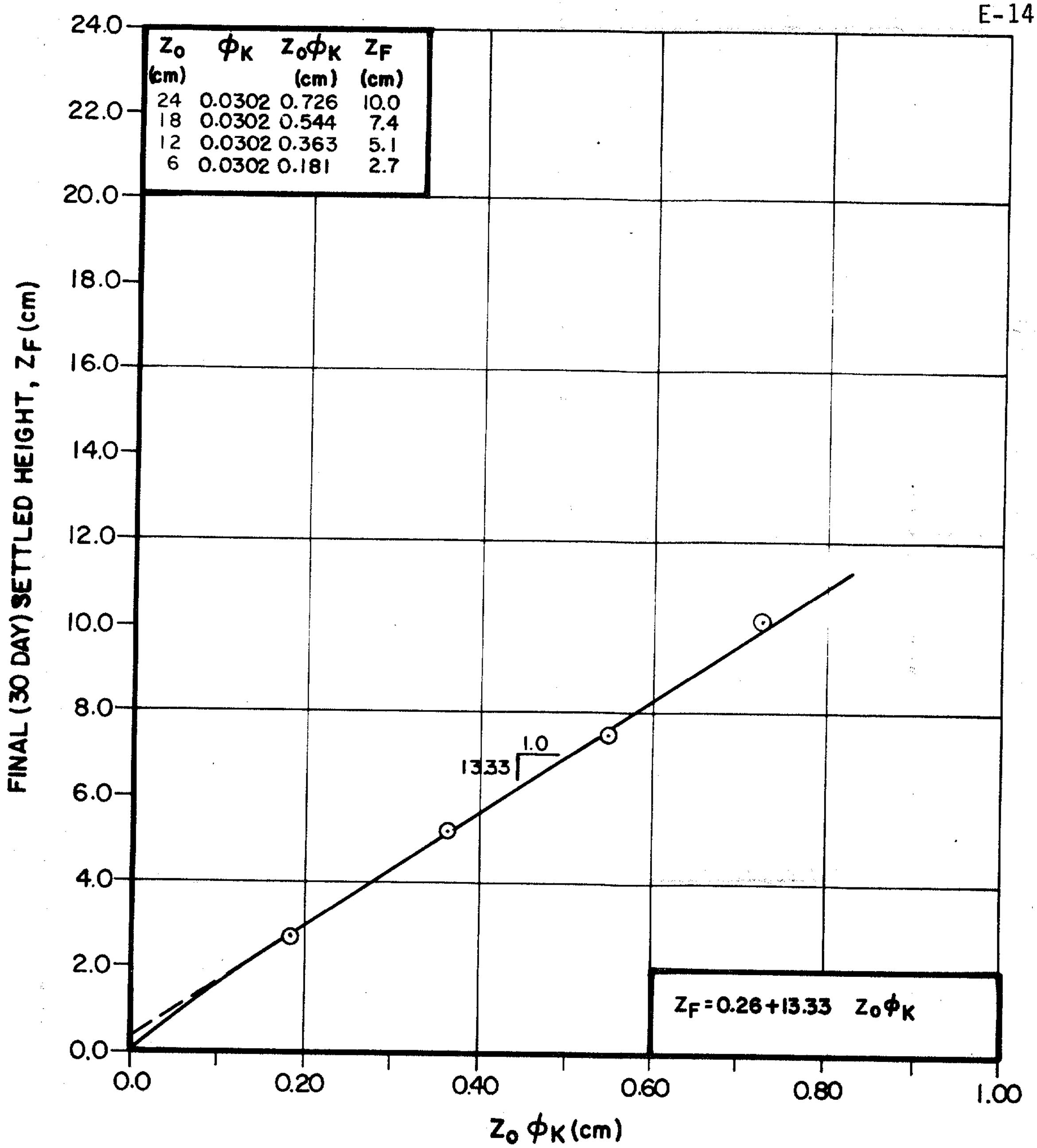


FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR AMAX-BIG FOUR PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%



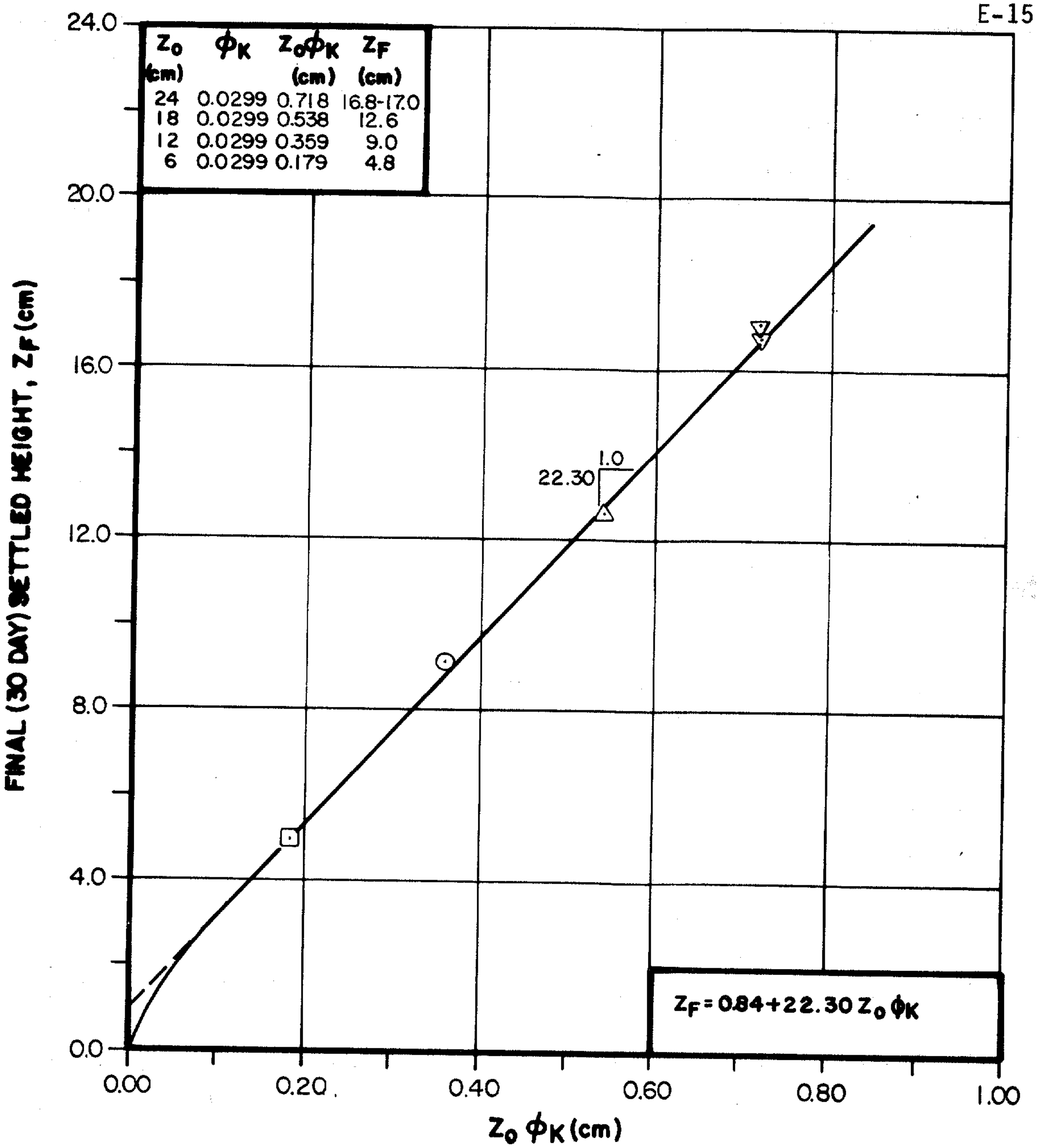
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-12



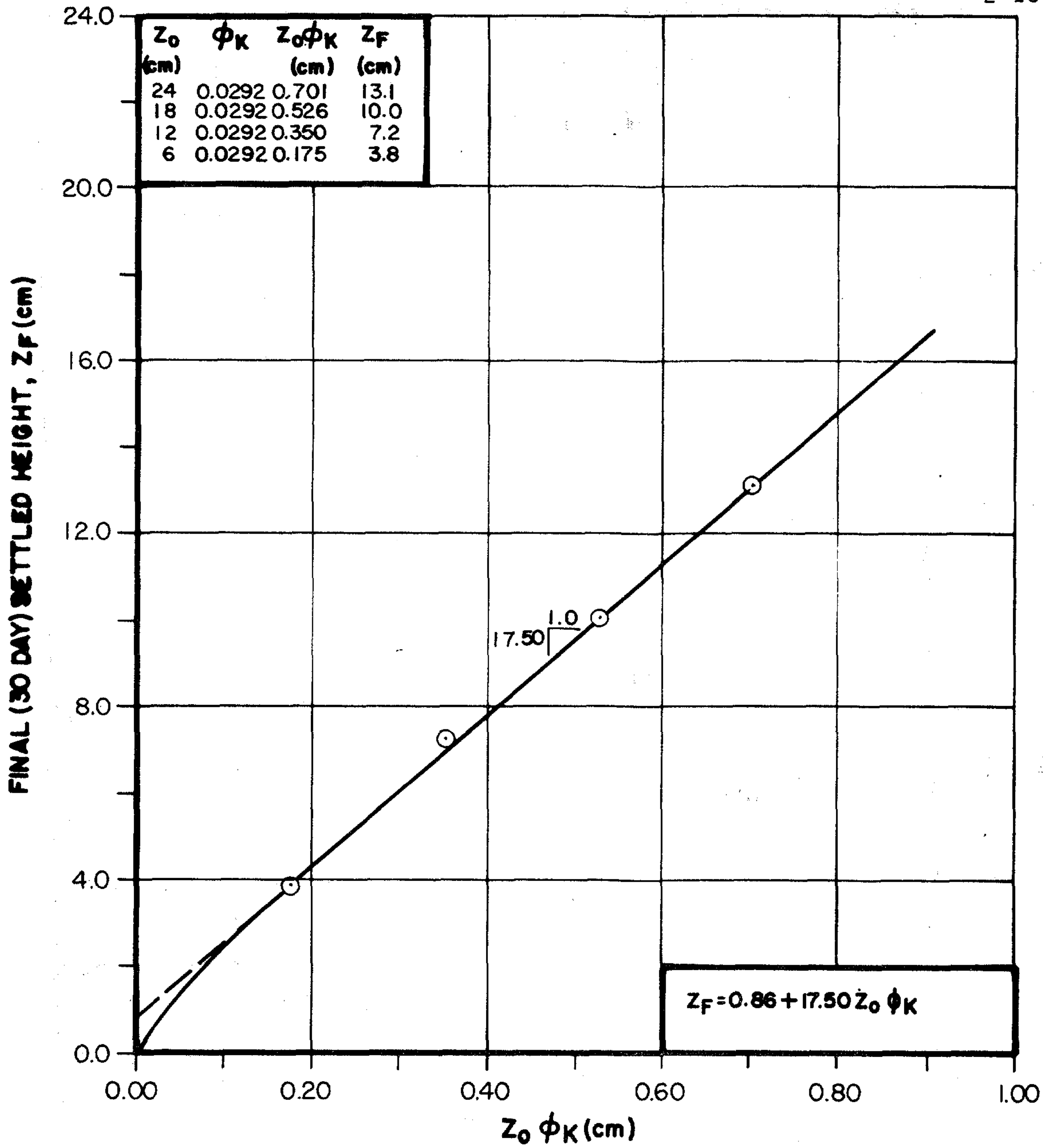
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR CF MINING-HARDEE PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-13



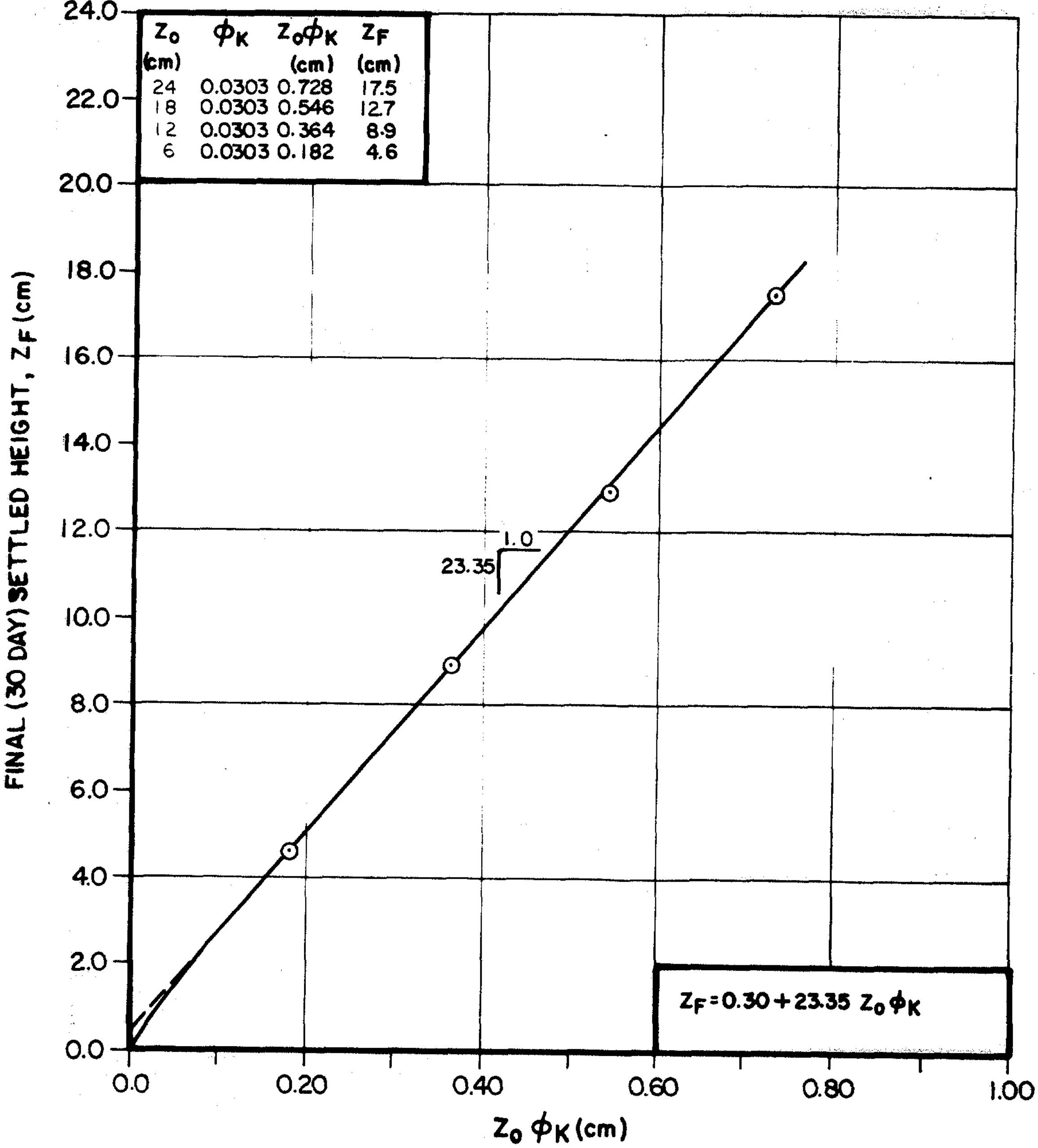
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR IMC-NORALYN PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-14



