

PERMEABILITY AND SHEAR STRENGTH
OF
DEWATERED HIGH ASH CONTENT
PULP AND PAPERMILL SLUDGES

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
ROBERT WILLIAM LAZA

1971



This is to certify that the

thesis entitled

PERMEABILITY AND SHEAR STRENGTH OF
DEWATERED HIGH ASH CONTENT PULP
AND PAPERMILL SLUDGES

presented by

Robert William Laza

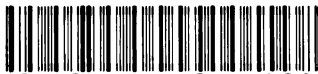
has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Civil Engineering

A handwritten signature in cursive script, reading "M. B. Anderson", written over a horizontal line.

Major professor

Date Feb 25, 1972



3 1293 10021 1089

~~B-279-3~~ 022

~~0220001~~

~~0220001~~ 067

ABSTRACT

PERMEABILITY AND SHEAR STRENGTH OF DEWATERED HIGH ASH CONTENT PULP AND PAPERMILL SLUDGES

By

Robert W. Laza

The improved treatment of pulp and papermill waste water for pollution control has resulted in large quantities of settleable solids to be disposed of. These solids are composed primarily of clay and cellulose fiber. This study is the third stage of a program sponsored by the National Council of the Paper Industry for Air and Stream Improvement for the evaluation of these waste sludges in organized landfill operations. This phase of the program consisted of the experimental evaluation of the shear strength parameters, the permeability characteristics, and the resulting effects of these properties due to a change in sludge composition. Two different types of sludge were evaluated for comparative purposes.

The shear strength study consisted of evaluation of the two sludges in the state as received from the source mill and with ten percent lime or flyash added. In addition, for

the sludge most representative of the high ash variety, sludge H-2, the organic content was altered to simulate decomposition and the strength characteristics were re-evaluated. Consolidated-undrained triaxial tests with pore pressure measurements were used for these determinations. The results of these tests indicated that the sludge would develop adequate shear strength, that this development would be primarily frictional in character, and that the addition of lime or flyash would contribute to the shear strength. With a reduction in organic content, a decrease in the angle of internal friction was noted which may correlate to a decrease in strength with natural decomposition.

The permeability study also considered both sludges in the state as received from the source mill, with different solids contents, and with the addition of ten percent lime or flyash. The different organic content samples of the triaxial portion of the study were also evaluated. This evaluation was by means of a falling head permeameter modified to permit the application of a backpressure. Both sludges had relatively low permeabilities, approaching that of a pure clay when the solids content was approximately 60 percent. It was found that entrapped air bubbles within the sludge significantly affected the permeability up to heads of 60 to 120 feet of water. By pretreating the sludge with a vacuum and/or sterilant, the effects of these air bubbles could be essentially eliminated. Lime or flyash were found to increase the permeability slightly with the

lime addition being more effective than the flyash. A decrease in organic content resulted in a decrease in permeability and a reduction in the ability of the material to retain water. These tests indicated that the drainage of such sludge deposits would be slow, that the entrapment of minute air bubbles would affect the flow rate, and that the material would retain large quantities of water.

PERMEABILITY AND SHEAR STRENGTH
OF
DEWATERED HIGH ASH CONTENT
PULP AND PAPERMILL SLUDGES

By

Robert William Laza

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Civil Engineering

1971

67-1620

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Dr. O. B. Andersland, Professor of Civil Engineering, under whose direction this research was performed, for his guidance, patience, and encouragement. Thanks are also due the other members of the writer's guidance committee: Dr. R. K. Wen, Chairman and Professor of Civil Engineering, Dr. W. A. Bradley, Professor of Applied Mechanics, and Dr. M. M. Mortland, Professor of Soil Science. In addition, the writer owes a debt of gratitude to Mr. W. J. Gillespie and Mr. C. A. Mazzola of the National Council of the Paper Industry for Air and Stream Improvement, Kalamazoo office, for their efforts in supplying the sludges, background, and other assistance.

Sincere appreciation is also extended to the National Council of the Paper Industry for Air and Stream Improvement and the Division of Engineering Research at Michigan State University for the financial assistance which made this research possible.

TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF APPENDICES	xi
NOTATIONS	xii
CHAPTER	
I. INTRODUCTION	1
II. LITERATURE REVIEW	6
2.1 High Ash Primary Clarifier Sludges . .	6
2.1.1 Composition	6
2.1.2 Water Content	8
2.1.3 Consistency Limits	11
2.1.4 Fiber Content	16
2.1.5 Admixtures	20
2.2 Conditions of Failure for Sludges . .	21
2.2.1 Shear Strength Theory	22
2.2.2 Similarity to Organic Soils . .	25
2.2.3 Vane Shear Strength	30
2.3 Water Flow in Sludge	31
2.3.1 Permeability Theory	32
2.3.2 Factors Which Alter Flow Rate .	33
III. SLUDGES STUDIED AND SAMPLE PREPARATION . . .	37
3.1 Secondary Fiber Mill Sludge	37
3.2 Integrated Pulp and Papermill Sludge .	43
3.3 Triaxial Specimen Preparation	43
3.4 Permeability Sample Preparation	45
IV. LABORATORY EQUIPMENT AND TEST PROCEDURES . .	47
4.1 Triaxial Equipment	47
4.2 Triaxial Test Procedures	48
4.3 Permeability Equipment	53
4.4 Permeability Test Procedures	58
4.5 Water Retention Procedures	59

V.	EXPERIMENTAL RESULTS	61
5.1	Triaxial Tests	61
5.1.1	Shear Strength for Natural Sludges	62
5.1.2	Shear Strength for Different Organic Contents	68
5.1.3	Shear Strength with Additions of Lime or Flyash	76
5.2	Permeability Tests	76
5.2.1	Flow Through Natural Sludges .	85
5.2.2	Influence of Organic Content on Flow	86
5.2.3	Influence of Lime or Flyash on Flow	87
5.2.4	Water Retention of Sludge . . .	88
VI.	DISCUSSION AND INTERPRETATION OF RESULTS . .	103
6.1	Shear Strength	103
6.1.1	Natural Sludges	103
6.1.2	Organic Content	106
6.1.3	Lime and Flyash Admixtures . .	111
6.2	Permeability	116
6.2.1	Natural Sludges	116
6.2.2	Organic Content	119
6.2.3	Lime and Flyash Admixtures . .	122
VII.	SUMMARY AND CONCLUSIONS	125
7.1	Shear Strength Parameters	125
7.2	Permeability of Pulp and Papermill Sludges	127
	BIBLIOGRAPHY	130
	APPENDICES	134

LIST OF TABLES

Table		Page
2.1	Sludge Properties of Fiber Content Studies (after NCASI Tech. Bull. No. 174)	19
3.1	Physical Property and Test Method	38
3.2	Physical Properties of the Sludge Materials	40
3.3	Properties of Lime and Flyash	41
5.1	Summary of Triaxial Test Results on the Natural Sludges	64
5.2	Summary of Triaxial Test Results on Sludge H-2 with Different Organic Contents	71
5.3	Summary of Triaxial Test Results on Sludges with Lime Added	77
5.4	Summary of Triaxial Test Results on Sludges with Flyash Added	78
5.5	Summary of $\bar{\phi}$ and $\bar{c}$ Values for the Triaxial Tests	84
5.6	Hydraulic Gradient Required to Initiate Flow	86
A-1 thru A-58	Triaxial Test Data	133 - 190
B-1 thru B-62	Permeability Test Data	191 - 221
C	Water Retention Data, Sludge H-2	222

LIST OF FIGURES

Figure		Page
2.1	Water Content vs Ash Content (after Mazzola, 1969)	12
2.2	Liquid Limit vs Ash Content (after Mazzola, 1969)	14
2.3	Plastic Limit vs Ash Content (after Mazzola, 1969)	14
2.4	Plastic Limit vs Liquid Limit (after Mazzola, 1969)	15
2.5	Percent Solids vs Applied Pressure (after NCASI Tech. Bull. No. 174)	18
2.6	Dry Solids vs Fiber Content of Sludge Sample (after NCASI Tech. Bull. No. 174)	18
2.7	Effect of Fiber Length Present on Drainage Rate (after NCASI Tech. Bull. No. 136)	20
2.8	Stress Circle and Failure Envelope	25
2.9	Straight Line Representation of Mohr Envelope	25
2.10	Equations and Definitions for Shear Strength Theory, Effective Stress Basis	26
2.11	Drained Compression Tests on Peat (after Adams, 1961)	29
3.1	Grain Size Distribution Curve for Flyash Admixture	41
3.2	Triaxial Samples and Mold (left to right--consolidated, failed, and new specimen)	44
3.3	Permeability Sample and Mold	44