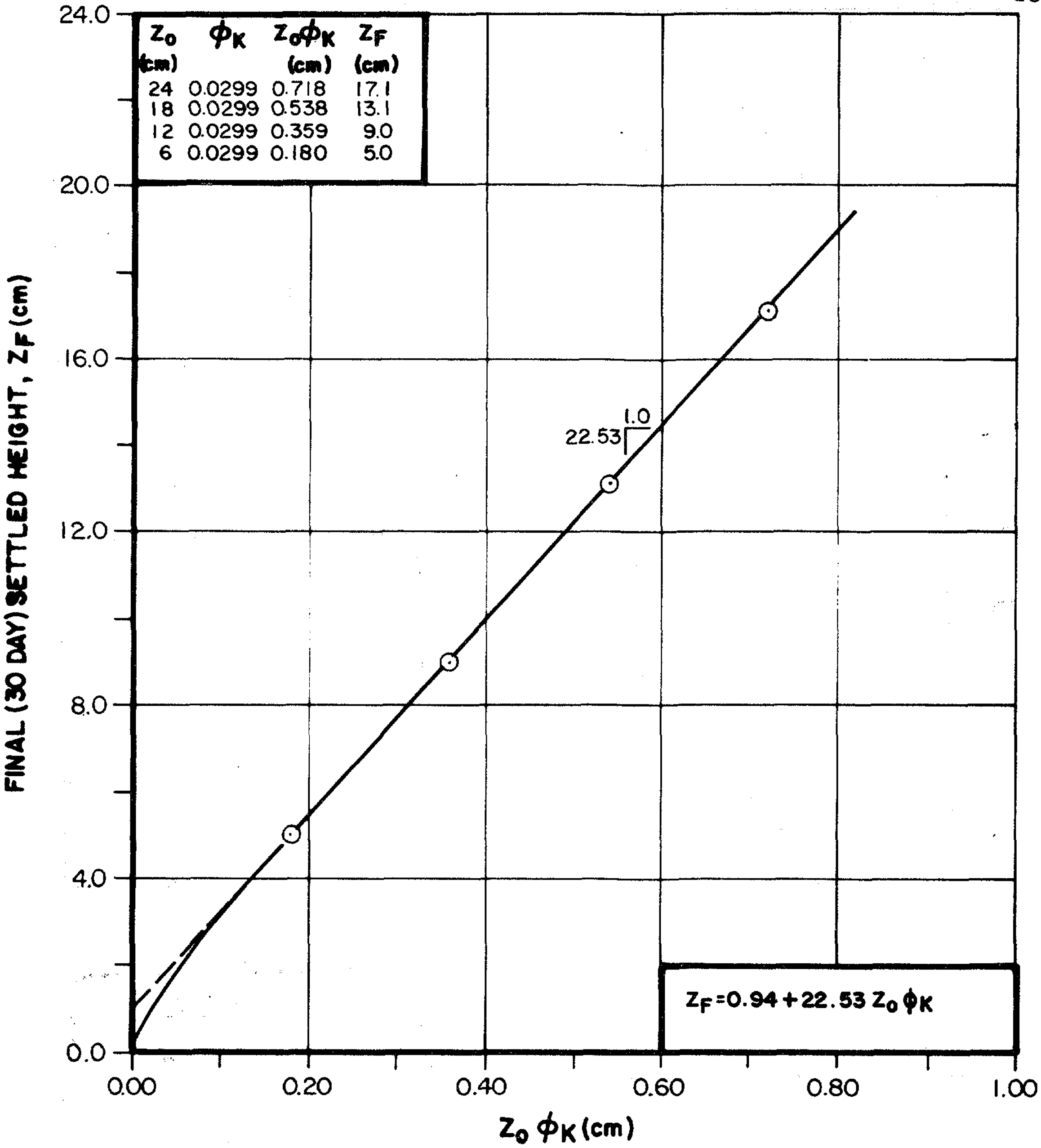
FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR MOBIL-NICHOLS PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-15



FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-16



FLOC VOLUME CONCENTRATION AND FINAL SETTLED HEIGHT FOR USSAC-ROCKLAND PHOSPHATIC CLAY AT INITIAL SOLIDS CONTENT OF 8%

FIGURE E-17

Appendix F

VOID RATIO VERSUS EFFECTIVE STRESS RELATIONSHIPS DETERMINED FROM SETTLING TESTS

Table F-1

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA-2	6.0	3.0	4.0	4.5	6.0	3.0	4.0	4.46	59.55	64.23	0.120
SA-2	12.0	3.0	7.0	5.1	6.0	3.0	3.0	5.89	44.42	64.84	0.361
SA-2	18.0	3.0	9.7	5.5	6.0	3.0	2.7	6.51	39.92	65.12	0.602
SA-2	6.0	8.0	5.8	8.3	6.0	8.0	5.8	8.26	30.87	65.90	0.333
SA-2	12.0	8.0	11.2	8.5	6.0	8.0	5.4	8.84	28.67	66.14	0.997
SA-2	18.0	8.0	15.9	9.0	6.0	8.0	4.7	10.07	24.83	66.69	1.328
• Constant Initial Height Settling Tests											
SA-2	24.0	1.0	6.8	3.5	-	-	-	-	77.33	63.82	0.158
SA-2	24.0	3.0	13.2	5.4	-	-	-	-	48.99	64.62	0.480
SA-2	24.0	8.0	21.2	9.0	-	-	-	-	28.12	66.22	1.320

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}vc$ = Effective stress

Table F-2

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR AMAX-BIG FOUR PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA BF-1	6.0	3.0	0.9	18.0	6.0	3.0	0.90	18.05	12.49	70.48	0.119
SA BF-1	12.0	3.0	2.0	16.4	6.0	3.0	1.10	15.08	15.48	69.04	0.338
SA BF-1	18.0	3.0	3.2	15.1	6.0	3.0	1.15	14.48	16.23	68.75	0.556
SA BF-1	6.0	8.0	2.4	18.9	6.0	8.0	2.35	18.93	11.78	70.94	0.328
SA BF-1	12.0	8.0	4.8	18.6	6.0	8.0	2.45	18.25	12.32	70.61	0.988
SA BF-1	18.0	8.0	7.1	18.8	6.0	8.0	2.30	19.29	11.51	71.11	1.646
• Constant Initial Height Settling Tests											
SA BF-1	24.0	1.0	1.2	17.8	-	-	-	-	12.66	70.41	0.158
SA BF-1	24.0	3.0	4.0	16.4	-	-	-	-	13.99	69.67	0.476
SA BF-1	24.0	8.0	9.0	19.7	-	-	-	-	11.23	71.35	1.322

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-3

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR BEKER-WINGATE PILOT PLANT PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
Pilot Plant	6.0	3.0	2.0	8.7	6.0	3.0	2.00	8.67	29.08	66.05	0.120
Pilot Plant	12.0	3.0	3.6	9.5	6.0	3.0	1.60	10.69	23.06	66.97	0.360
Pilot Plant	18.0	3.0	5.2	10.0	6.0	3.0	1.55	11.01	22.31	67.12	0.600
Pilot Plant	24.0	3.0	6.8	10.1	6.0	3.0	1.60	10.68	23.06	66.97	0.720
Pilot Plant	6.0	8.0	4.2	11.2	6.0	8.0	4.20	11.18	21.92	67.19	0.330
Pilot Plant	12.0	8.0	7.6	12.2	6.0	8.0	3.40	13.59	17.55	68.33	0.990
Pilot Plant	18.0	8.0	11.2	12.5	6.0	8.0	3.60	12.89	18.64	68.00	1.652
Pilot Plant	24.0	8.0	14.1	13.2	6.0	8.0	2.80	16.20	14.27	69.63	2.316
• Constant Initial Height Settling Tests											
Pilot Plant	24.0	1.0	2.7	8.6	-	-	-	-	29.28	66.03	0.158
Pilot Plant	24.0	3.0	6.6	10.5	-	-	-	-	23.61	66.87	0.480
Pilot Plant	24.0	8.0	14.6	12.8	-	-	-	-	18.85	67.93	1.320

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-4

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR CF MINING-HARDEE PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
● Variable Initial Height Settling Tests											
SA N-1	6.0	3.0	1.0	16.4	6.0	3.0	1.00	16.42	14.20	69.75	0.121
SA N-1	12.0	3.0	1.9	17.2	6.0	3.0	0.90	18.04	12.68	70.55	0.362
SA N-1	18.0	3.0	2.7	18.0	6.0	3.0	0.80	20.00	11.16	71.58	0.602
SA N-1	6.0	8.0	2.7	16.7	6.0	8.0	2.70	16.73	13.89	69.89	0.332
SA N-1	12.0	8.0	5.1	17.6	6.0	8.0	2.40	18.57	12.23	70.86	0.996
SA N-1	18.0	8.0	7.4	18.1	6.0	8.0	2.30	19.28	11.68	71.22	1.662
● Constant Initial Height Settling Tests											
SA N-1	24.0	1.0	1.2	16.6	-	-	-	-	14.02	69.82	0.158
SA N-1	24.0	3.0	3.7	17.6	-	-	-	-	13.06	70.35	0.482
SA N-1	24.0	8.0	11.2	15.3	-	-	-	-	15.44	69.19	1.268
SA N-1	23.6	12.0	13.9	19.1	-	-	-	-	11.82	71.11	1.986
SA N-1	24.0	16.0	17.4	21.0	-	-	-	-	10.49	72.11	2.771

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-5

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR ESTECH-WATSON PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
● Variable Initial Height Settling Tests											
SA-13	6.0	3.0	1.5	11.7	6.0	3.0	1.45	11.70	21.74	67.57	0.123
SA-13	12.0	3.0	3.0	11.3	6.0	3.0	1.55	10.99	23.31	67.24	0.369
SA-13	18.0	3.0	4.3	12.0	6.0	3.0	1.25	13.40	18.61	68.38	0.614
● Constant Initial Height Settling Tests											
SA-13	24.0	1.0	1.9	11.7	-	-	-	-	21.65	67.58	0.162
SA-13	24.0	3.0	5.9	11.6	-	-	-	-	21.94	67.52	0.491
SA-13	24.0	8.0	13.2	14.0	-	-	-	-	17.77	68.64	1.350

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-6

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR IMC-NORALYN PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA N-14	6.0	3.0	2.2	7.9	6.0	3.0	2.20	7.92	32.80	65.76	0.121
SA N-14	12.0	3.0	4.5	7.8	6.0	3.0	2.30	7.59	34.34	65.60	0.363
SA N-14	18.0	3.0	6.2	8.4	6.0	3.0	1.70	10.09	25.12	66.74	0.606
SA N-14	24.0	3.0	8.1	8.6	6.0	3.0	1.90	9.09	28.19	66.29	0.848
SA N-14	6.0	8.0	4.8	9.8	6.0	8.0	4.85	9.78	26.02	66.61	0.334
SA N-14	12.0	8.0	9.0	10.4	6.0	8.0	4.20	11.18	22.40	67.25	1.004
SA N-14	18.0	8.0	12.6	11.2	6.0	8.0	3.55	13.06	18.78	68.14	1.673
SA N-14	24.0	8.0	17.0	11.1	6.0	8.0	4.40	11.06	22.68	67.19	1.339
• Constant Initial Height Settling Tests											
SA N-14	24.0	1.0	2.2	10.5	-	-	-	-	24.10	66.92	0.160
SA N-14	24.0	3.0	6.7	10.2	-	-	-	-	24.73	66.82	0.486
SA N-14	24.0	8.0	16.8	11.2	-	-	-	-	22.40	67.25	1.338

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-7

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR MOBIL-NICHOLS PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA N-3	6.0	3.0	1.6	10.7	6.0	3.0	1.60	10.67	24.18	67.10	0.122
SA N-3	12.0	3.0	3.0	11.3	6.0	3.0	1.40	12.08	21.04	67.74	0.369
SA N-3	18.0	3.0	4.2	12.1	6.0	3.0	1.20	13.91	17.89	68.64	0.614
SA N-3	6.0	8.0	3.8	12.3	6.0	8.0	3.80	12.26	20.68	67.85	0.339
SA N-3	12.0	8.0	7.2	13.0	6.0	8.0	3.35	13.76	18.11	68.59	1.019
SA N-3	18.0	8.0	10.0	13.8	6.0	8.0	2.85	15.92	15.26	69.66	1.698
• Constant Initial Height Settling Tests											
SA N-3	24.0	1.0	2.3	9.8	-	-	-	-	26.51	66.70	0.162
SA N-3	24.0	3.0	5.5	12.3	-	-	-	-	20.64	67.86	0.493
SA N-3	24.0	8.0	13.1	14.1	-	-	-	-	17.69	68.70	1.354

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-8

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY

	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA-8	6.0	3.0	2.1	8.5	6.0	3.0	2.05	8.47	30.04	65.98	0.120
SA-8	12.0	3.0	3.9	8.9	6.0	3.0	1.85	9.33	27.02	66.36	0.360
SA-8	18.0	3.0	5.4	9.6	6.0	3.0	1.50	11.34	21.73	67.30	0.602
SA-8	6.0	8.0	4.6	10.3	6.0	8.0	4.60	10.27	24.29	66.79	0.331
SA-8	12.0	8.0	8.9	10.6	6.0	8.0	4.30	10.94	22.63	67.10	0.994
SA-8	18.0	8.0	12.7	11.1	6.0	8.0	3.80	12.27	19.88	67.71	1.657
• Constant Initial Height Settling Tests											
SA-8	24.0	1.0	2.8	8.2	-	-	-	-	31.22	65.86	0.159
SA-8	24.0	3.0	7.2	9.6	-	-	-	-	26.27	66.96	0.480
SA-8	24.0	8.0	17.5	10.8	-	-	-	-	23.04	67.02	1.326

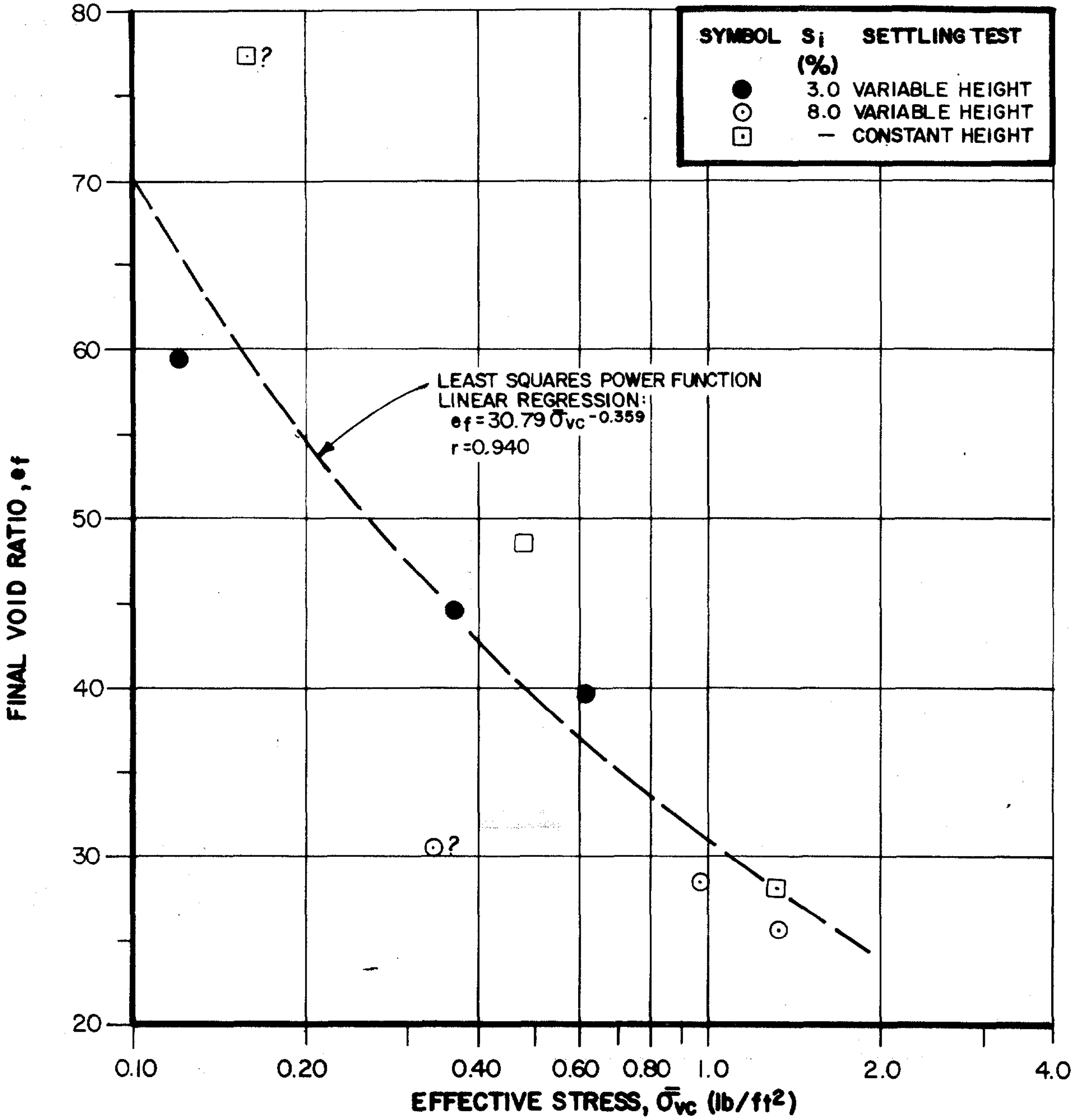
Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress

Table F-9

SETTLING TEST RESULTS FOR VOID RATIO VERSUS EFFECTIVE STRESS FOR USSAC-ROCKLAND PHOSPHATIC CLAY

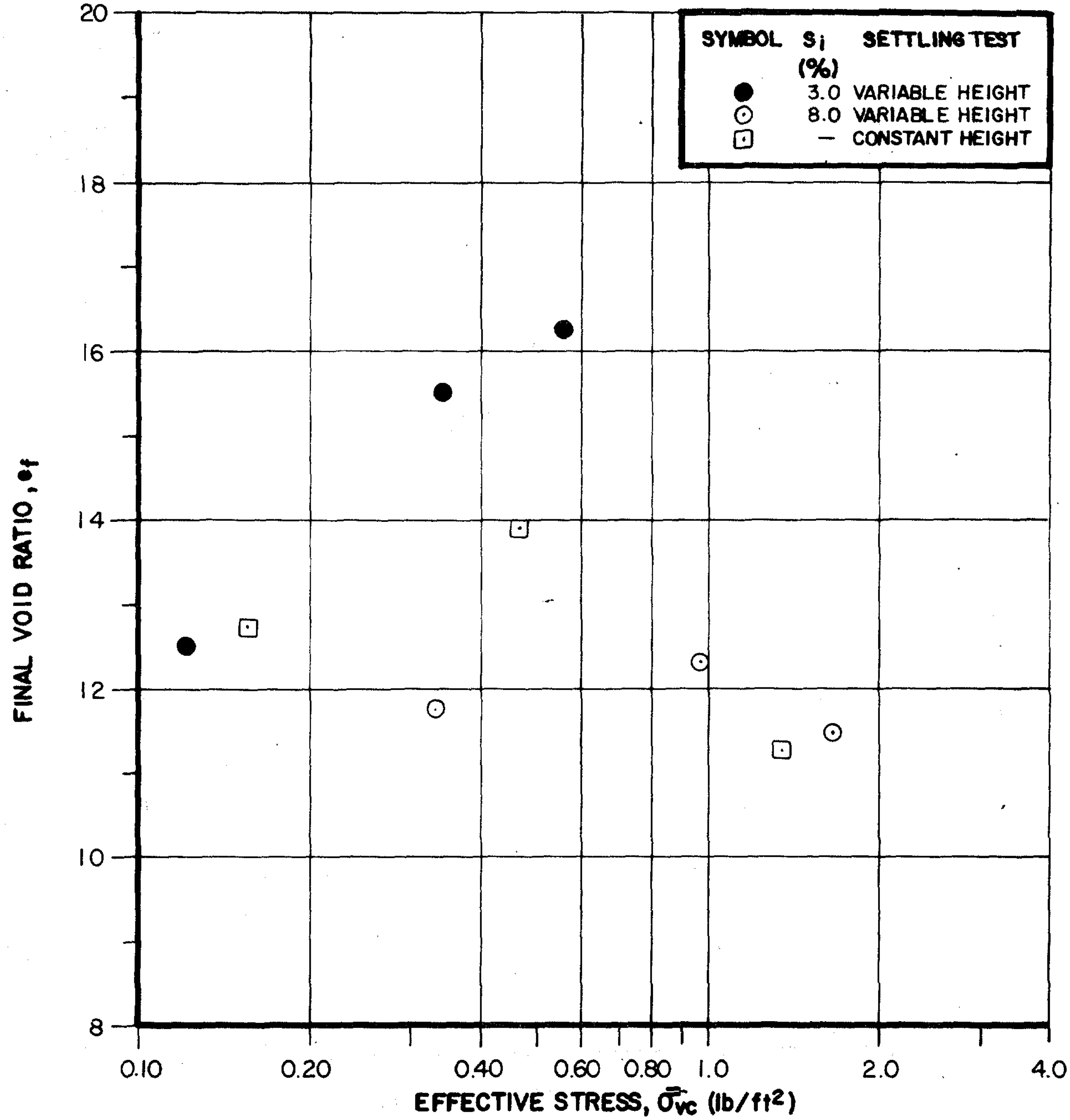
	Total Sample				Lower 6 cm Increment of Sample				Void Ratio - Effective Stress Data		
Sample	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	Z_o (cm)	S_i (%)	Z_F (cm)	S_F (%)	e_f	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)
• Variable Initial Height Settling Tests											
SA-6	6.0	3.0	2.8	6.3	6.0	3.0	2.80	6.29	42.02	65.04	0.122
SA-6	12.0	3.0	4.9	7.2	6.0	3.0	2.10	7.98	32.54	65.78	0.358
SA-6	18.0	3.0	6.8	7.7	6.0	3.0	1.90	8.77	29.34	66.15	0.590
SA-6	24.0	3.0	8.7	8.0	6.0	3.0	1.85	8.99	28.54	66.25	0.720
SA-6	6.0	8.0	5.0	9.5	6.0	8.0	5.00	9.50	26.86	66.47	0.334
SA-6	12.0	8.0	9.0	10.4	6.0	8.0	4.05	11.56	21.56	67.45	1.004
SA-6	18.0	8.0	13.1	10.8	6.0	8.0	4.05	11.56	21.56	67.45	1.674
SA-6	24.0	8.0	17.1	11.0	6.0	8.0	4.00	11.70	21.29	67.48	2.334
• Constant Initial Height Settling Tests											
SA-6	24.0	1.0	3.0	7.7	-	-	-	-	34.02	65.65	0.160
SA-6	24.0	3.0	7.5	9.2	-	-	-	-	27.81	66.33	0.848
SA-6	24.0	8.0	16.5	11.4	-	-	-	-	21.98	67.35	1.340

Where: Z_o = Initial height; S_i = Initial solids content; Z_F = Final height; S_F = Final solids content; e_f = Final void ratio; γ_t = Total unit weight; and $\bar{\sigma}_{vc}$ = Effective stress



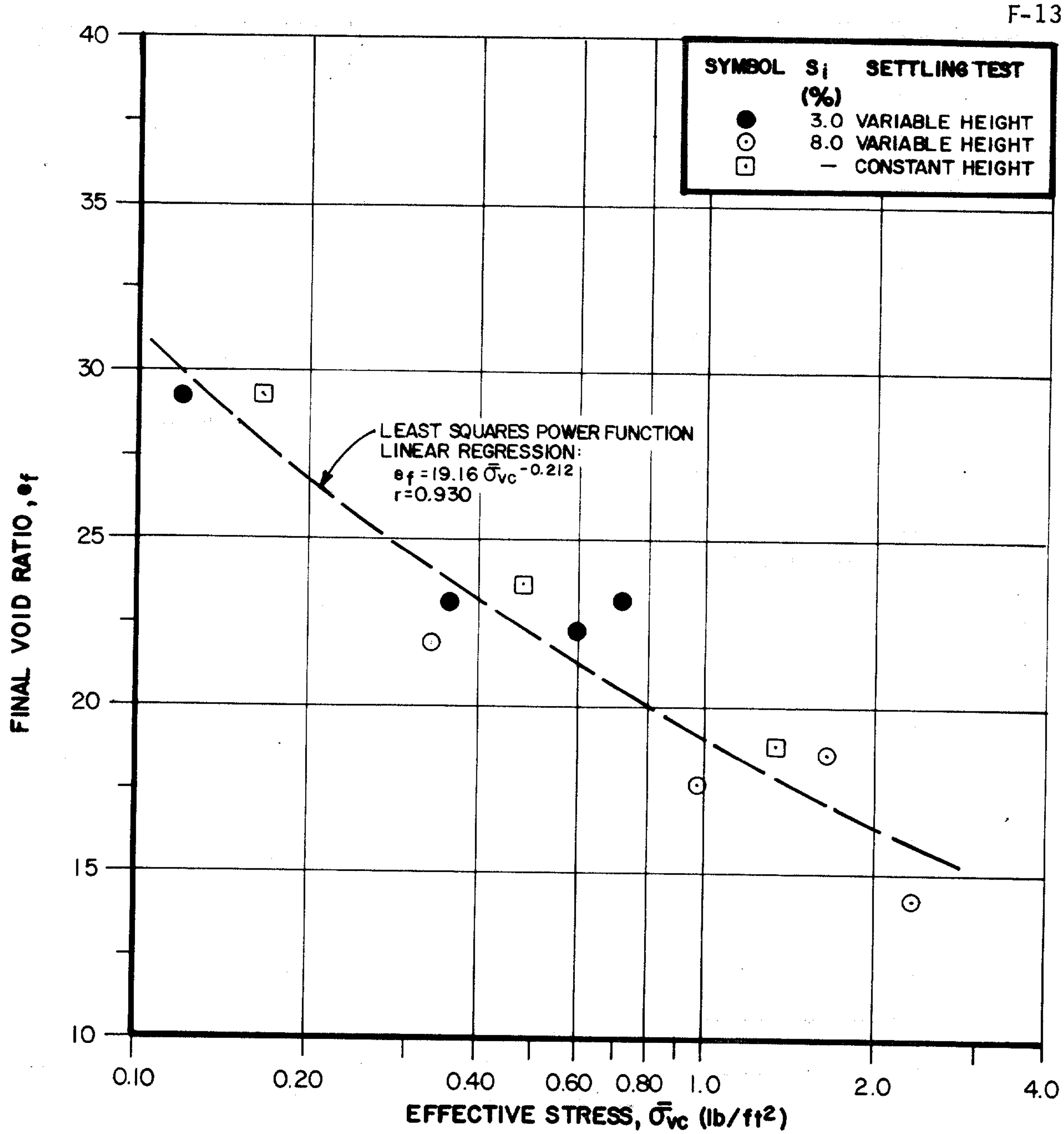
VOID RATIO VS. EFFECTIVE STRESS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY

FIGURE F-1



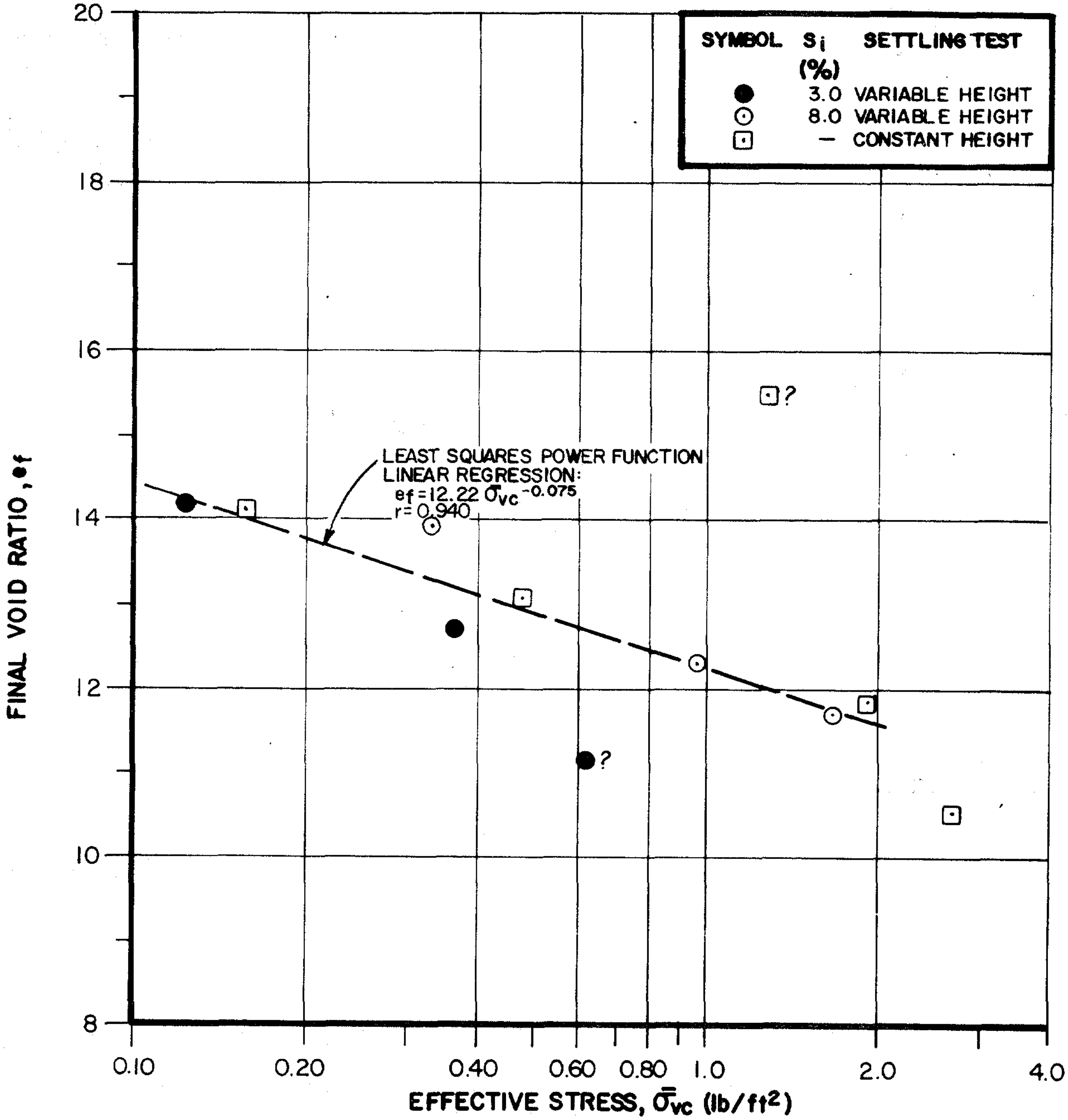
VOID RATIO VS. EFFECTIVE STRESS FOR AMAX-BIG FOUR PHOSPHATIC CLAY

FIGURE F-2



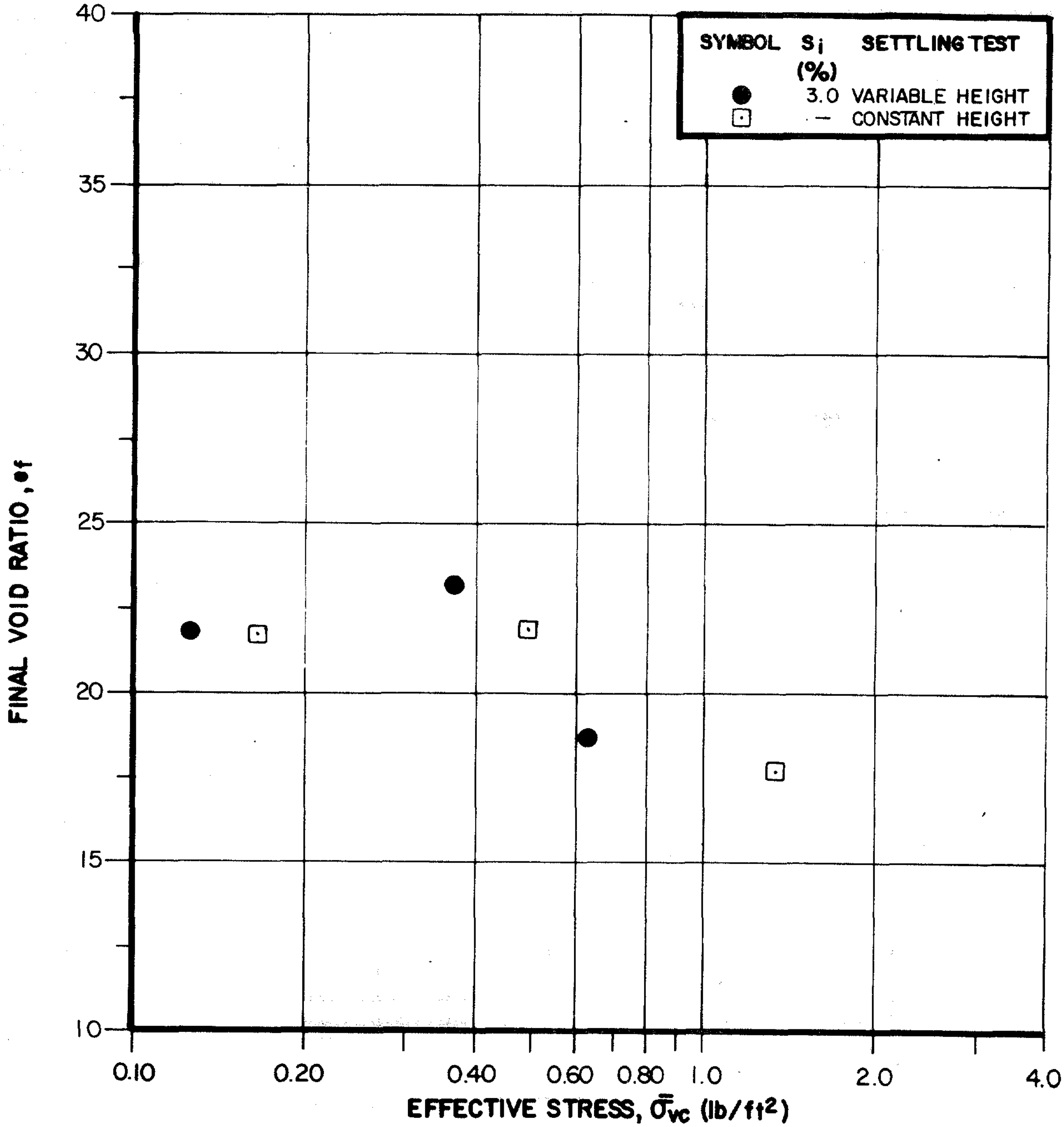
VOID RATIO VS. EFFECTIVE STRESS FOR BEKER-WINGATE CREEK PILOT PLANT PHOSPHATIC CLAY