Figure		Page
4.1	Diagrammatic Representation of the Modified Triaxial Cell	49
4.2	Triaxial Equipment and Recorder	50
4.3	Modified Triaxial Cell with Sample	50
4.4	Triaxial Sample, Porous Stones, Loading Cap, Paper Side Drains, and Protective Membrane	52
4.5	Measured Pore Pressures at Mid-height and at Base of Sludge Sample (a) strain-rate of 0.010 in/min (b) strain-rate of 0.005 in/min (c) strain-rate of 0.001 in/min	54
4.6	Diagrammatic Representation of Permeability Equipment	56
4.7	Permeability Equipment	57
4.8	Permeameters and Pressure Cells	57
5.1	Typical Stress-strain Curves for Sludge H-2, 43 percent organic content	63
5.2	Consolidated-undrained Test Results for Sludge H-1 (a) Mohr envelope and k_f rupture line (b) Water content (c) Undrained strength	65
5.3	Consolidated-undrained Test Results for Sludge H-2, 43 percent organic matter (a) Mohr envelope and k_f rupture line (b) Water content (c) Undrained strength	66
5.4	Consolidated-undrained Test Results for Sludge C-1 (a) Mohr envelope and k_f rupture line (b) Water content (c) Undrained strength	67
5.5	Typical Stress-strain Curves for Sludge H-2 (a) 28 % organic matter (b) 35 % organic matter (c) 43 % organic matter (d) 50 % organic matter	69
5.6	Consolidated-undrained Test Results for Sludge H-2, 28 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	72

Figure		Page
5.7	Consolidated-undrained Test Results for Sludge H-2, 35 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	73
5.8	Consolidated-undrained Test Results for Sludge H-2, 43 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	74
5.9	Consolidated-undrained Test Results for Sludge H-2, 50 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	75
5.10	Consolidated-undrained Test Results for Sludge H-2 with 10 % lime added, 43 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	79
5.11	Consolidated-undrained Test Results for Sludge H-2 with 10 % lime added, 28 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	80
5.12	Consolidated-undrained Test Results for Sludge C-1 with 10 % lime added (a) k_f rupture line (b) Water content (c) Undrained strength	81
5.13	Consolidated-undrained Test Results for Sludge H-2 with 10 % flyash added, 43 % organic matter (a) k_f rupture line (b) Water content (c) Undrained strength	82
5.14	Consolidated-undrained Test Results for Sludge C-1 with 10 % flyash added (a) k_f rupture line (b) Water content (c) Undrained strength	83
5.15	Permeability of Sludge H-2 with Varying Average Head	89
5.16	Permeability of Sludge C-1 with Varying Average Head	89
5.17	Permeability, Solids content, and Average Head for Sludge H-2	90

Figure		Page
5.18	Permeability, Solids Content, and Average Head for Sludge C-1	91
5.19	Change in Permeability with Change in Organic Content (a) 25.7 % solids (b) 34.2 % solids (c) 40.25 % solids (d) 50.18 % solids	92
5.20	Permeability of Sludge H-2 with 10 % Lime Added	94
5.21	Permeability of Sludge C-1 with 10 % Lime Added	94
5.22	Permeability of Sludge H-2 with 10 % Lime Added at Three Solids Contents	95
5.23	Permeability of Sludge C-1 with 10 % Lime Added at Three Solids Contents	95
5.24	Permeability of Sludge H-2 with 10 % Lime Added and Pretreated (a) 25.7 % solids (b) 40.25 % solids	96
5.25	Permeability of Sludge C-1 with 10 % Lime Added and Pretreated (a) 30.7 % solids (b) 46.7 % solids	97
5.26	Permeability of Sludge H-2 with 10 % Flyash Added	98
5.27	Permeability of Sludge C-1 with 10 % Flyash Added	98
5.28	Permeability of Sludge H-2 with 10 % Flyash Added at Three Solids Contents	99
5.29	Permeability of Sludge C-1 with 10 % Flyash Added at Three Solids Contents	99
5.30	Permeability of Sludge H-2 with 10 % Flyash Added and Pretreated (a) 25.7 % solids (b) 40.25 % solids	100
5.31	Permeability of Sludge C-1 with 10 % Flyash Added and Pretreated (a) 30.7 % solids (b) 46.7 % solids	101
5.32	Water Retention Characteristics for Sludge H-2	102

Figure		Page
6.1	Organic Content and Stress-strain Behavior, Sludge H-2	108
6.2	Organic Content and Angle of Internal Friction ϕ , Sludge H-2	109
6.3	Water Contents after Consolidation in the Triaxial Cell, Sludge H-2 at Different Organic Contents	112
6.4	Undrained Strengths after Consolidation in the Triaxial Cell, Sludge H-2 at Different Organic Contents	113
6.5	K_f -Line for Natural Sludge H-2 Compared to k_f -Line for Sludge H-2 with 10 % Lime or Flyash Admixture	115
6.6	Permeability, Organic Content, and Solids Content Relationships for Sludge H-2	120
6.7	Permeability, Solids Content, and Lime or Flyash Relationships for Sludge H-2	124
D-1	Calibration Curve for Permeameter Standpipe	223

LIST OF APPENDICES

Appendix		Page
A	Triaxial Test Data	133
B	Permeability Test Data	191
C	Water Retention Data	222
D	Calibration of Permeameter Standpipe	223

NOTATIONS

- A = Area
- B, A_f = Pore pressure coefficients
- C = Shape factor
- D_s = Average grain size
- H = Henry's coefficient of solubility
- L = Length
- Q = Rate of flow
- S_o = Initial saturation
- $\bar{a}$ = y intercept, k_f failure line
- c = Cohesion
- $\bar{c}$ = Cohesion, effective stress basis
- c_u = Undrained strength
- c_v = Coefficient of consolidation
- e = Void ratio
- h = Head of water
- i = Hydraulic gradient
- k = Permeability
- $k(\theta)$ = Permeability as a function of the volumetric water content, θ
- l_o = Initial length
- p = Consolidation pressure
- $\bar{p} = \frac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3)$

- $q = \frac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)$
 u = Pore pressure
 u_{a_0} = Initial pressure of air in voids
 Δu_{a_s} = Pressure increase needed to obtain full saturation
 v = Velocity
 w = Water content
 z = Elevation head
 $\bar{\alpha}$ = Angle of k_f failure line
 γ_w = Unit weight of water
 ϵ = Strain
 μ = Viscosity
 $\bar{\sigma}_1$ = Effective principal stress
 $\bar{\sigma}_3$ = Effective minor stress
 τ = Shear stress
 ϕ = Angle of internal friction
 $\bar{\phi}$ = Angle of internal friction, effective stress basis
 γ = $z + u$

CHAPTER I

INTRODUCTION

With the advent of an active environmentally conscious community, many established industrial practices have had to be either improved, altered, or eliminated. In so trying to correct a situation in one area, it has often been the case that a new problem has been created in a different one. Such is the case within the paper industry. There has always been associated with the production of paper, certain wastes resulting from both the inherent nature of the process and inefficient operations. When the number of companies were small and the pollution problem not the extent of what it is today, it was an acceptable procedure to merely discharge these wastes into a convenient stream or river and let nature treat the effluent. As time went on and plants were expanded, it was soon recognized that if the nation's natural resources were to be maintained it would be necessary to reduce both the biochemical oxygen demand (BOD) and the settleable solids discharged. Systems of treatment similar to or identical with that of municipal sewage treatment plants have been found to do this adequately; but at the same time, the problem has evolved of how to dispose of the large quantities of removed solids, up to 300 cubic yards

per day at the larger plants.

The composition of these solids or sludge will vary according to the type of paper being produced and the process involved. They are normally grey to brown in color with composition varying only in the percentage of the different constituents; which are, clay, titanium oxide, starches, dextrans, aluminum hydrates, cellulose, and other organic and inorganic compounds. The solids content will be anywhere from 2 to 50 percent solids by weight depending upon whether any mechanical means of dewatering has been employed, what type, and the sludge itself. In kraft mills, where the product is heavy paper with a low filler content, the sludge will normally be highly organic and easily dewatered. These sludges can usually be disposed of quite readily by incineration, although for the smaller mills this may be economically unfeasible. With the secondary fiber mills and the manufacturers of fine paper, the paper is high in mineral filler and often treated, to achieve certain surface qualities, with different mineral coatings, part of which are lost in the process. Here the sludges are high in ash content, up to 70 percent, and resist dewatering due to the coating of the cellulose fibers by the mineral constituents. Incineration is not feasible due to the large quantity of noncombustible material and the large amount of heat that would be needed to be expended to bring the sludge to a burnable state. Hence, disposal to date has been accomplished by some type of land fill operation, usually lacking

rationale and being only a temporary measure. The procedure has been to purchase conveniently located waste land, such as an abandoned gravel pit, fill this area to the elevation of the surrounding area, then cover the sludge with a layer of soil and move the operation to a different area. Only in a limited number of cases has any attempt been made to place the sludge in an embankment above ground, and then, it has been mixed with sand and gravel. As the availability of such conveniently located waste lands is rapidly decreasing and the value of land is rising sharply, an efficient system of disposal is urgently needed.