FIGURE F-3



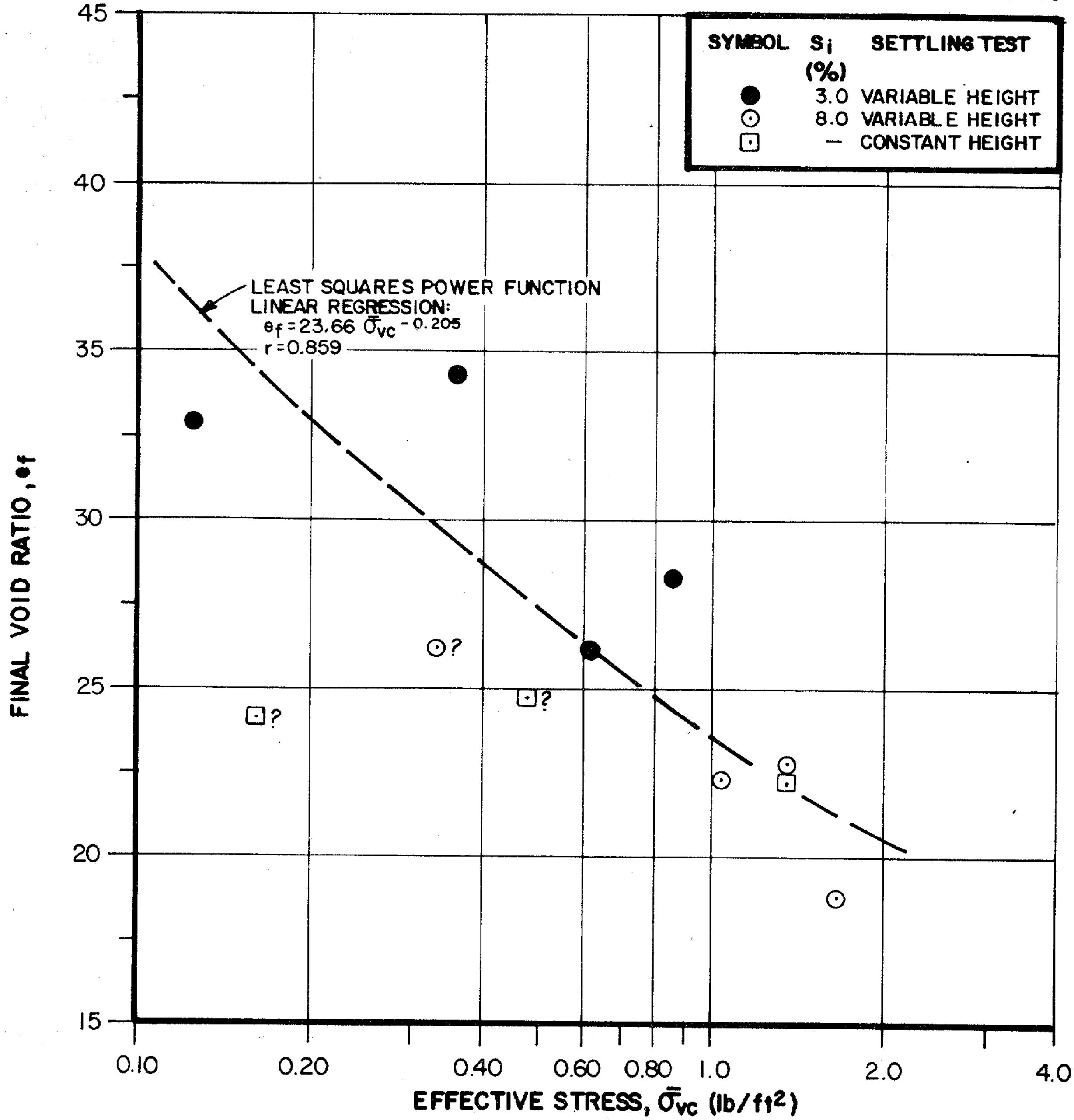
VOID RATIO VS. EFFECTIVE STRESS FOR CF MINING-HARDEE PHOSPHATIC CLAY

FIGURE F-4



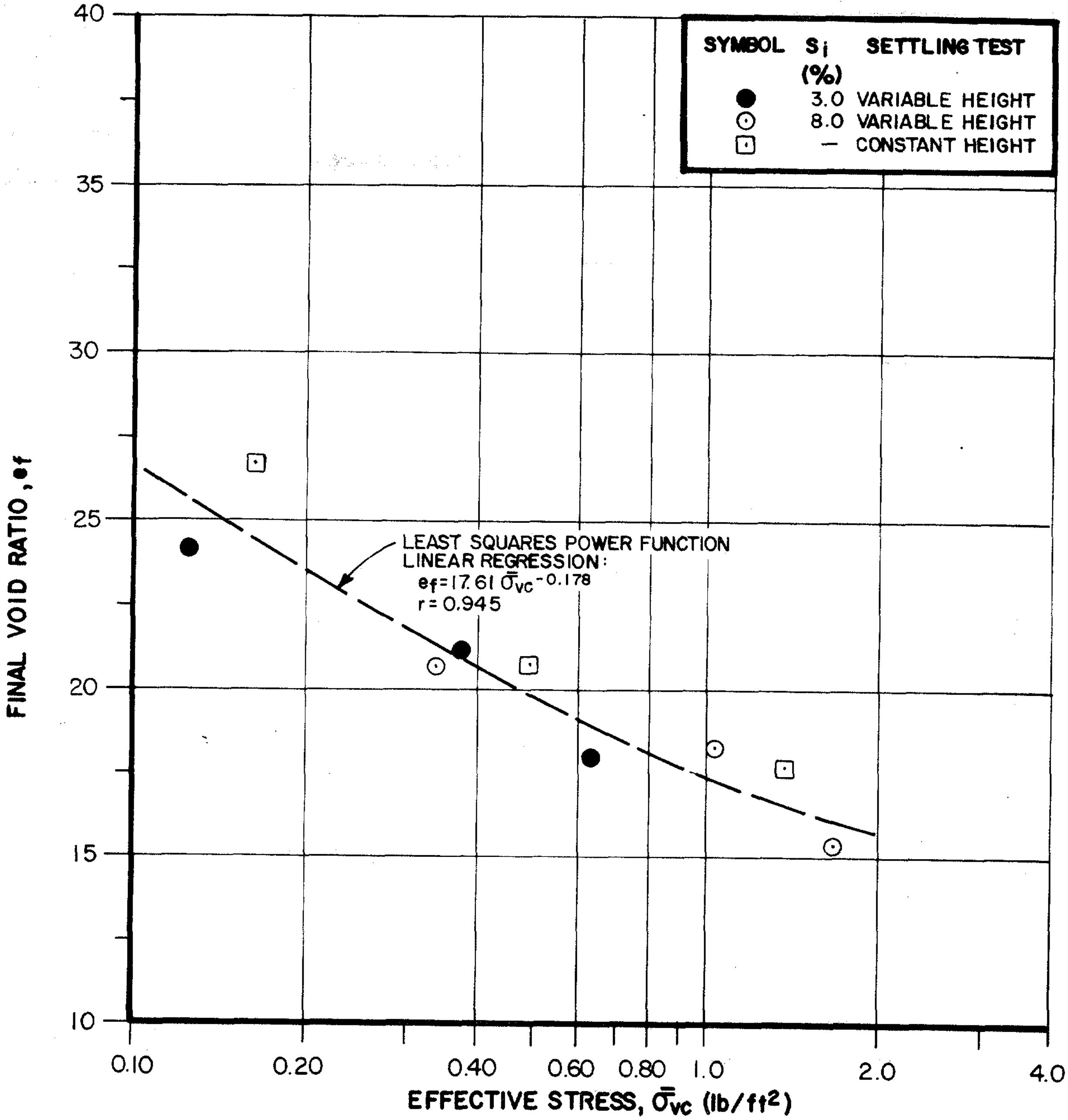
VOID RATIO VS. EFFECTIVE STRESS FOR ESTECH-WATSON PHOSPHATIC CLAY

FIGURE F-5



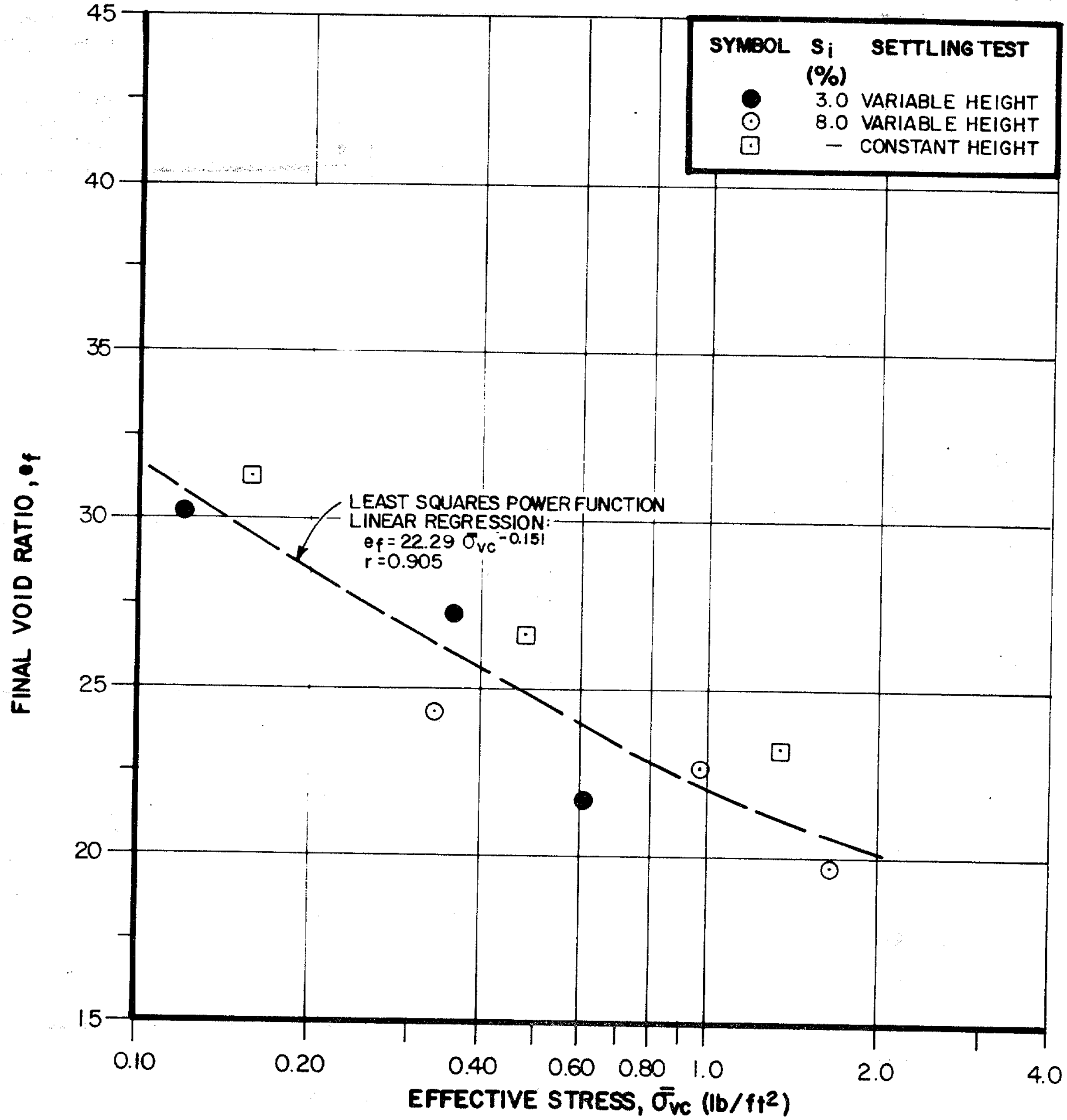
VOID RATIO VS. EFFECTIVE STRESS FOR IMC-NORALYN PHOSPHATIC CLAY

FIGURE F-6



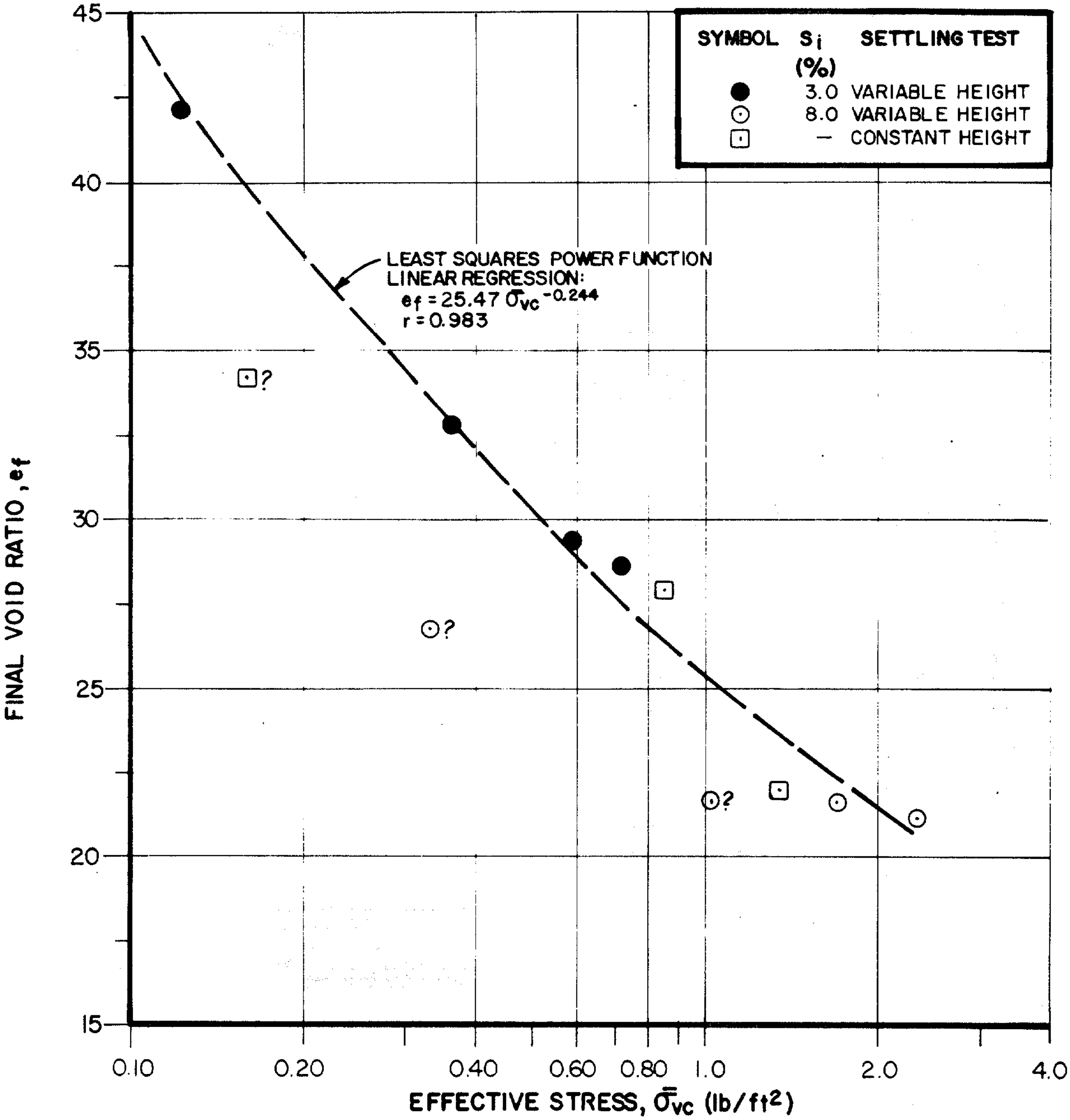
VOID RATIO VS. EFFECTIVE STRESS FOR MOBIL-NICHOLS PHOSPHATIC CLAY

FIGURE F-7



VOID RATIO VS. EFFECTIVE STRESS FOR OCCIDENTAL-SUWANNEE RIVER PHOSPHATIC CLAY

FIGURE F-8



VOID RATIO VS. EFFECTIVE STRESS FOR USSAC-ROCKLAND PHOSPHATIC CLAY

FIGURE F-9

Appendix G

GRAPHICAL PLOTS OF SOLIDS CONTENT AND HEIGHT OF INTERFACE VERSUS TIME FOR SAND-CLAY MIX SETTLING TESTS

Table G-1

SAND-CLAY MIX SETTLING TEST RESULTS FOR AGRICO-SADDLE CREEK PHOSPHATIC CLAY

	Sample Data			Initial Conditions		Final Conditions			Void Ratio – Effective Stress Data				Particle Size Analysis		
SCR	ρ (g/cm^3)	Z_o (cm)	Z_s (cm)	S_{ic} (%)	S_{it} (%)	S_{Fc} (%)	S_{Ft} (%)	Z_F (cm)	e_{fc}	e_{ft}	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)	Ideal (%)	Top Half (%)	Lower Half (%)
1:1*	2.75	24.0	1.427	8.0	14.8	10.2	18.4	18.8	24.61	12.17	70.70	2.56	50	-	-
2:1*	2.74	24.0	2.086	8.0	20.7	10.1	25.3	19.0	24.69	8.11	74.30	3.70	33	34	33
3:1*	2.74	24.0	2.704	8.0	25.8	11.3	33.7	17.3	21.88	5.38	79.41	4.82	25	-	-
1:1**	2.82	24.0	1.394	8.0	14.8	10.3	18.7	18.5	24.20	12.27	70.98	2.60	50	51	50
2:1**	2.83	24.0	2.026	8.0	20.7	10.9	26.8	17.7	22.70	7.71	75.52	3.80	33	34	34
3:1**	2.84	24.0	2.619	8.0	25.8	11.6	34.4	16.8	21.19	5.41	80.36	4.94	25	26	25
2:1*	2.74	24.0	3.117	12.0	29.0	12.9	30.7	22.4	18.84	6.19	77.46	5.54	33	34	34

Where: SCR = Sand-clay ratio by dry weight; ρ = Effective specific gravity of solids; Z_o = Initial height; Z_s = Height of solids; S_{ic} = Initial solids content of clay; S_{it} = Initial total solids content; S_{Fc} = Final clay solids content; S_{Ft} = Final total solids content; Z_F = Final height; e_{fc} = Final void ratio of clay; e_{ft} = Final total void ratio; γ_t = Total unit weight; $\bar{\sigma}_{vc}$ = Effective stress at mid-layer.

Equations: $S_{it} = (1 + SCR)/((1/S_{ic}) + SCR)$

$$e_{fc} = e_{ft}\left(1 + (\rho_c SCR/\rho_s)\right)$$

$$S_{Fc} = 1/\left(((1 + SCR)/S_{Ft}) - SCR\right)$$

*Agrico clay mixed with CF sand tailings with ρ_s = 2.72.
**Agrico clay mixed with Agrico sand tailings with ρ_s = 2.86.

Table G-2

SAND-CLAY MIX SETTLING TEST RESULTS FOR CF MINING-HARDEE PHOSPHATIC CLAY

	Sample Data			Initial Conditions		Final Conditions			Void Ratio - Effective Stress Data				Particle Size Analysis		
SCR	ρ (g/cm^3)	Z_o (cm)	Z_s (cm)	S_{ic} (%)	S_{it} (%)	S_{Fc} (%)	S_{Ft} (%)	Z_F (cm)	e_{fc}	e_{ft}	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)	Ideal (%)	Top Half (%)	Lower Half (%)
1:1*	2.76	24.0	2.158	12.0	21.4	18.4	31.0	15.4	12.42	6.13	77.84	3.90	50	57	50
2:1*	2.74	24.0	3.118	12.0	29.0	19.1	41.4	15.2	11.84	3.88	84.59	5.54	33	36	29
3:1*	2.74	24.0	3.984	12.0	35.3	19.4	49.1	15.3	11.57	2.84	90.68	7.10	25	27	23
1:1*	2.76	24.0	2.911	16.0	27.6	24.6	39.4	15.3	8.59	4.24	83.33	5.24	50	-	-
2:1*	2.74	24.0	4.141	16.0	36.4	22.7	46.9	17.0	9.46	3.10	88.96	7.40	33	33	31
3:1*	2.74	24.0	5.221	16.0	43.2	24.7	56.7	16.2	8.52	2.09	97.60	9.32	25	-	-
1:1**	2.74	24.0	2.930	16.0	27.6	25.4	40.6	14.7	8.19	4.02	83.99	5.20	50	41	39
2:1**	2.72	24.0	4.166	16.0	36.4	27.6	53.3	14.1	7.32	2.38	94.23	7.36	33	27	27
3:1**	2.72	24.0	5.251	16.0	43.2	26.2	58.6	15.4	7.89	1.92	99.22	9.28	25	22	21

Where: SCR = Sand-clay ratio by dry weight; ρ = Effective specific gravity of solids; Z_o = Initial height; Z_s = Height of solids; S_{ic} = Initial solids content of clay; S_{it} = Initial total solids content; S_{Fc} = Final clay solids content; S_{Ft} = Final total solids content; Z_F = Final height; e_{fc} = Final void ratio of clay; e_{ft} = Final total void ratio; γ_t = Total unit weight; $\bar{\sigma}_{vc}$ = Effective stress at mid-layer.

Equations: $S_{it} = (1 + SCR)/((1/S_{ic}) + SCR)$

$$e_{fc} = e_{ft} \left(1 + (\rho_c SCR/\rho_s)\right)$$

$$S_{Fc} = 1/\left(((1 + SCR)/S_{Ft}) - SCR\right)$$

*CF clay mixed with CF sand tailings with ρ_s = 2.72.
**CF clay mixed with CF sand tailings with ρ_s = 2.69.

Table G-3

SAND-CLAY MIX SETTLING TEST RESULTS FOR USSAC-ROCKLAND PHOSPHATIC CLAY

	Sample Data			Initial Conditions		Final Conditions			Void Ratio - Effective Stress Data				Particle Size Analysis		
SCR	ρ (g/cm^3)	Z_o (cm)	Z_s (cm)	S_{ic} (%)	S_{it} (%)	S_{Fc} (%)	S_{Ft} (%)	Z_F (cm)	e_{fc}	e_{ft}	γ_t (lb/ft^3)	$\bar{\sigma}_{vc}$ (lb/ft^2)	Ideal (%)	Top Half (%)	Lower Half (%)
1:1*	2.76	24.0	1.422	8.0	14.8	12.4	22.0	15.3	19.94	9.76	72.61	2.56	50	52	52
2:1*	2.74	24.0	2.086	8.0	20.7	13.3	31.5	14.5	18.37	5.95	78.02	3.72	33	35	34
3:1*	2.75	24.0	2.713	8..0	25.8	13.5	38.4	14.6	18.10	4.38	82.47	4.81	25	27	26
1:1*	2.76	24.0	2.157	12.0	21.4	14.4	25.2	19.8	16.72	8.18	74.37	3.89	50	50	51
2:1*	2.74	24.0	3.118	12.0	29.0	15.3	35.2	18.9	15.60	5.05	80.35	5.55	33	33	33
3:1*	2.73	24.0	3.996	12.0	35.3	15.7	42.8	18.6	15.09	3.65	85.62	7.08	25	26	25

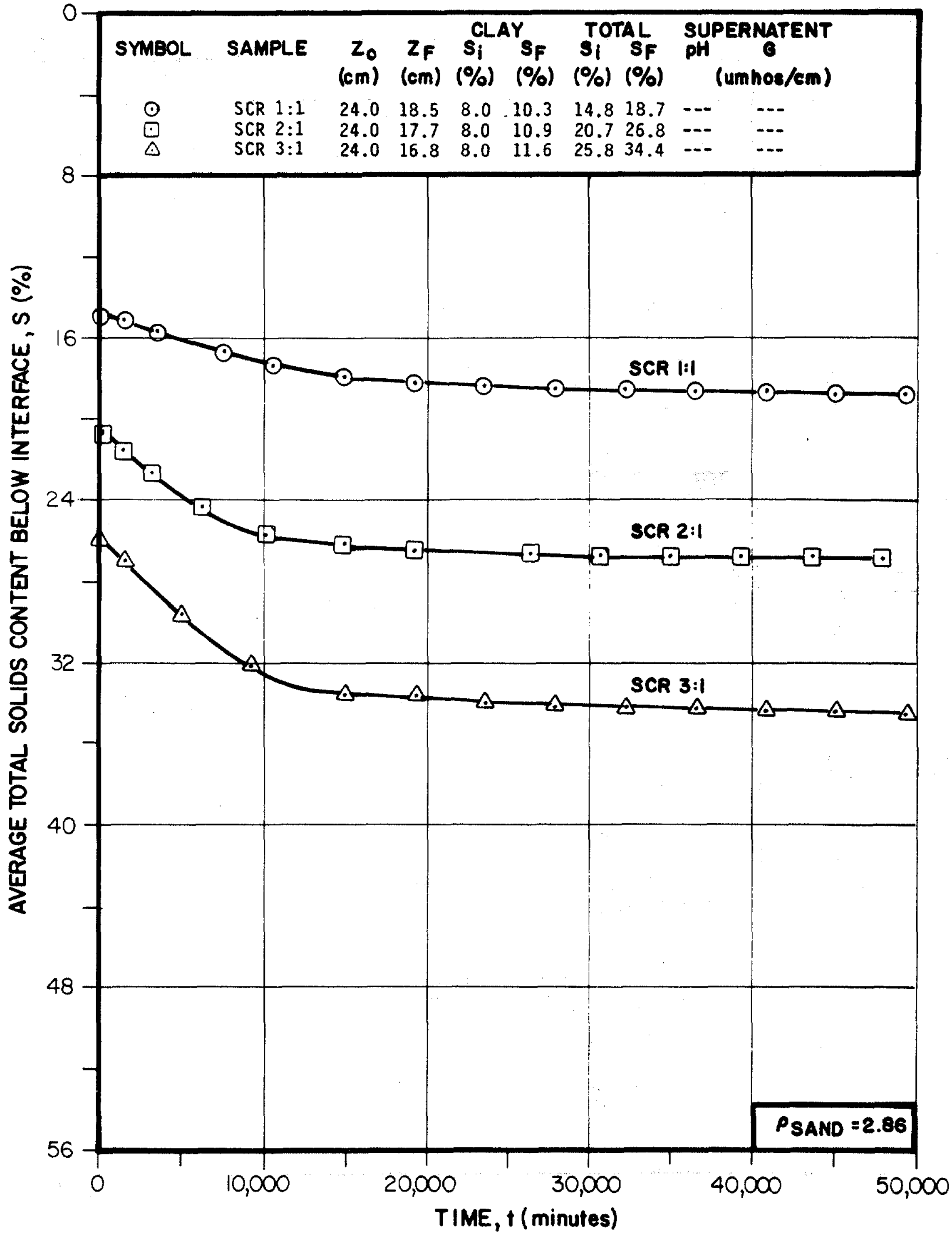
Where: SCR = Sand-clay ratio by dry weight; ρ = Effective specific gravity of solids; Z_o = Initial height; Z_s = Height of solids; S_{ic} = Initial solids content of clay; S_{it} = Initial total solids content; S_{Fc} = Final clay solids content; S_{Ft} = Final total solids content; Z_F = Final height; e_{fc} = Final void ratio of clay; e_{ft} = Final total void ratio; γ_t = Total unit weight; $\bar{\sigma}_{vc}$ = Effective stress at mid-layer.

Equations: $S_{it} = (1 + SCR)/((1/S_{ic}) + SCR)$

$$e_{fc} = e_{ft}\left(1 + (\rho_c SCR/\rho_s)\right)$$

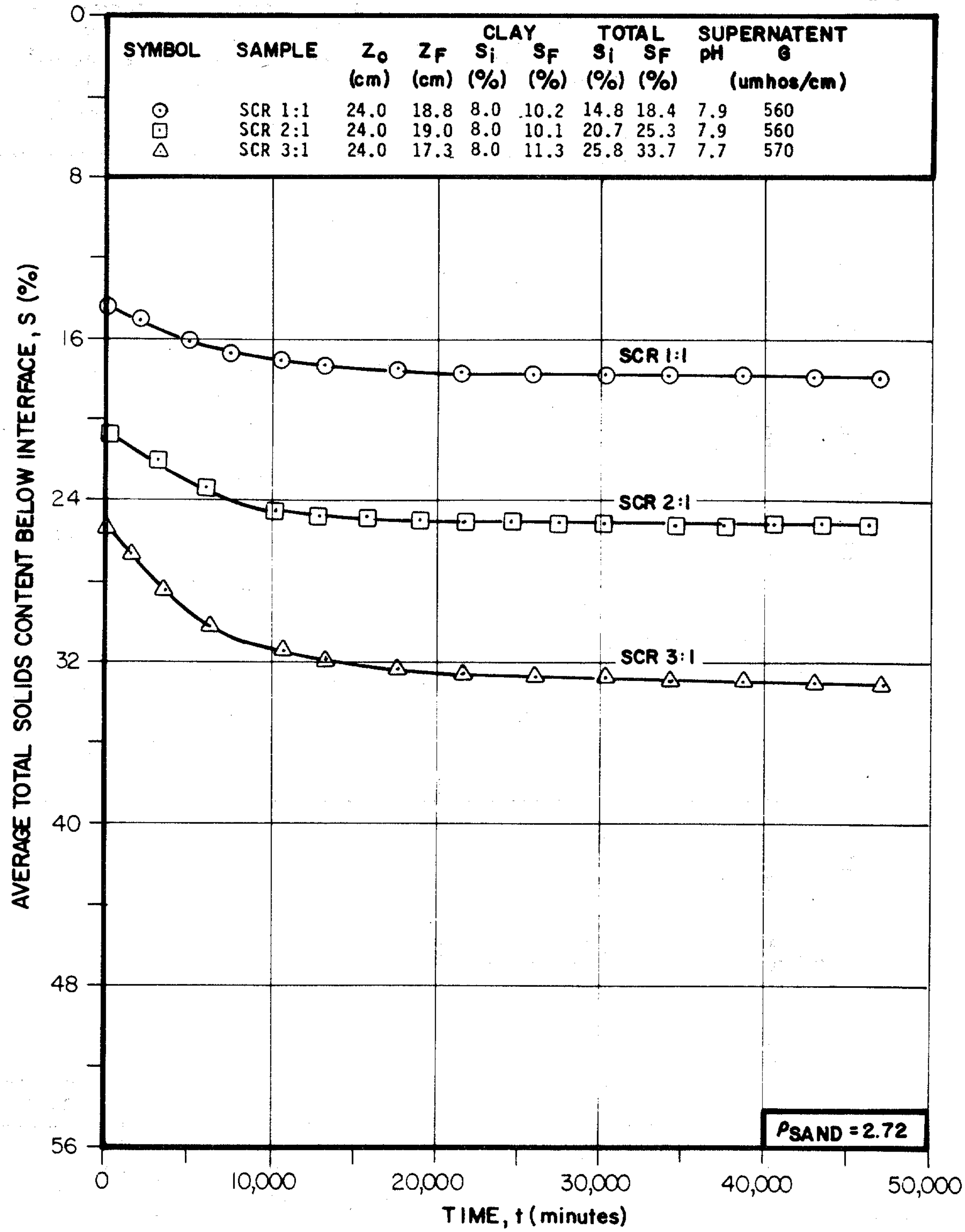
$$S_{Fc} = 1/\left(((1 + SCR)/S_{Ft}) - SCR\right)$$

*USSAC clay mixed with USSAC sand tailings with $\rho_s = 2.71$.



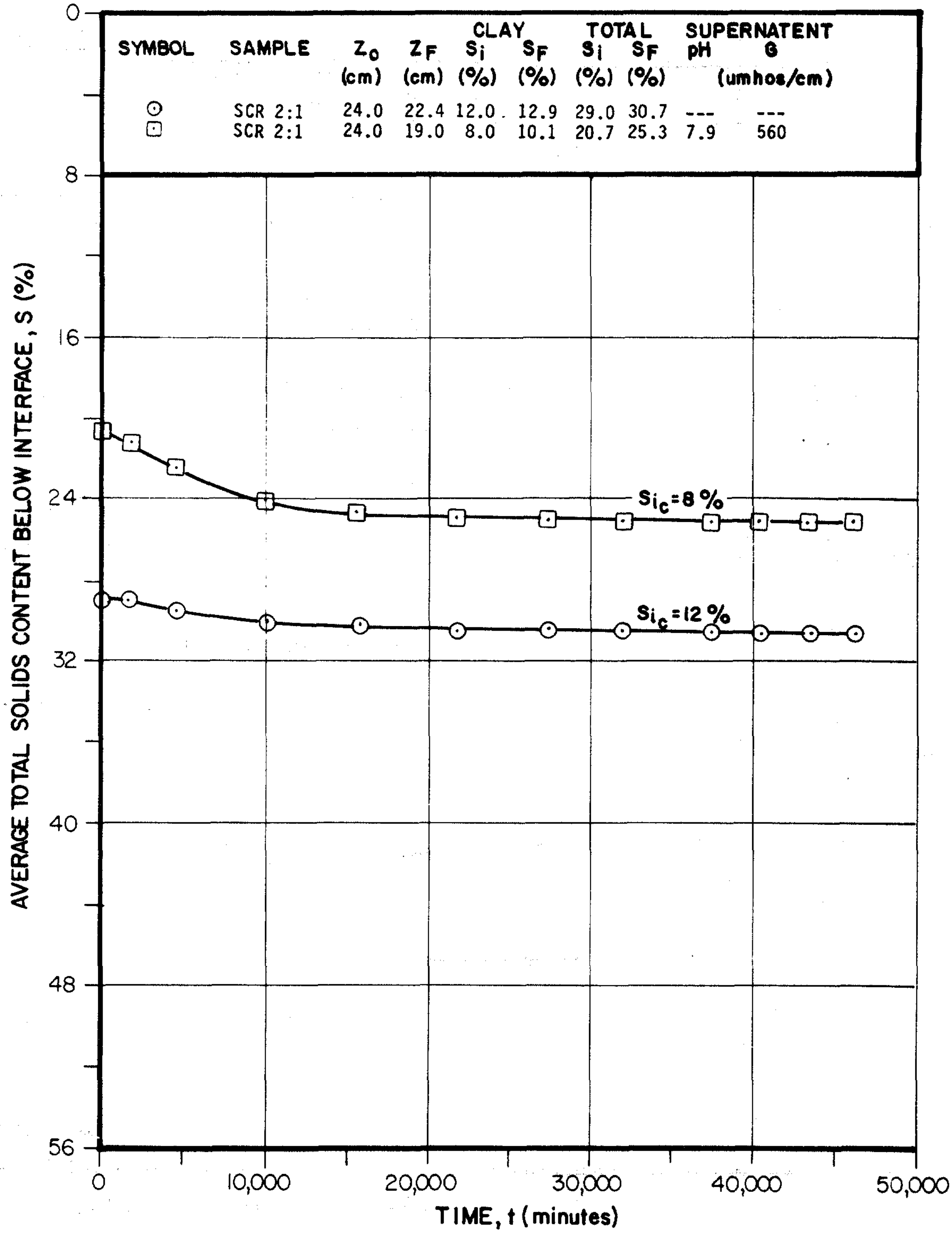
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