The National Council of the Paper Industry for Air and Stream Improvement has launched a three-phase program to evaluate landfill disposal of the papermill waste solids. The first phase involved a questionnaire survey of current land disposal practices (Gillespie, et al., 1970). This survey showed that while many difficulties are encountered, a land disposal method is to the best advantage of the mills. The second phase involved a core sampling investigation of existing deposits to measure certain soil mechanics related properties (Mazzola, 1969). Many of these existing deposits were shown to be very unstable, of low shear strength, and in a state of high water content. The third phase, for which this study is a part, seeks to provide information relative to (1) the shear strength parameters, cohesion c and the angle of internal friction ϕ , (2) the change in these parameters with a change in organic content thereby

simulating decomposition, (3) the influence of lime and flyash additives on the strength parameters, and (4) the variance in permeability due to entrapped air, changes in void ratio, and the addition of lime or flyash.

Since the composition of these sludges is very similar to that of peat or muskeg, it was assumed that the behavior would approximate that of these high organic soils. It was necessary to recognize certain differences, the main one being that the size of the organic fiber will be much smaller than that in either peat or muskeg. It is also important to recognize that there can be a considerable difference in fiber length and diameter from one papermill to another, depending on the fiber source.

The research program formulated was based on studying two different sludges, one being a long fiber sludge from an integrated pulp and papermill, the other being a short fiber sludge from a secondary fiber mill. Since the major problems of the industry exist with sludges of the secondary fiber mill type, this was the principal sludge used. Evaluations of the other were made for comparative purposes.

The actual experimental program consisted of two different phases. Phase one consisted of determining the shear strength parameters for each sludge and examining the influence of the sludge composition on these parameters. The sludges were first tested in their natural state and the angle of internal friction and cohesive value determined. Lime or flyash, two substances readily available in the

production of paper, was then introduced and the strength parameters re-evaluated to determine what effects these additives would have. Since only the organic portion of the sludge would be affected by natural decomposition, decomposition was simulated by reducing the fiber content of the material. In this way the role of the organic matter could also be evaluated.

The second phase of the program consisted of examining the permeability of the two sludges, as the results of phase one indicated that entrapped air and gas from either bio-degradation or mechanical dewatering equipment were having a large effect on water movement in the material. In this area the effects of the lime and flyash additives and sludge decomposition were also evaluated. The water retention characteristics of the secondary fiber mill sludge were also included as they relate to sludge permeability.

CHAPTER II

LITERATURE REVIEW

2.1 High Ash Primary Clarifier Sludges

Considerable literature relating to pulp and papermill sludges is available but little has been directed toward the engineering characteristics of this material. The principal emphasis has been in the areas of composition, improved dewatering techniques, improved methods of solids removal, and recirculation of the sludge back into paper production. By examining this work considerable insight can be gained in understanding the engineering properties and behavior of pulp and papermill sludges. The physical properties relevant to shear strength and permeability include composition, water content, consistency (Atterberg) limits, fiber content, and admixtures.

2.1.1 Composition

Gillespie, Gellman, and Janes (1970) define "high ash sludges" as those which have a fixed solids content of 60 percent or greater. This fixed solids portion is mainly clay with small amounts of aluminum hydrate, titanium oxide, lime, and iron. The remaining portion is composed of cellulose, starches, dextrans, and minute amounts of other

organic compounds (Mazzola, 1969). The proportion of each is dependent upon the type of paper being produced and the internal methods being used to recover the fiber. The result is that the physical properties of these sludges show a wide variation.

Mazzola (1969) examined the sludge deposited from eight different mills for various physical properties including water content, Atterberg limits, ash content, and vane shear strength. In addition microscopic and visual inspections were used as a basis to evaluate decomposition. This decomposition study was minimal since only one deposit was examined and only a visual evaluation was made. Photomicrographs were made of two samples, representing ages of 1 and 12 years, taken from a single deposit. Visually, no difference could be detected. This lack of decomposition was primarily attributed to three factors; (1) the nature of the cellulose fiber, (2) the absence of available nitrogen in the material, and (3) the lignin content of the fiber. Compared to other organic materials cellulose is highly resistant to decomposition and, in the absence of oxygen, anaerobic decomposition is mainly confined to the mesophilic and thermophilic spore forming bacteria. The major factors affecting the rate of breakdown are the available nitrogen, temperature, pH, and proportion of lignin. Decomposition of cellulose becomes inactive when the available nitrogen becomes less than 1.2 percent (Umbreit, 1962). Mazzola estimated the available nitrogen for the sludges

examined at 0.0002 to 0.0005 percent. In addition the lignin content was high which would retard breakdown of the material.

In other investigations of cellulose decomposition (Blosser, 1963) it has been reported that slow decomposition of cellulose has been found in sludges piled on land. Analysis of a deinking sludge which had been on the ground for only four years showed a reduction of about one-third the volatiles. Waksman (1960) investigated the decomposition of cellulose in soil on a laboratory program. His results also showed that cellulose decomposition could be expected providing a favorable carbon-nitrogen ratio was maintained. In samples composed of a garden soil, small amounts of a sand cellulose mixture, and one percent sludge, he observed 90 percent cellulose decomposition in 45, 50, and 80 days with carbon to available nitrogen ratios of 5:1, 10:1, and 550:1, respectively. Thus it can be concluded that cellulose decomposition will occur if available nitrogen is present, supplied through direct application, or made available by mixing the sludge with soil mixtures.

2.1.2 Water Content

The water found in pulp and papermill sludges exists in three different phases (Gehm, 1959); (1) free water, (2) interstitial water, and (3) water of imbibition. The free water is readily removed. Interstitial water is held by adsorption and can only be removed with difficulty, while

water of imbibition cannot be removed at all by present mechanical methods. The suspended solids in the sludge also fall in three classes; (1) fibrous solids, (2) fillers, and (3) colloidal sols. The amount of each will vary depending on the source mill and the type of process employed. Of the three, the first two are easily separated from the liquid phase of the material but the sols are not. These sols consist of highly hydrated wood dust, fibrous debris, ray cells, aluminum hydrate, starches, dextrans, resins, and proteins. As their percentage increases, the amount of water held interstitially by adsorption on the hydrogel surfaces and on the surfaces of the enmeshed fibers and particles also increases. This, in turn, increases the difficulty in concentrating the solids and causes the resulting mass to be thixotropic and gelatinous in nature. It has been found that a very small proportion of sols added to a relatively free mass will appreciably increase the water holding properties of the entire mass (NCASI Tech. Bull. No. 190). The difference in the amount of these materials is the principal explanation offered for the variability between sludges in dewaterability. One of the keys to increasing the percentage of solids thus lies in finding a means to free the water from the sols. Chemical treatment, heating, or freezing has not been found effective for pulp and papermill sludges (Gehm, 1959).

With respect to dewaterability, four methods have been extensively investigated; (1) natural settling, (2) vacuum

filtering, (3) centrifugation, and (4) mechanical pressing. The effectiveness of the different methods has been consistently in the same range for numerous studies; 2-5 percent for natural settling, 20-45 percent for vacuum filtering and centrifugation, and up to 65 percent for mechanical pressing. The variability is dependent on the composition of the sludge. The real significance of these studies then lies in relating them to the expected drainage behavior or water retention properties.

Of the nine sites examined by Mazzola (1969), the material at three had been deposited without prior mechanical dewatering; at the remaining six the material had been subjected to either vacuum filtering or centrifugation before deposition. At four of the sites, other materials including mill waste, sand, and gravel had been placed with the sludge to form a layered structure. The age of the deposits ranged from three months to twenty years. In looking at the water content of these deposits, he found variations ranging from 46 to 740 percent, representing solids contents of 68 to 12 percent, respectively. None of the samples represented material from an elevation below the ground water table. The data presented shows that the sludge that had not been dewatered by mechanical means was, in general, represented by the higher water content values. One of the deposits filled with a dewatered sludge did exhibit water contents up to 711 percent. The data also shows that the water content cannot be related to age since some of the

older deposits showed higher values than more recent ones placed with approximately the same initial percentage of solids.

In examining the water content variation within a single deposit, Mazzola found a larger variation in the vertical direction than in the horizontal. In attempting to relate this variation to depth and thus overburden pressure, he found the variation was inconsistent with the values fluctuating from high to low, back to high, etc. This result is not surprising in that the material studied was placed over a period of years. During that time, the type of paper produced and the processes employed varied, causing the deposits to be stratified.

In comparing the amount of ash per sample with the water content, he did find an inverse linear relationship could be written between the two. His results are given in Figure 2.1. From these findings it was concluded that the more ash present, the more readily a sludge would drain and the more stable it would be.