FIGURE G-1



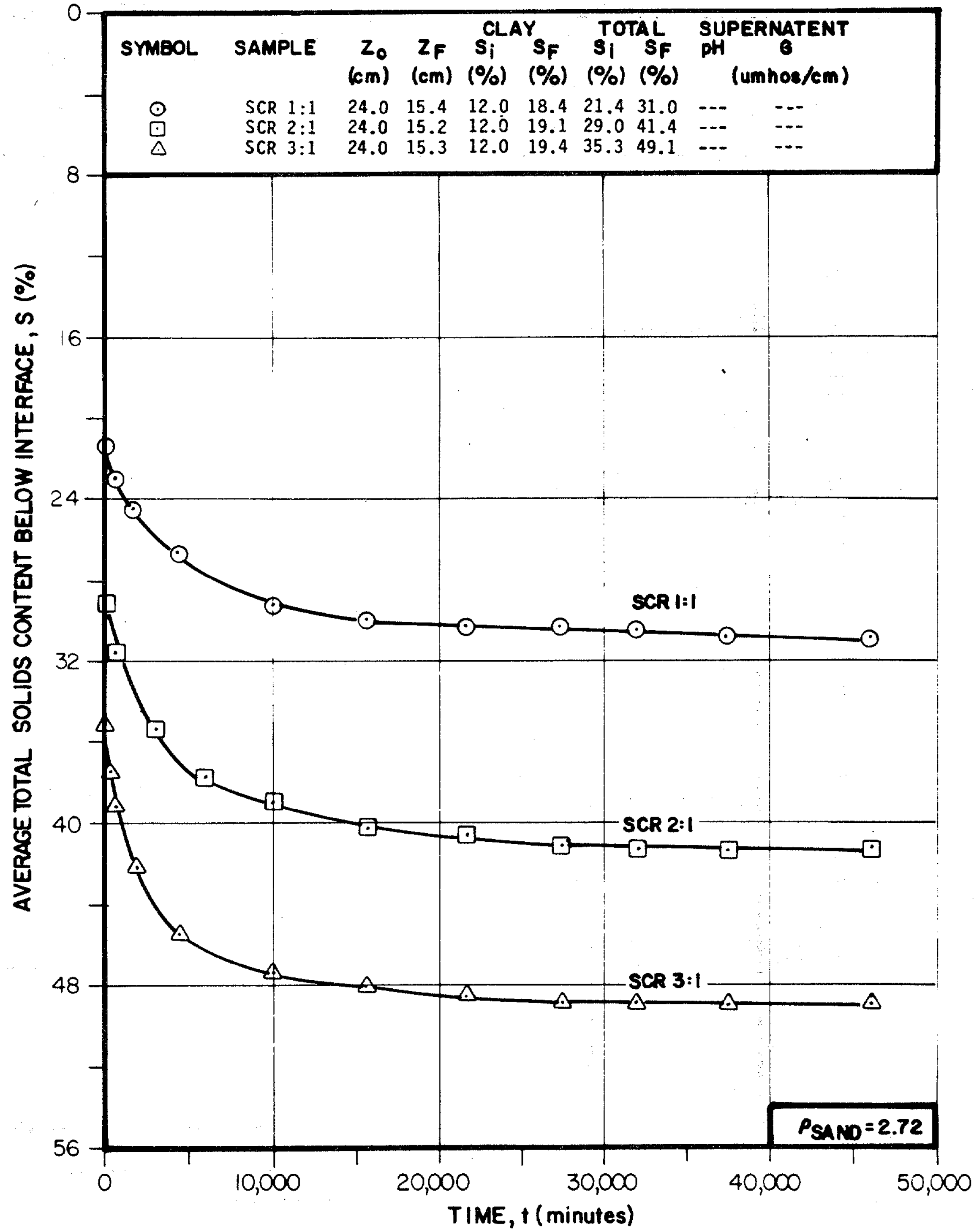
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

FIGURE G-2



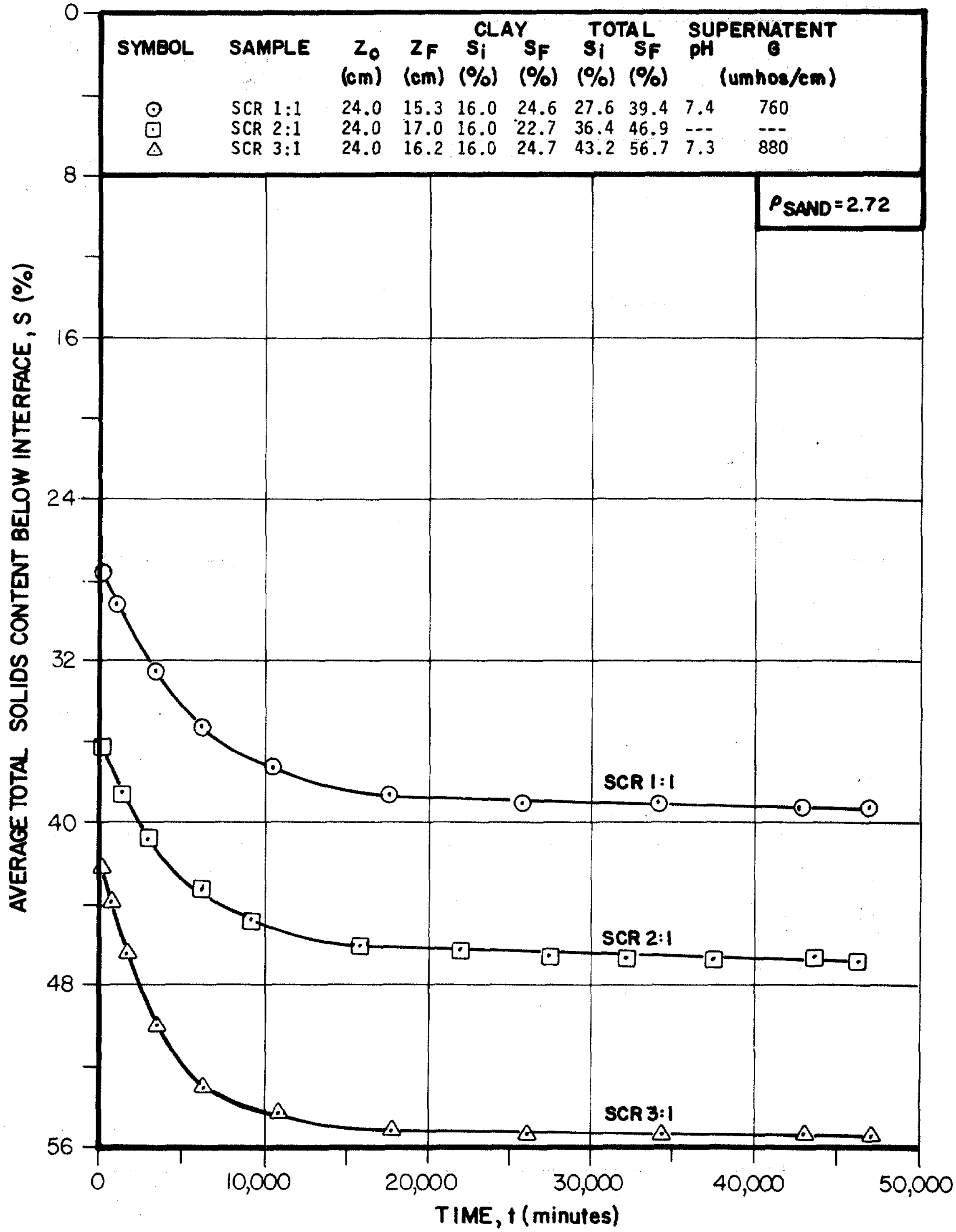
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH SCR OF 2:1

FIGURE G-3



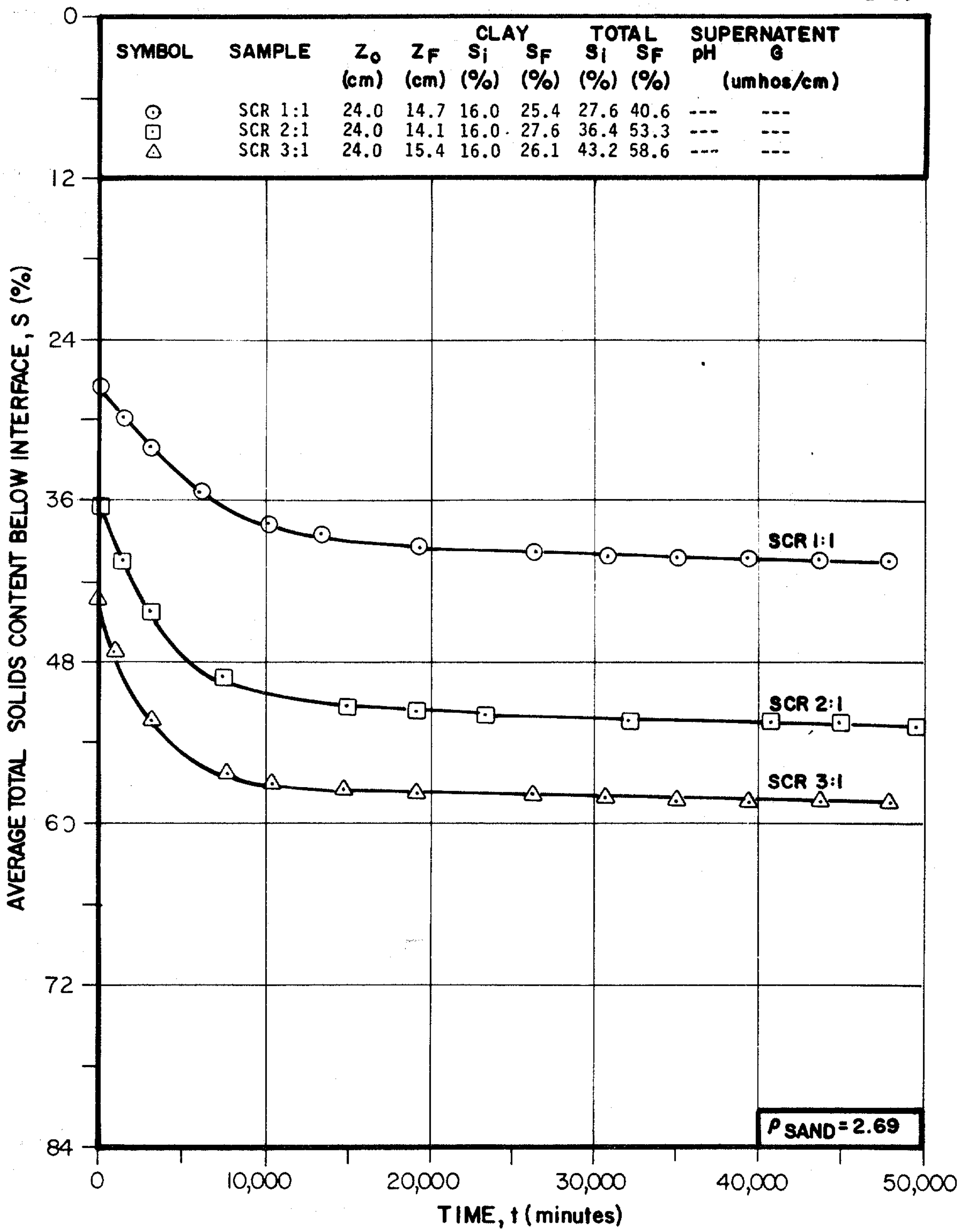
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 12%

FIGURE G-4



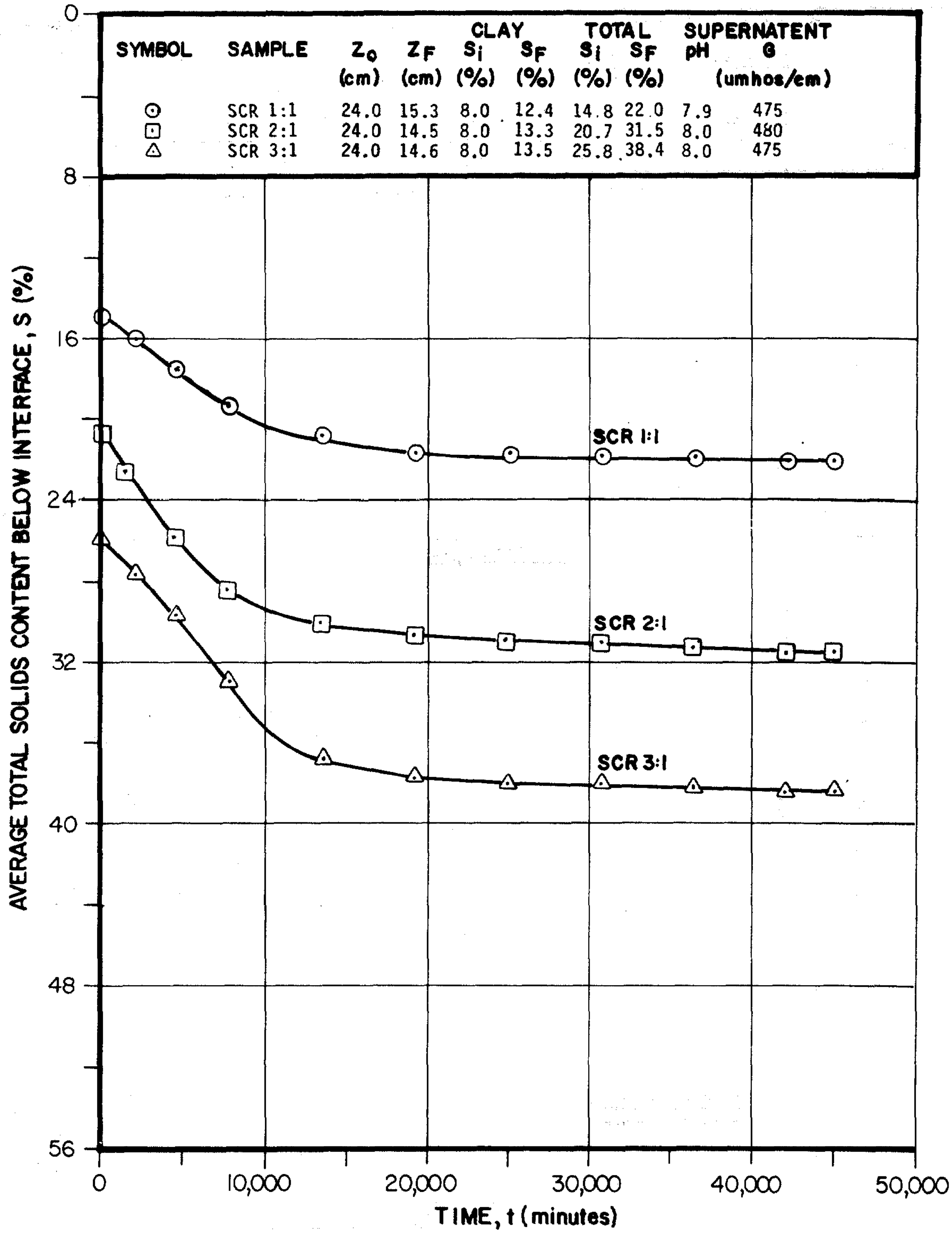
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 16%

FIGURE G-5



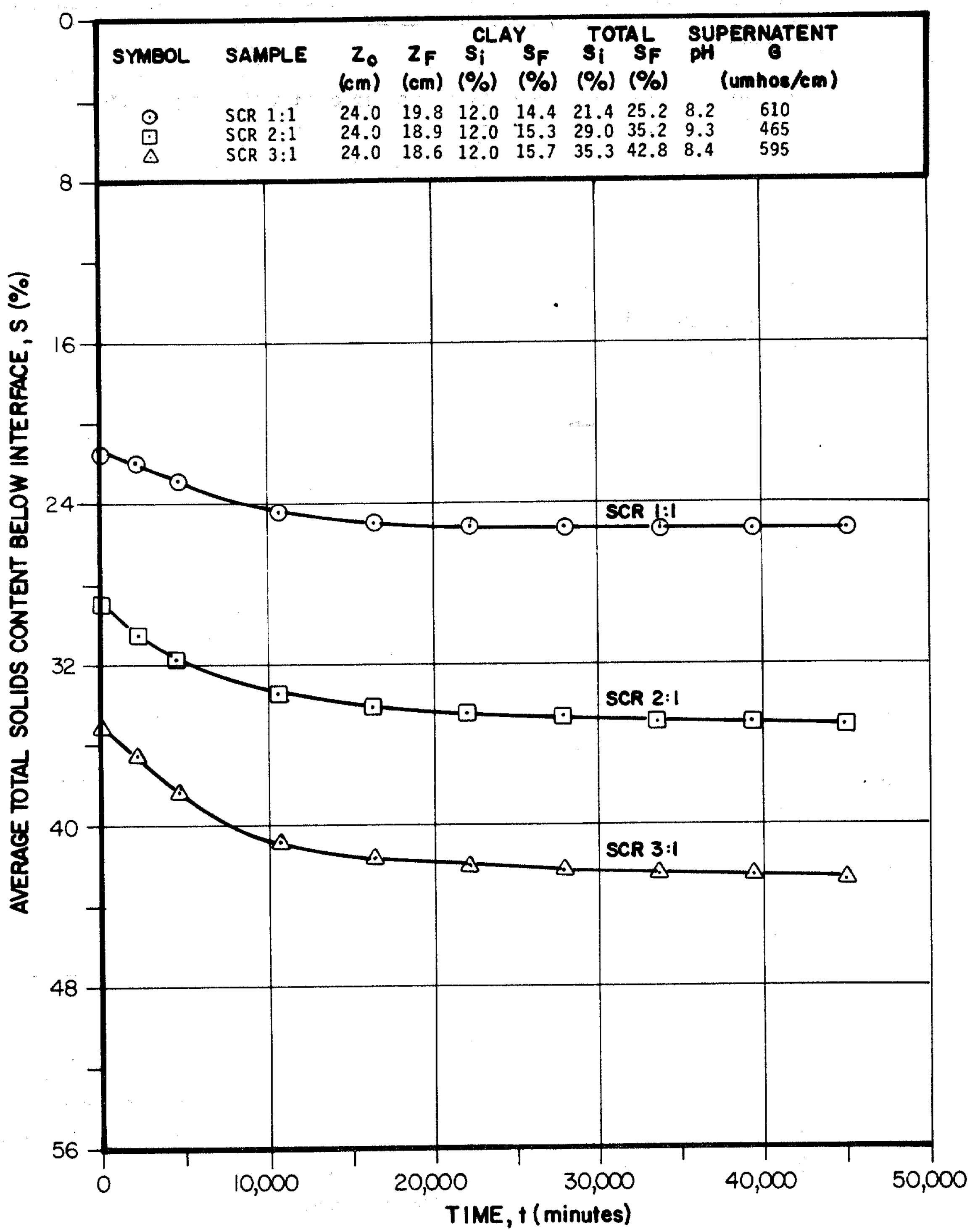
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 16%

FIGURE G-6



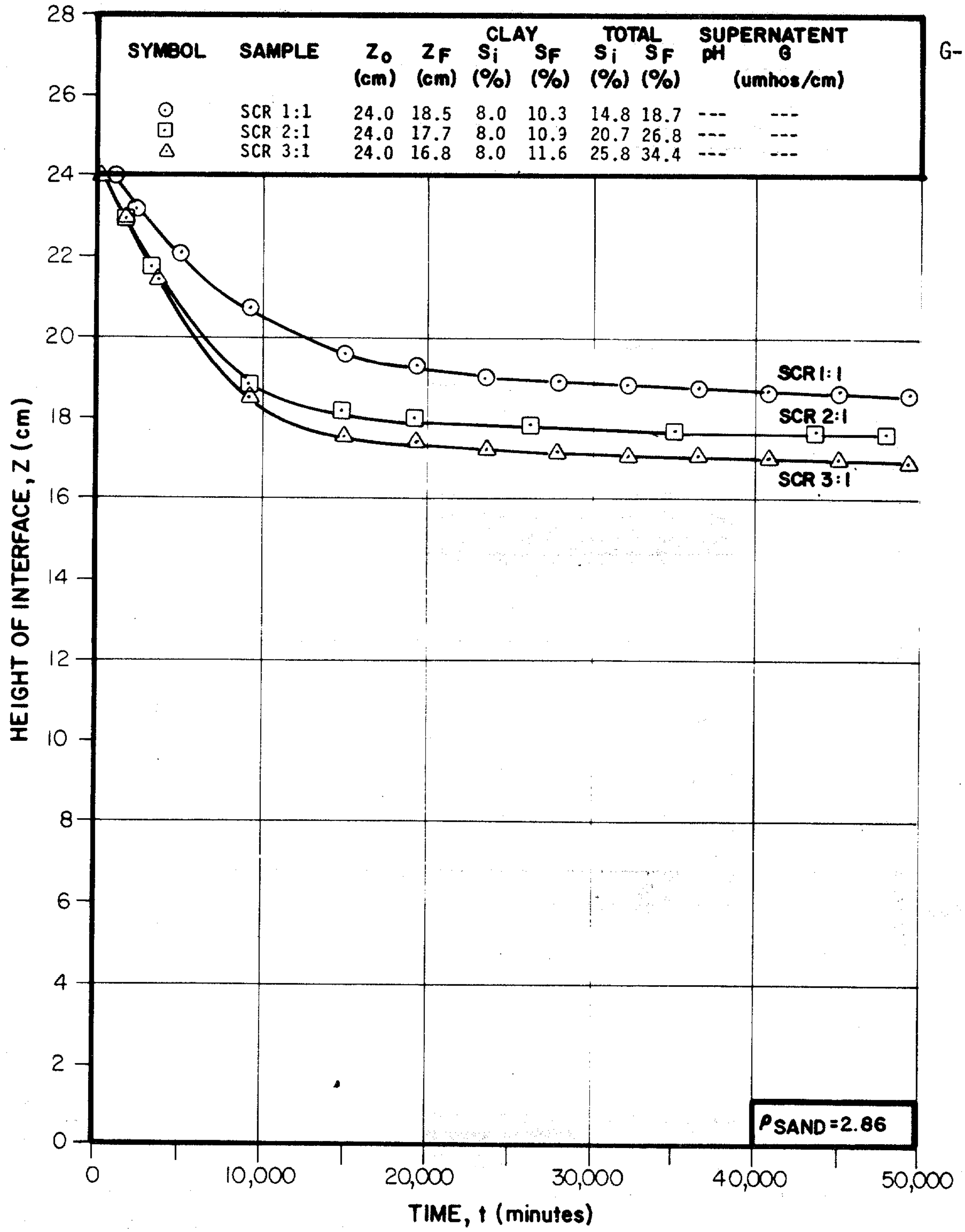
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

FIGURE G-7



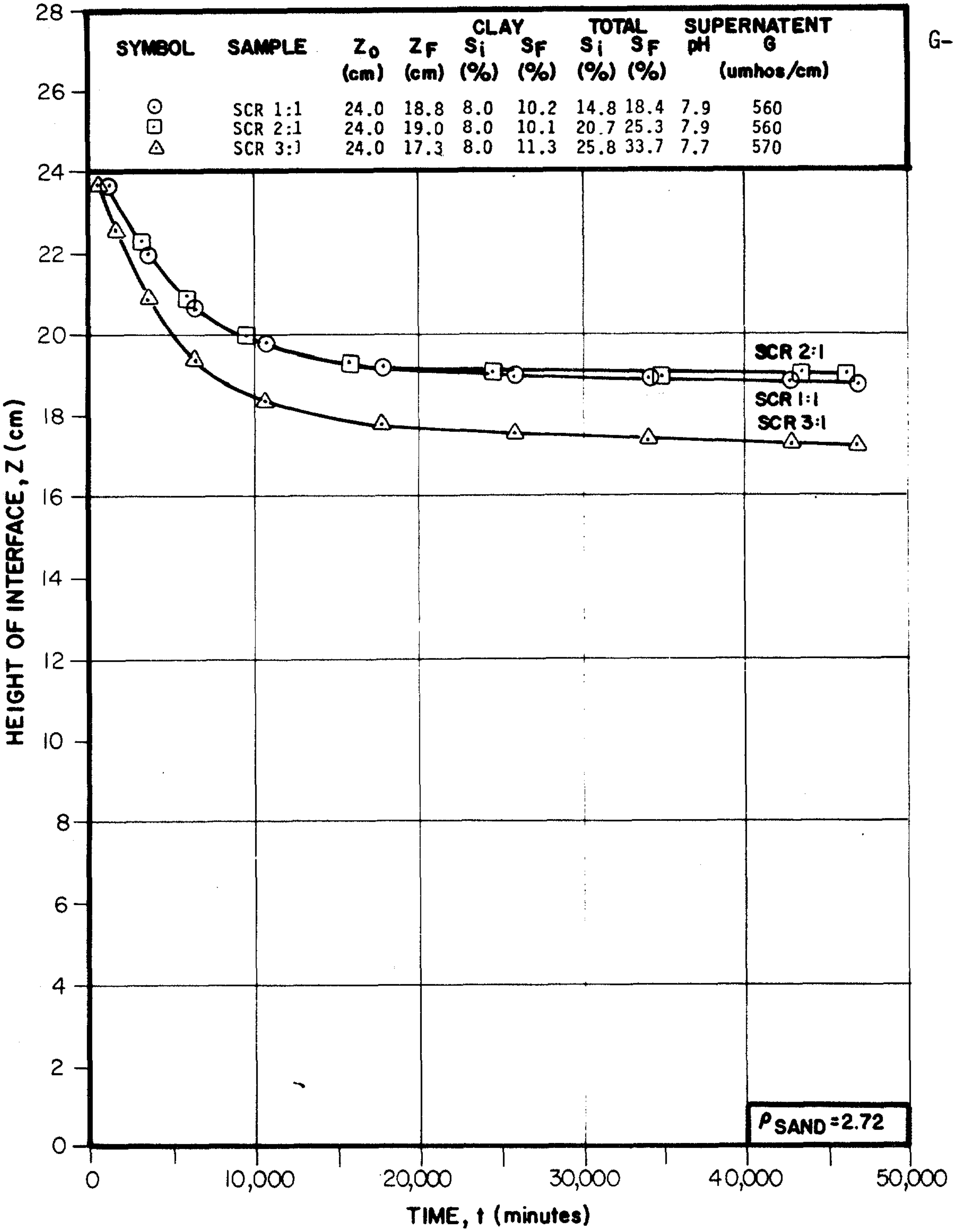
SETTLING TEST-SOLIDS CONTENT VS. TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 12%

FIGURE G-8



SETTLING TEST-HEIGHT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

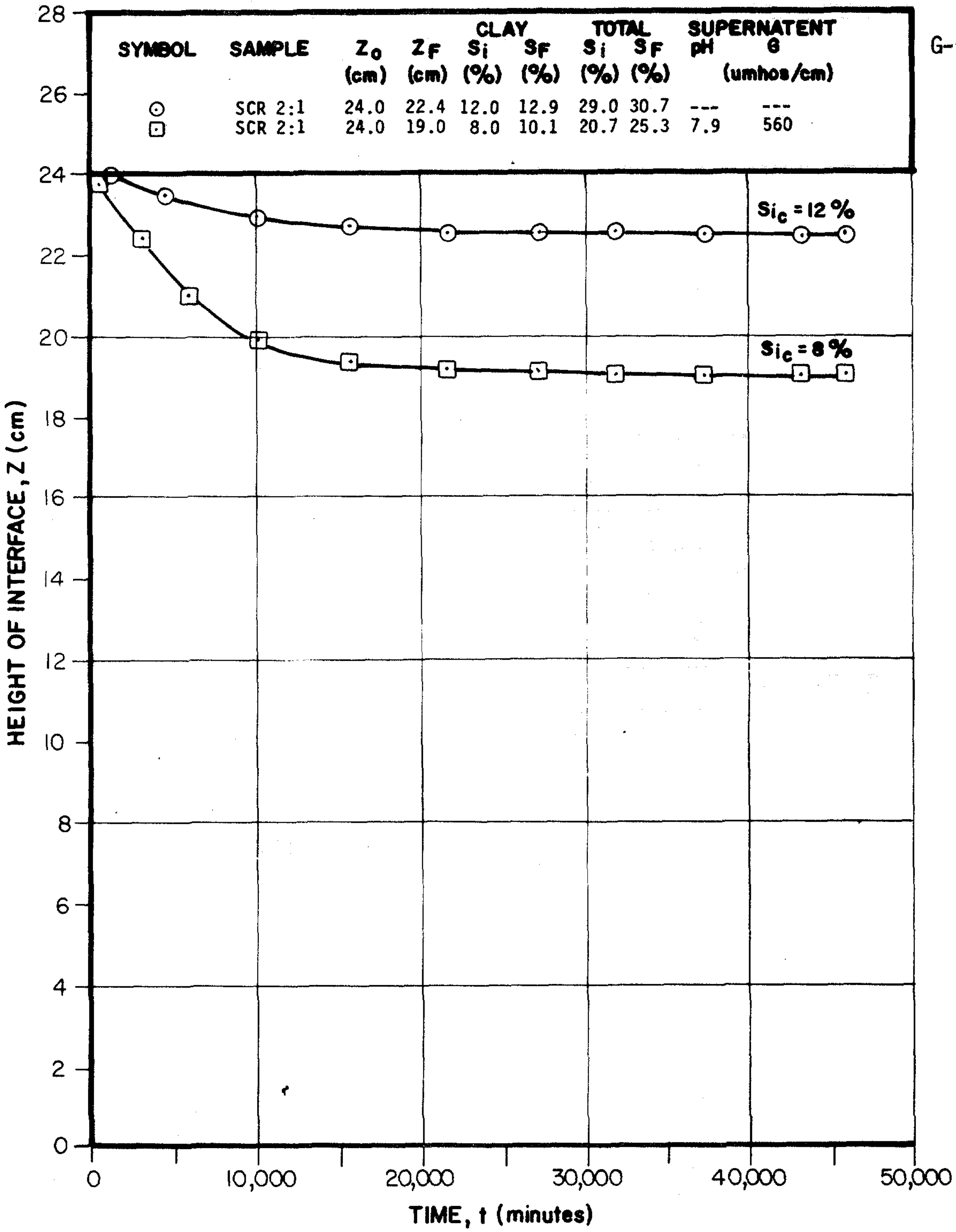
FIGURE G-9



SYMBOL	SAMPLE	Z_o (cm)	Z_F (cm)	CLAY S_i (%)	CLAY S_F (%)	TOTAL S_i (%)	TOTAL S_F (%)	SUPERNATENT pH	SUPERNATENT G (umhos/cm)
⊙	SCR 1:1	24.0	18.8	8.0	10.2	14.8	18.4	7.9	560
⊡	SCR 2:1	24.0	19.0	8.0	10.1	20.7	25.3	7.9	560
△	SCR 3:1	24.0	17.3	8.0	11.3	25.8	33.7	7.7	570

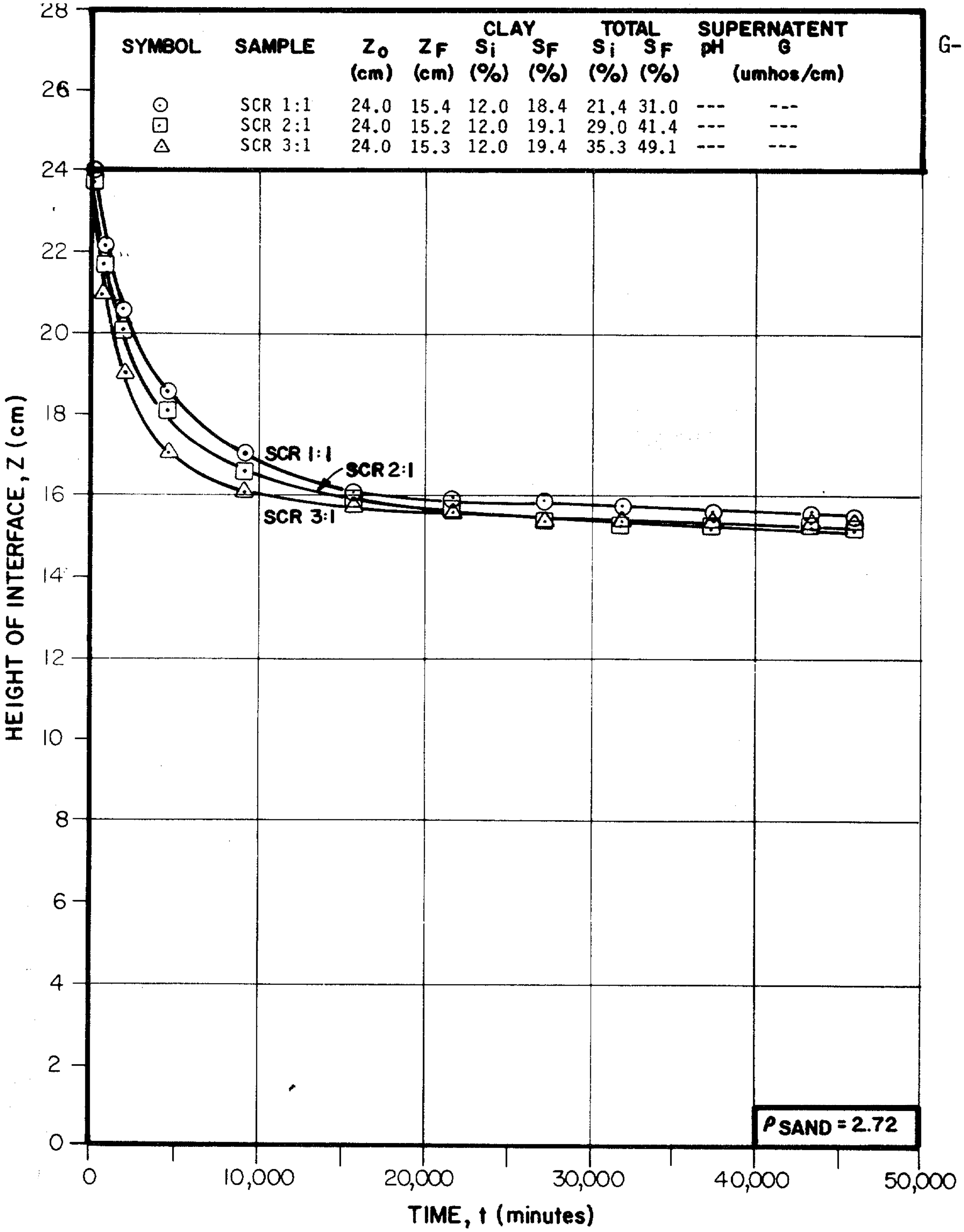
SETTLING TEST-HEIGHT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