2.1.3 Consistency Limits

The consistency or Atterberg limits indicate the range of water contents in which a soil or sludge may be considered as a fluid, plastic, or solid. The liquid limit is the water content at which the soil or sludge has such a small shear strength that it will flow and close a groove of standard width when jarred in a specified manner. The plastic limit is the water content at which the soil or sludge begins to

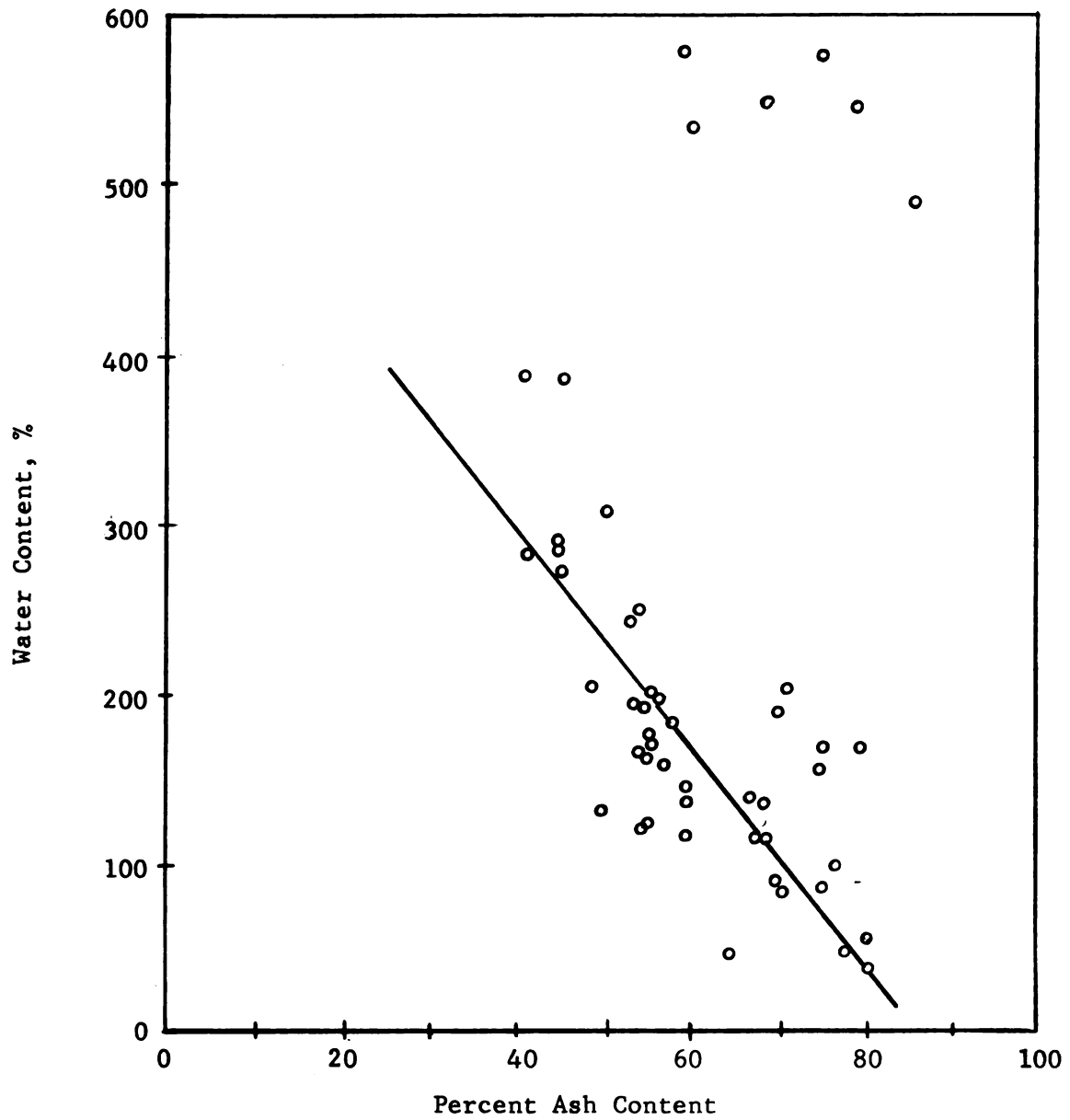


Figure 2.1 Water Content vs Ash Content (after Mazzola, 1969)

10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000

crumble when rolled into threads of a specified size. The difference in water content between the liquid limit and plastic limit is an indication of the plasticity of the material. Organic materials containing fibers do not lend themselves to the standard consistency tests (Lambe, 1951). Mazzola (1969) states that in running the liquid limit test, the fibrous nature of the sludge sample interfered with making the required groove cross section. The fibers also altered the shear strength of the sludge next to the groove which in turn affected the results.

Mazzola (1969) examined the Atterberg limits of the previously described sites to determine if they could be related to the ash content. Of the 63 samples examined, the values of both the liquid limit and plastic limit were found to be high. When the liquid limit was plotted against the percent ash in the sample, it was observed that the point representation of the samples fell within a narrow band that established an inverse relationship. A similar relationship was found when the plastic limit was plotted against the ash content. From these results, plotted in Figures 2.2 and 2.3, it was concluded that the liquid limit and plastic limit are dependent on the ash content. A plot of the liquid limit versus the plastic limit gives a near one to one relationship indicating that these sludge materials have a low plasticity (Figure 2.4). Since it was known that the material contained a large fraction of clay, he concluded that the fiber must be affecting the behavior

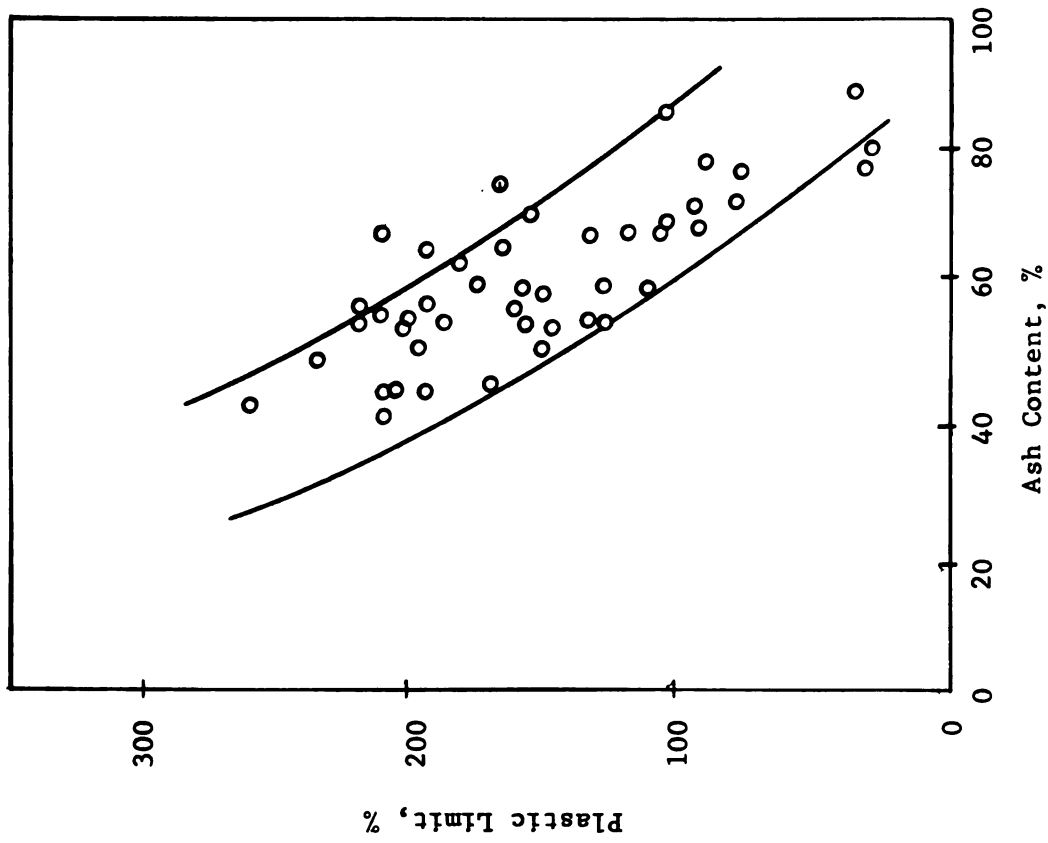


Figure 2.3 Plastic Limit vs Ash Content (after Mazzola, 1969)

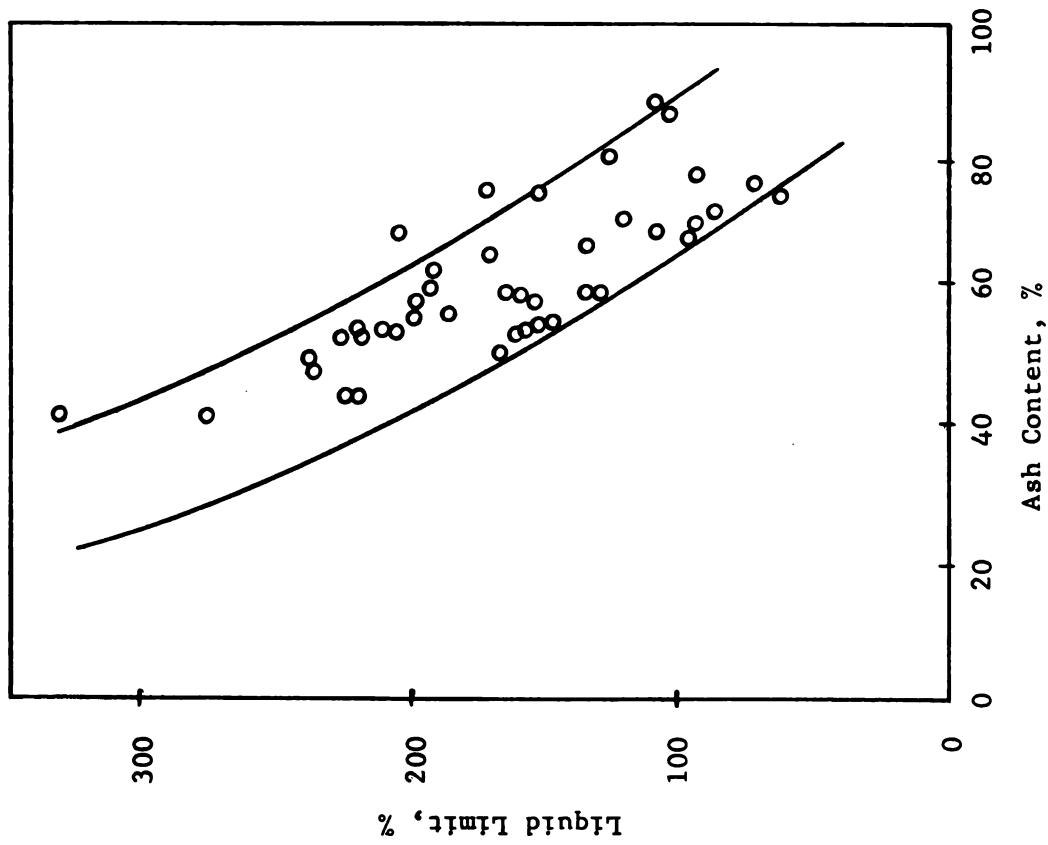


Figure 2.2 Liquid Limit vs Ash Content (after Mazzola, 1969)

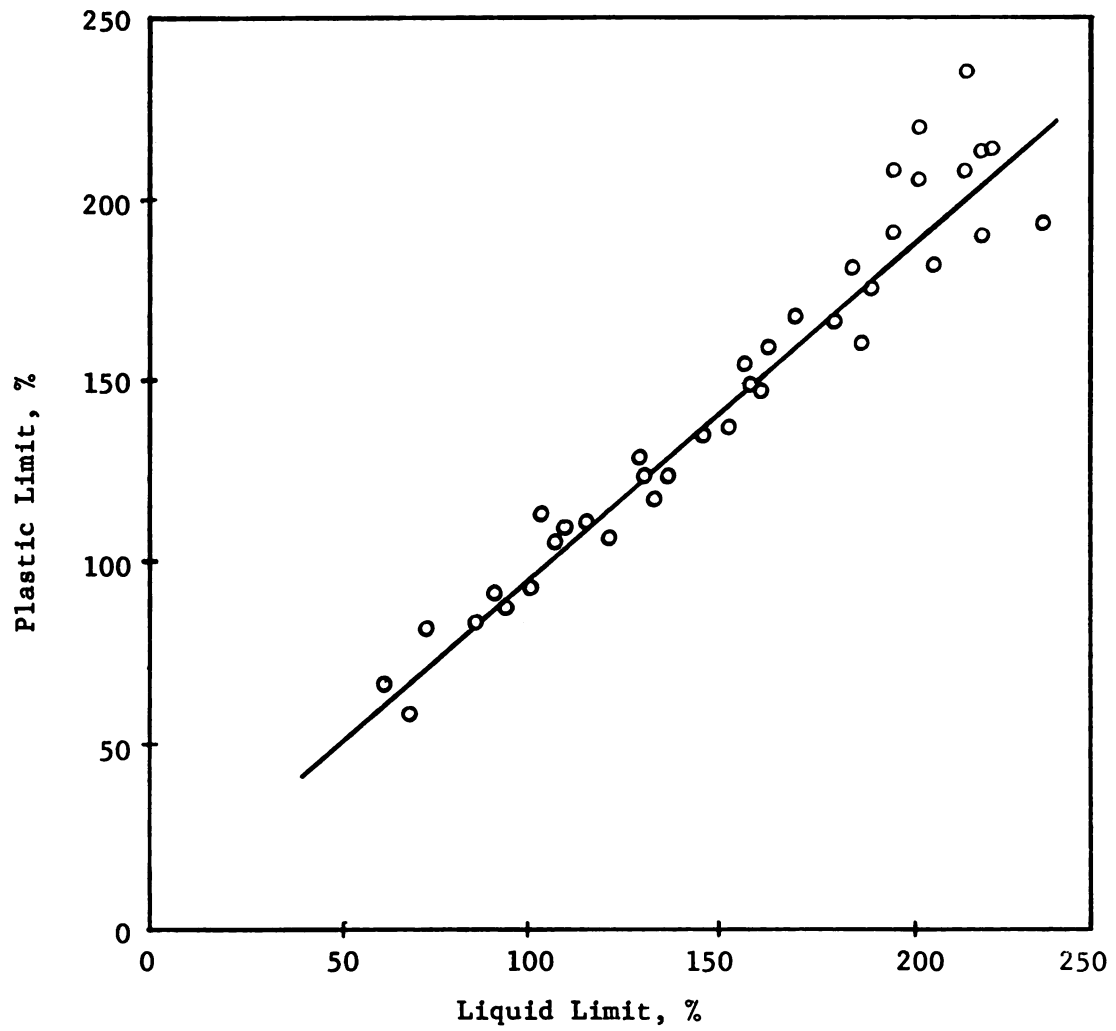


Figure 2.4 Plastic Limit vs Liquid Limit (after Mazzola, 1969)

of the total mass in a manner that reduced the plasticity. Since this relationship was somewhat less than one to one, it appeared that the effect was greater on the plastic limit than on the liquid limit. These findings are identical to those found in examining peat, muck, and similar highly organic materials (Baver, 1966).

Evaluation of the water-plasticity ratio for these samples (Mazzola, 1969) established values ranging from one to in excess of 1000, with most of the deposits in a fluid state. Sands, silts, and clays will normally be found with a water-plasticity ratio of less than one and usually less than zero. Since a high ratio indicates material which, when loaded, will experience a large degree of consolidation, the consolidation potential for these deposits was high. In general, it was found that the lower values were associated with deposits containing a large proportion of ash or with deposits where a load had been imposed on the material. The higher values were generally associated with deposits that had a high fiber content. No relationship could be found based on ash content alone. In that even the older samples, which had been subjected to a load, still had a water-plasticity ratio in excess of one, the drainage characteristics of the material must be such that the material will retain a large portion of the water.

2.1.4 Fiber Content

Several studies have been carried out for the purpose of evaluating the effects of fiber on sludge behavior.

These studies have examined both the length of fiber present and the relative proportion of fiber in comparison to the remaining composition. In reporting on mechanical pressing methods (NCASI Tech. Bull. No. 174) it became apparent that the amount of fiber had a strong influence on the effectiveness of the method. Two types of sludge were examined, a boardmill sludge and a deinking sludge. The characteristics for each are given in Table 2.1. These sludges were subjected to various pressures ranging from 0 to 900 psi. The results are given in Figure 2.5 for pressures applied at five minute durations. Mechanical pressing was found to be considerably more effective with the deinking sludge than with the boardmill sludge. The difference was attributed to the higher inorganic content of the former. Approximately 25 to 50 percent more water was removed from this sludge for the same pressure and pressing time. To further substantiate this conclusion, samples of both sludges were prepared with fiber contents of 5, 10, 15, 20, and 25 percent. It was found that the addition of fiber caused a reduction in solids content and this reduction was proportional to the amount of fiber present. These results are given graphically in Figure 2.6. These findings did substantiate the previous conclusions. Not only is the amount of fiber important, but so is the length of fiber (NCASI Tech. Bull. No. 136). In a study on the filterability of pulp and papermill sludges, it was found that a definite relationship existed between the length of fiber

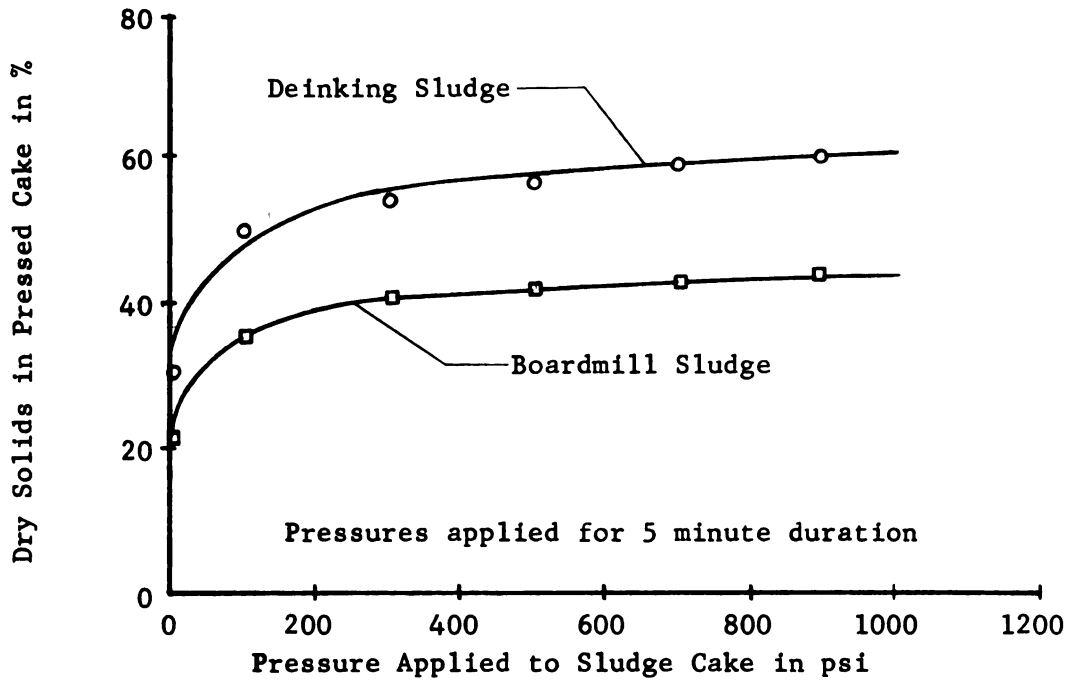


Figure 2.5 Percent Solids vs Applied Pressure (after NCASI Tech. Bull. No. 174)