FIGURE G-10



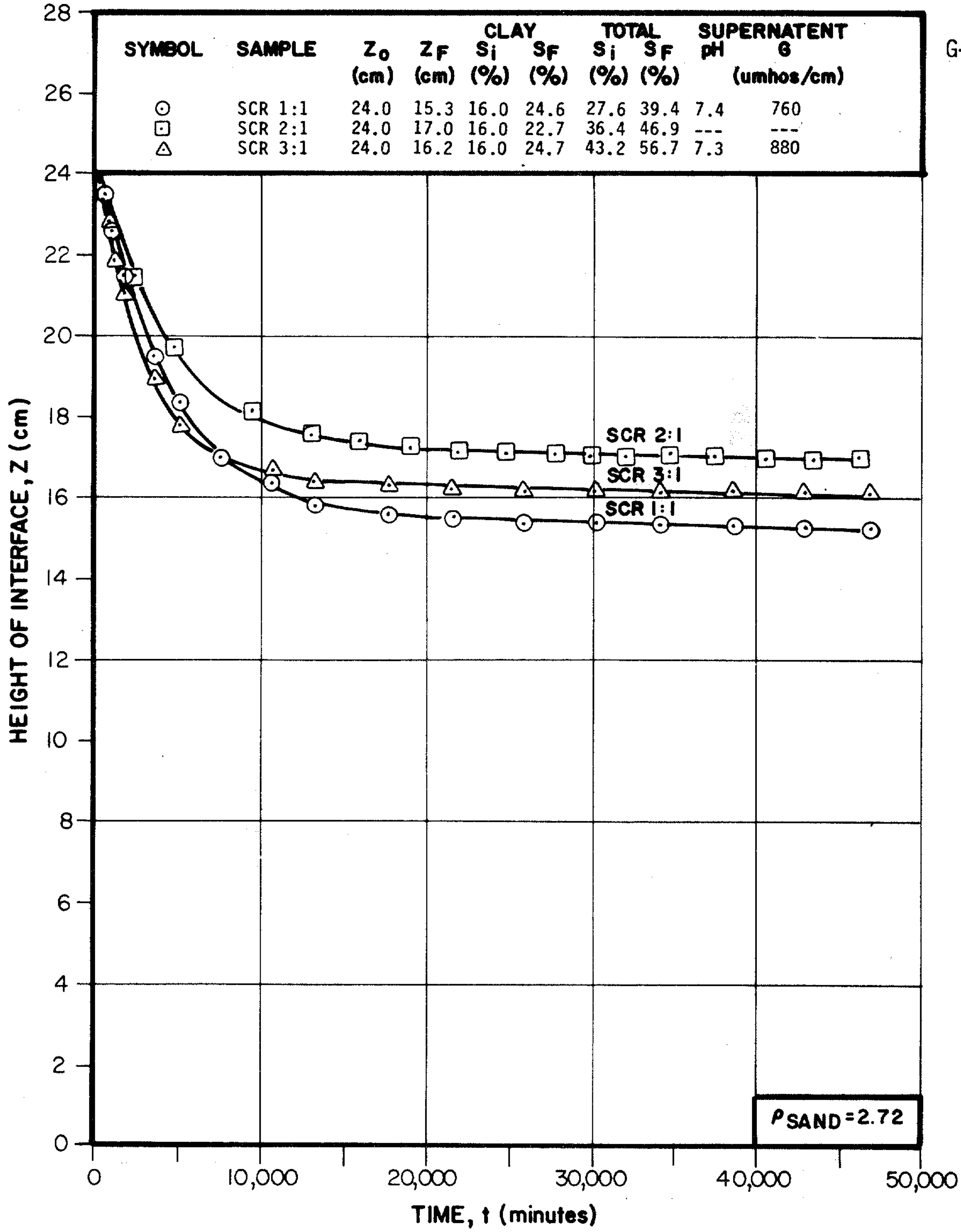
SETTLING TEST-HEIGHT VS. TIME FOR AGRICO-SADDLE CREEK SAND-CLAY MIXES WITH SCR OF 2:1

FIGURE G-11



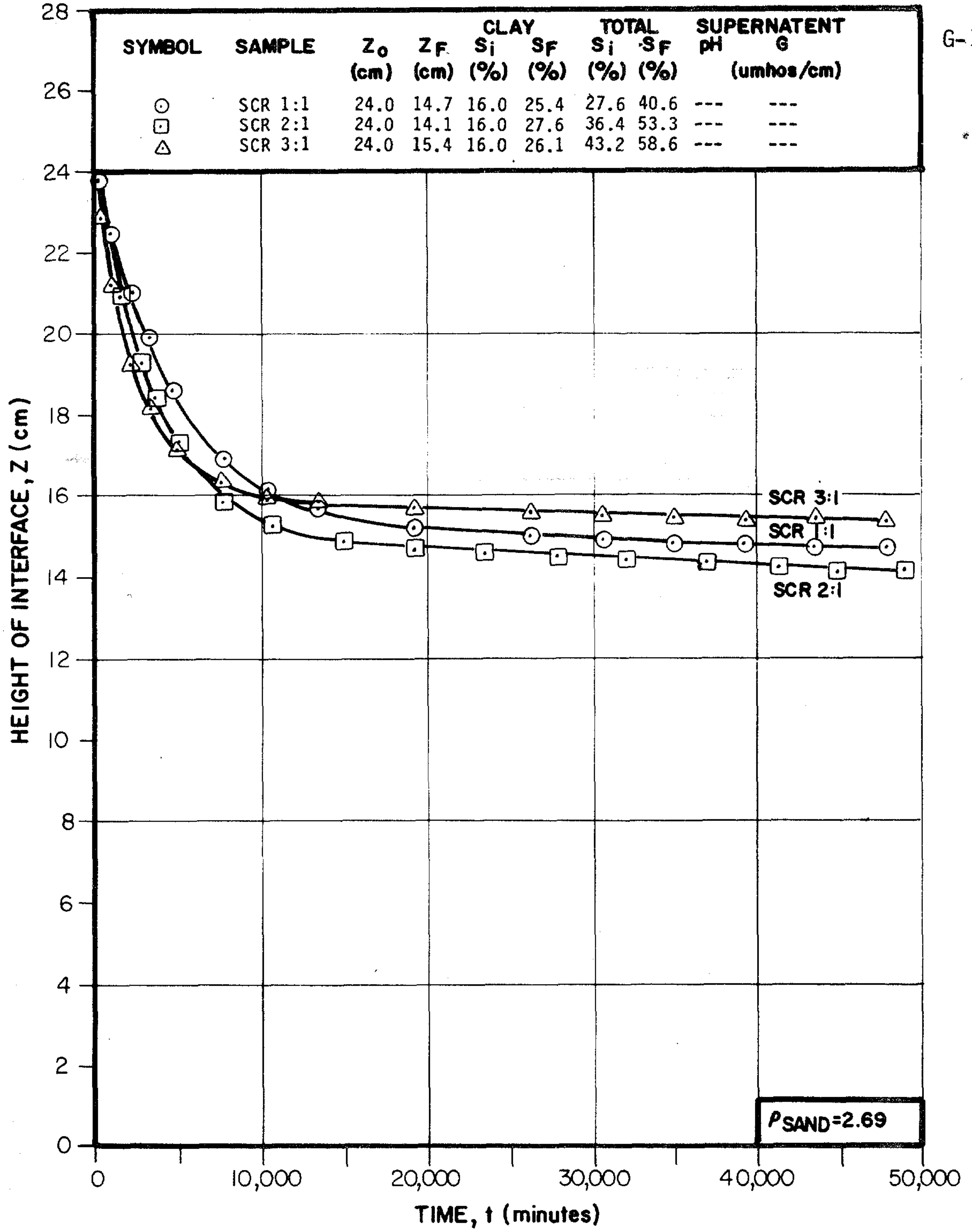
SETTLING TEST-HEIGHT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 12%

FIGURE G-12



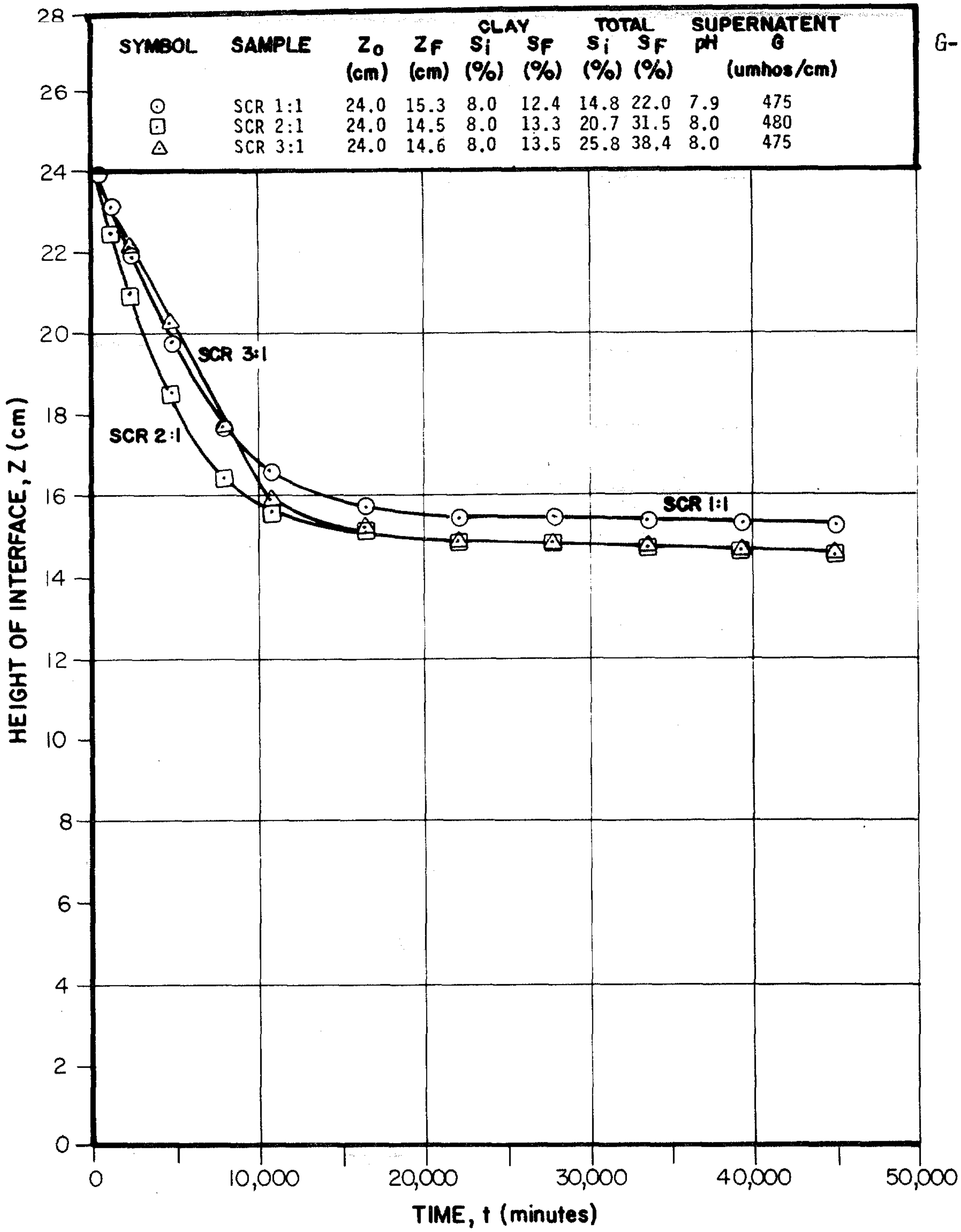
SETTLING TEST-HEIGHT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 16%

FIGURE G-13



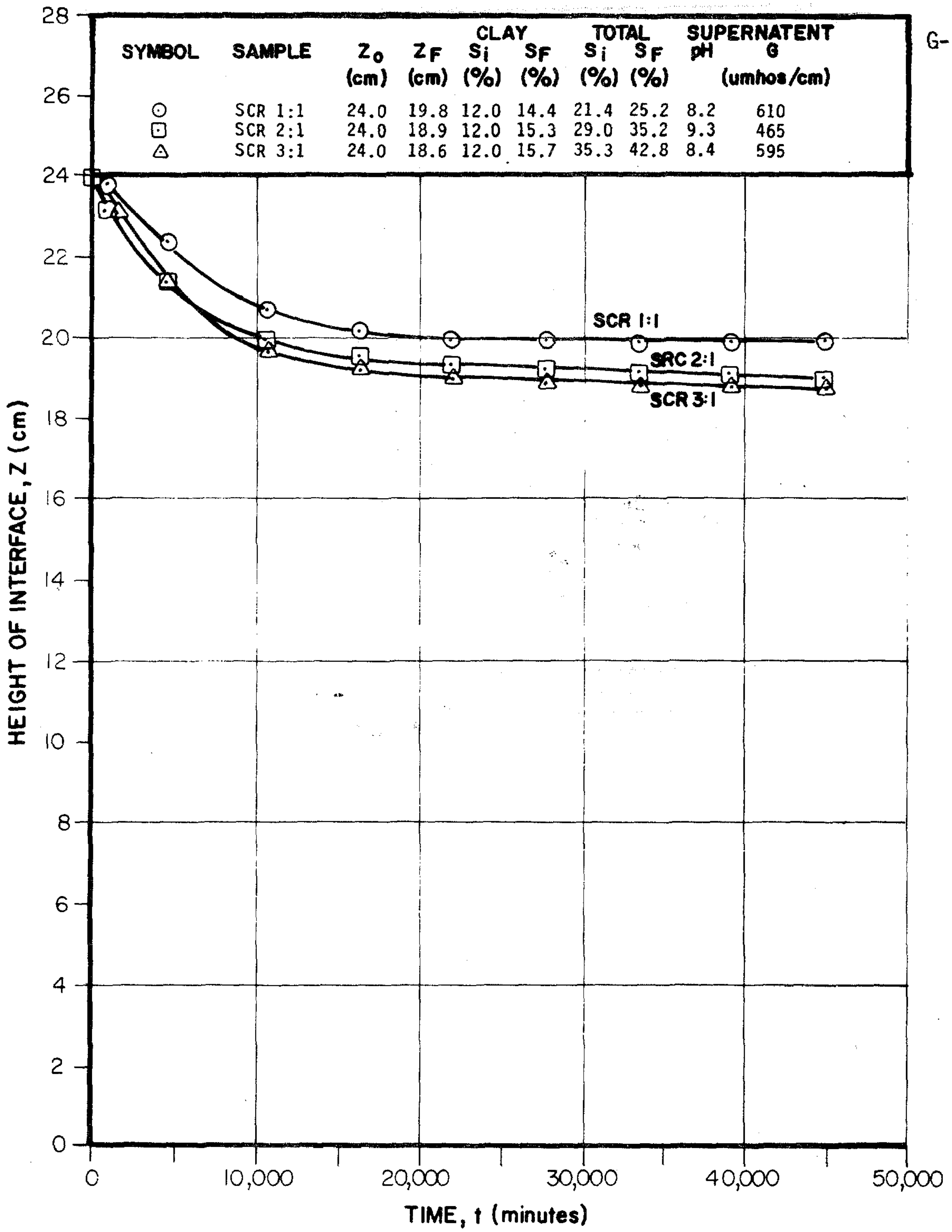
SETTLING TEST-HEIGHT VS. TIME FOR CF MINING-HARDEE SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 16%

FIGURE G-14



SETTLING TEST-HEIGHT VS. TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 8%

FIGURE G-15



SETTLING TEST-HEIGHT VS. TIME FOR USSAC-ROCKLAND SAND-CLAY MIXES WITH INITIAL CLAY SOLIDS CONTENT OF 12%

FIGURE G-16