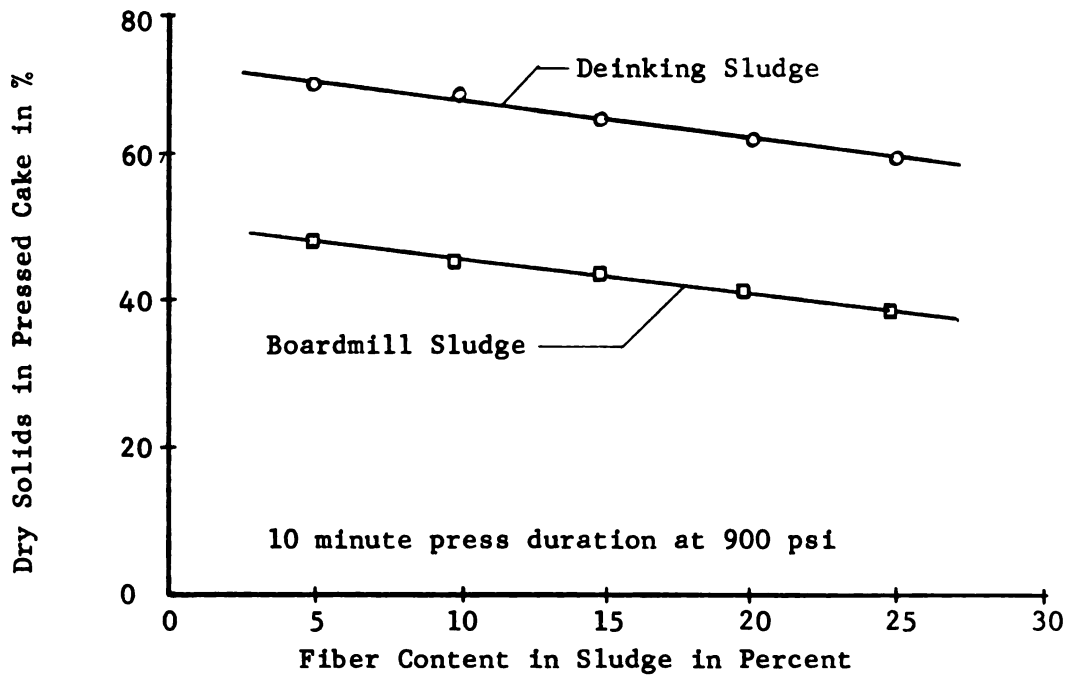


Figure 2.6 Dry Solids Content vs Fiber Content of Sludge Sample (after NCASI Tech. Bull. No. 174)

Table 2.1 Sludge Properties of Fiber Content Studies
(after NCASI Tech. Bull. No. 174)

Sludge	Boardmill	Deinking
Solids content	21 %	30 %
Combustible fraction	74 %	53 %
Ash content	26 %	47 %

and drainability. In that this relationship proved to be nonlinear, a small percentage of long fiber will appreciably increase the drainability. This fact is shown in Figure 2.7.

2.1.5 Admixtures

Efforts to improve the dewaterability of pulp and papermill sludges have considered the addition of flyash from boiler operations to the material. In a laboratory study conducted in 1962 (NCASI Tech. Bull. No. 158) several aspects of such procedures were examined in connection with vacuum filtration. One of the first observations made was that there is a considerable difference in flyash as collected from various mills. Hence, an additional project phase was necessary to consider the effects of different flyash. In all, twelve different samples of flyash were used in the evaluation. A summary of the pertinent results are given below (NCASI Tech. Bull. No. 158).

1. For the sludge materials examined, the precoat using any of the twelve flyash samples increased the filter loadings.

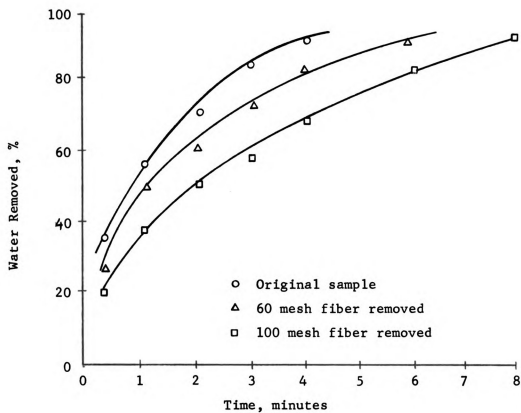


Figure 2.7 Effect of Fiber Length Present on Drainage Rate (after NCASI Tech. Bull. No. 136)

2. For those sludges high in organic materials, the precoat of flyash considerably increased the drainability.
3. For those sludges low in organic materials, the precoat of flyash decreased the drainability.
4. Sludges not dewaterable by ordinary vacuum filtration could be handled with the addition of flyash.
5. Flyash samples having a uniform particle size distribution yielded more favorable results with respect to the quantity required than those well graded. However, if the flyash had a large proportion of fines, the drainability would decrease.

Field experience has shown similar results (NCASI Tech. Bull. No. 37) in that an increase in ash content from 5 to 20 percent of the sludge solids increased the filter loading by 20 percent and an increase of ash to 75 percent caused a 200 percent increase in loading.

A second additive that has been widely investigated and used is lime (CaO). Acting as a flocculating agent, a 5 percent addition of lime has been found to increase the filter loading an average of 28 percent (NCASI Tech. Bull. No. 37). Increasing the lime to 10 percent showed little additional benefit. Other studies (NCASI Tech. Bull. Nos. 136, 190) report similar results with respect to both loading and drainability.

2.2 Conditions of Failure for Sludges

Sludges, like soil materials, fail either in tension or shear. Tensile stresses may cause opening of cracks which are undesirable or detrimental. In the majority of the engineering problems only the resistance to failure by shear requires consideration. Shear starts at a point in a mass

of sludge when, on some surface passing through the point, a critical combination of shearing and normal stresses is reached. This section deals with shear strength theory, similarity of sludges to organic soils, and vane shear strength.

2.2.1 Shear Strength Theory

Experience has shown that the Mohr-Coulomb theory of failure has been very successful for defining failure in soil materials (Terzaghi and Peck, 1948; Wu, 1966). This theory, represented in the usual form

$$\tau_{ff} = c + \sigma_{ff} \tan \phi \quad (2.1)$$

states that the shear stress, τ_{ff} , on a failure surface at failure is a function of the normal stress on that plane at failure, σ_{ff} , and the material properties, cohesion c and the angle of internal friction ϕ . In this form the soil skeleton must carry all the normal stress, that is, the soil must be free draining.

For cohesive materials that are not free draining, such as pulp and papermill sludges, the pore fluid will carry part of the normal stress. This portion cannot contribute to the frictional resistance and strength. Hence, for these materials, the stress carried by the fluid must be subtracted from the total normal stress and the shear strength based only on that portion of the normal stress carried by the soil skeleton. This can be done by measuring the pore pressure during triaxial testing and presenting the results in terms of effective stresses. So

represented, equation 2.1 becomes

$$\tau_{ff} = \bar{c} + (\sigma_{ff} - u)\tan\bar{\phi} \quad (2.2)$$

where u is the pore pressure, $\bar{c}$ is the cohesion intercept based on effective stresses, and $\bar{\phi}$ is the frictional angle based on effective stresses. The equation then represents a straight line with the intercept on the shear stress axis equal to $\bar{c}$ and the slope angle equal to $\bar{\phi}$. The shear strength so defined is the maximum shear stress that can be sustained on any plane in a given soil or sludge material. Determination of truly representative values for the material properties of the sample is essential in order to reflect field behavior.

Experience has shown that the values determined by consolidated-undrained triaxial tests with pore pressure measurements (Bishop and Henkel, 1962) correlate well with the actual field behavior. For these tests, a soil sample, usually $1\frac{1}{2}$ inches in diameter by 3 inches high, is subjected to an all around pressure σ_3 and allowed to consolidate under drained conditions. The vertical stress σ_1 is next increased under undrained conditions until the sample fails. During the loading period, measurements are taken of the pore water pressure, axial deformation, and axial load. Results from each test represent an effective stress circle at failure. If several triaxial tests are performed with different all around pressures and the measured stresses corresponding to failure are plotted, the points representing failure are given by the envelope of the stress circles

as shown in Figure 2.8. This envelope is known as the rupture line; and, although it is not perfectly straight, it can be represented by a straight line with sufficient accuracy that the resulting material properties adequately reflect field behavior for soils. In normal laboratory evaluation, three to five tests are made and the rupture line drawn tangent to the observed failure circles as shown in Figure 2.9. Since this method of evaluation depends on visual determination of the tangent points, it is desirable to adopt a representation that uses the points of maximum shear stress at failure. Lambe and Whitman (1969) represents these points as

$$\bar{p}_f = \frac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3), \quad q_f = \frac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)$$

These points are unambiguous and precisely determined, allowing curve fitting methods to determine the line of best fit. This method gives the k_f failure line and results in a y intercept $\bar{a}$ and a slope angle $\bar{\alpha}$, which, with the proper geometric transformations, give the desired values $\bar{c}$ and $\bar{\phi}$, respectively, as shown in Figure 2.10.

2.2.2 Similarity to Organic Soils

Although considerable work has been reported in the literature on the consolidation properties of highly organic soils, that regarding the shear strength has been limited since these types of materials have been avoided in engineering practice. Hanrahan (1954) points out that one of the biggest handicaps in the testing of peat is the anisotropic nature of the material. The probability of obtaining

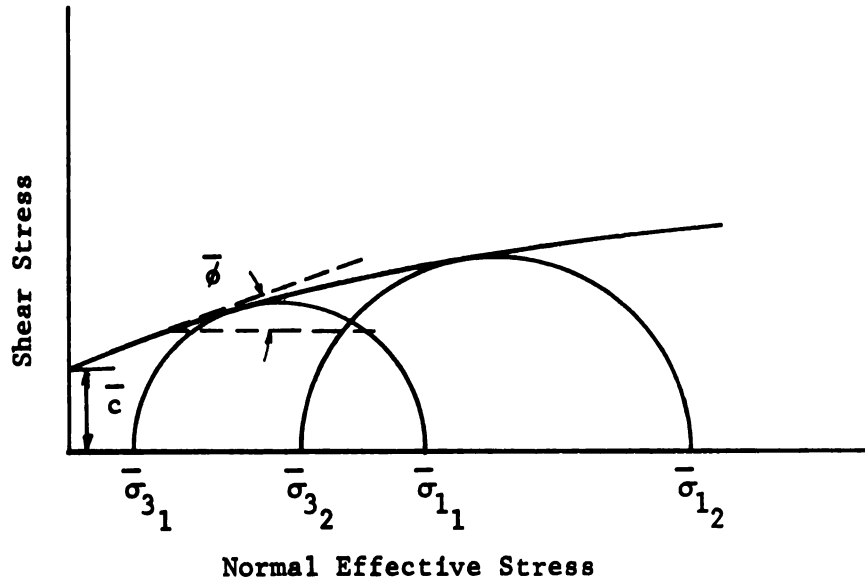


Figure 2.8 Stress Circles and Failure Envelope

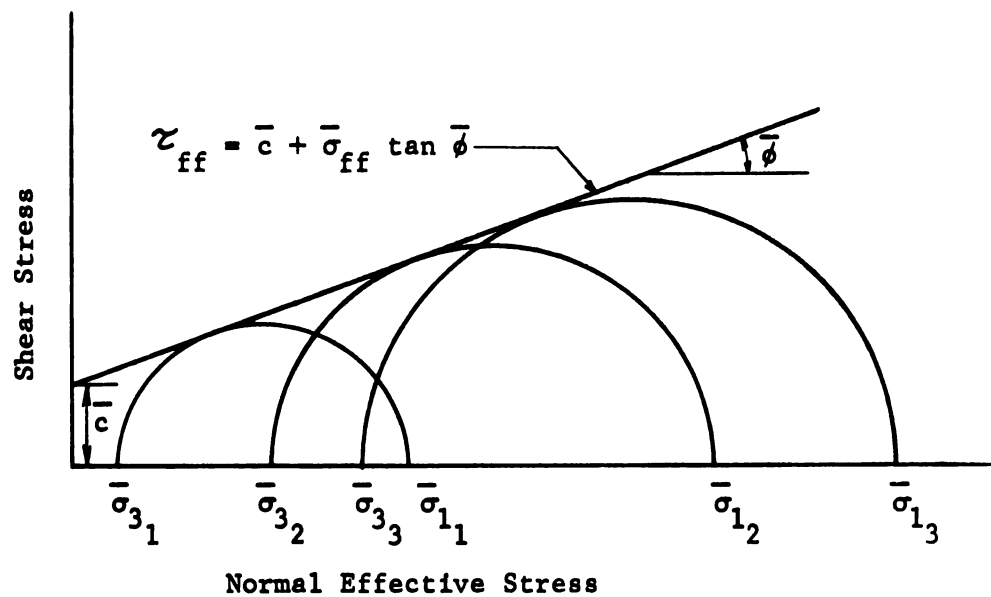
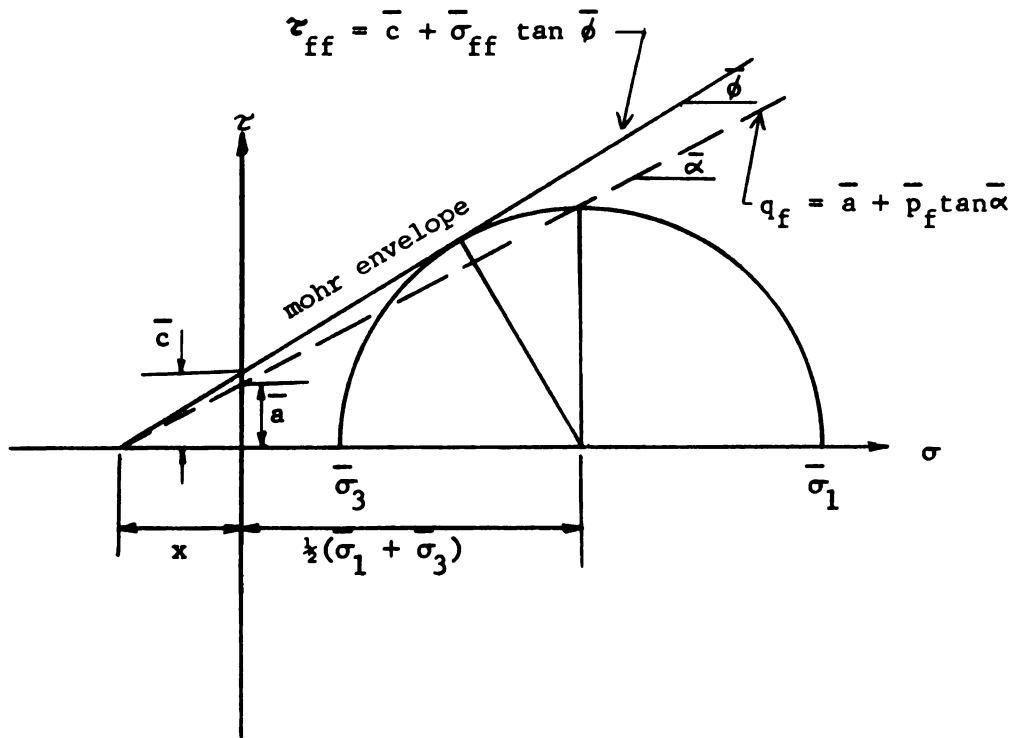


Figure 2.9 Straight Line Representation of the Mohr Envelope



$$\tan \bar{\alpha} = \frac{\frac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)}{\frac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3) + x}$$

$$\tan \bar{\alpha} = \frac{\bar{a}}{x} \quad \text{or} \quad x = \frac{\bar{a}}{\tan \bar{\alpha}}$$

$$\sin \bar{\phi} = \frac{\frac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)}{\frac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3) + x}$$

$$\tan \bar{\phi} = \frac{\bar{c}}{x} \quad \text{or} \quad x = \frac{\bar{c}}{\tan \bar{\phi}}$$

$$\therefore \frac{\bar{a}}{\tan \bar{\alpha}} = \frac{\bar{c}}{\tan \bar{\phi}}$$

$$\therefore \tan \bar{\alpha} = \sin \bar{\phi}$$

$$\text{but } \tan \bar{\alpha} = \sin \bar{\phi}$$

$$\therefore \frac{\bar{c}}{\tan \bar{\phi}} = \frac{\bar{a}}{\sin \bar{\phi}}$$

$$\bar{c} = \frac{\bar{a}}{\cos \bar{\phi}}$$

Figure 2.10 Equations and Definitions for Shear Strength Theory, Effective Stress Basis

representative undisturbed samples is minute. On the other hand, recompacted samples are unlikely to be representative because the structure will be destroyed in remolding. Hanrahan chose to use undisturbed samples that were obtained and prepared with extraordinary care. Consolidated triaxial tests were found difficult to carry out due to the large volume change associated with the peat and the nonuniformity of this volume change. To make calculations possible, it was necessary to assume that the peat was equally compressible horizontally and vertically. In reality, this is not true; but, even with this assumption, the results of several tests were consistent. It was found that the shape of the curve relating water content to the deviator stress at failure was characterized by a decreasing slope for decreasing water content. This result indicated that the water removed in later stages of consolidation results in considerably greater increases in strength than the same quantity removed during early stages. Consolidation was permitted under three different chamber pressures; 15, 25, and 35 psi. For one series of tests the undrained shear strength was evaluated after a consolidation period of 24 hours and with no decrease in lateral pressure. The results showed that no increase in strength resulted from the increased lateral pressure and at failure the pore pressure was approximately equal to the chamber pressure. For a second series of tests the undrained shear strength was evaluated after the consolidated test specimens were allowed to swell

for at least one-half hour. The results of these tests led to strengths 20 to 40 percent less than the previous group with pore pressures at failure only 30 to 50 percent of the chamber pressure. The $\bar{\phi}$ angle for the swollen samples was only about 5° leading Hanrahan to conclude that the strength of peat is exclusively cohesive in character. The rate of deformation was normally 0.001 in/sec. A comparison of strength was made to that determined when a rate of deformation of 0.01 in/sec was used. The faster rate resulted in an increase in strength of approximately 5 percent. No other evaluations or conclusions were made on testing rates.

Adams (1961), in conducting consolidated-undrained triaxial tests on peat, found $\bar{\phi}$ angles of approximately 50 degrees. These results were obtained from samples 1.9 inches in diameter by 4.5 inches high, consolidated under confining pressures of 2, 10, 20, and 30 psi. In each test the pore water pressure build up was rapid and, at failure, essentially equal to the lateral pressure. Two drained tests were also carried out, running for a period of three months. The observed results were almost identical to the consolidated-undrained tests, giving a $\bar{\phi}$ value of 51° . A comparison of the results from the two types of tests is given in Figure 2.11. The cohesive value determined in both types of tests was essentially zero.

Investigations undertaken at University College, Dublin, (Hanrahan, et al., 1967) have shown similar results. Remolded samples of an organic peat were examined by means

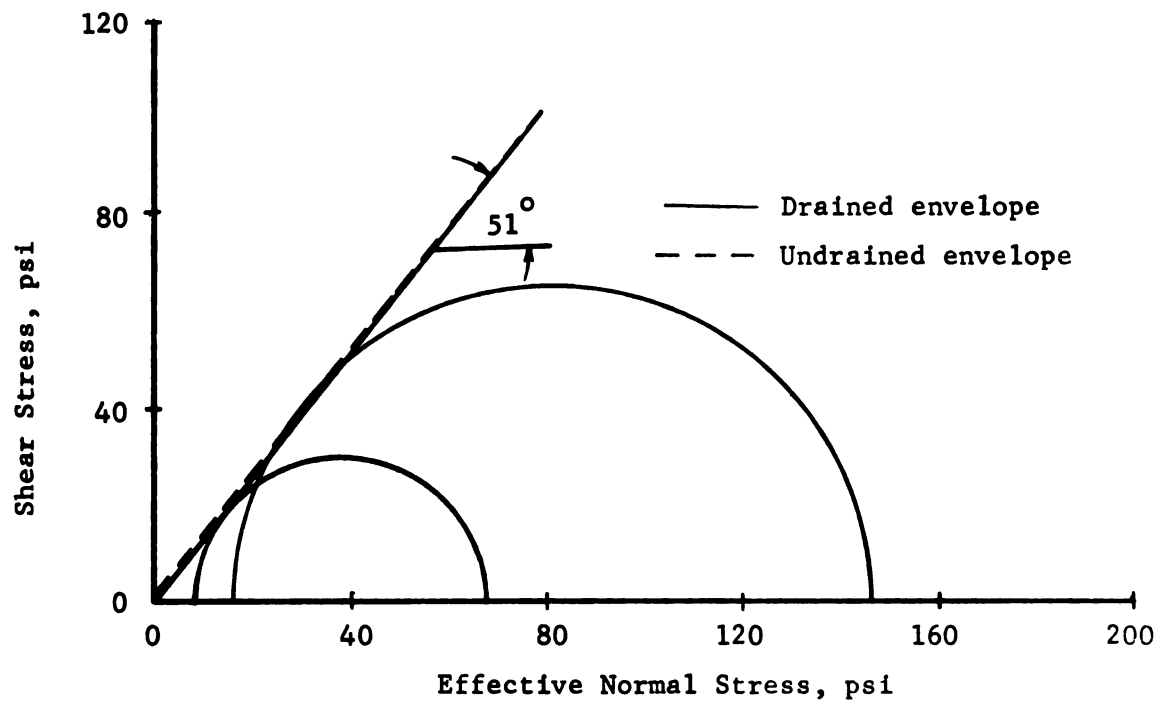


Figure 2.11 Drained Compression Tests on Peat (after Adams, 1961)

of consolidated-undrained triaxial tests. The values observed for $\bar{c}$ varied from 0.7 to 1.0 psi and $\bar{\phi}$ varied from approximately 35 to 44 degrees. These studies showed that $\bar{\phi}$ was affected by the water content, decreasing at higher values. The strain rate used was established by a separate series of tests in which the pore pressure was measured simultaneously at midheight and at the base of the sample. Determination of the most satisfactory testing rate was based on the difference in the pore water pressure between the two points and on the resulting time required to complete a triaxial test. A rate of 0.0024 in/min was determined to be the most satisfactory with respect to both the results and time required. The pore pressure coefficient B was found invariably to be one for the soft peats with no evidence exhibited to suggest a value greater than unity, i.e., the loss of effective stress due to instability of the solid structure. The applicability of the A coefficient for peat was questioned because the pore pressure for all the samples increased during shear, becoming equal to the confining pressure for the samples with a water content in excess of 400 percent. For drier samples the pore pressure attained values of only 90 to 100 percent of the cell pressure, then fell off slightly.

2.2.3 Vane Shear Strength

When undrained conditions are expected to prevail in deposits of saturated clay in the field, vane shear tests (Terzaghi and Peck, 1967) are often used advantageously in

evaluating the cohesion c . In the simplest form, the mechanism for evaluation consists of a four-bladed vane fastened to the bottom of a vertical rod. The vane and rod can be pushed into the soil without appreciable disturbance. This assembly is then rotated and from the measured torque the shear strength determined. Field measurements on the shearing strength of peat (muskeg) have shown a variation from 100 to 1700 psf (Hardy, 1964). Results show that high shear strengths for peat can be mobilized but they will be accompanied by abnormally high deformations. These results are based on extensive vane shear strength tests conducted under the supervision of Hardy at the University of Alberta.

In examining the vane shear strength of the sludge deposits described by Mazzola (1969) in situ values ranged from 0.12 to 0.37 kg/cm². Variations in sludge properties with depth were such that little correlation existed between depth and water content or depth and vane shear strength. Where sludges of similar physical properties were found, as shown by similar consistency limits, the water content did decrease with depth and the vane shear strength increase. This behavior is similar to that found for soft marine clays.

2.3 Water Flow in Sludge

The physical nature and the arrangement of constituent particles in sludge greatly affect the size and continuity of pores and/or capillaries. Such differences plus incomplete saturation result in a wide range in permeability for

pulp and papermill sludges. Sludges containing a high proportion of sols tend to discourage permeability by water while the open meshed fibrous sludges are initially quite permeable. This section reviews the permeability theory and the factors which affect flow through a material.

2.3.1 Permeability Theory

The importance of the permeability of soil is reflected by the number of properties which are dependent on flow, e.g. drainage, consolidation, and shear strength on an effective stress basis. The most widely used representation of flow is given by Darcy's law (Terzaghi and Peck, 1967; Lambe and Whitman, 1969). Darcy's law is usually written in the form

$$v = \frac{Q}{A} = k \frac{\Delta h}{L} = ki \quad (2.3)$$

where the rate of flow, Q , is dependent upon a permeability constant, k , the hydraulic gradient $i = \frac{\Delta h}{L}$, and the cross sectional area A . The accuracy of the equation is generally dependent on the permeability k . For the permeability to be truly constant certain conditions must be satisfied or accounted for including (1) a completely saturated medium, (2) an incompressible fluid, (3) no change of void ratio in the porous medium, (4) low flow velocities, (5) a homogeneous porous media, (6) a homogeneous fluid, (7) continuous flow, and (8) steady state flow (Leonards, 1962; De Wiest, 1969).

Examination of the above conditions in terms of the usual engineering problems reveals that items five through

eight are insignificant since the laboratory determination of the permeability adequately takes them into account. In addition, the void size and configuration in ordinary soils is such that the flow velocities are normally small. A change in void ratio may be due to solid material going into solution and can be accounted for by altering the permeability value in accordance with the different stages. Most investigators assume that the absence of conditions one or two, i.e., an unsaturated material or a compressible fluid, will result in a considerable variance in permeability (Leonards, 1962; Scott, 1963; De Wiest, 1969). Both of these conditions introduce the factor of air (gas) occupying part of the pore space and restricting flow.

2.3.2 Factors Which Alter Flow Rate

Richards (1967) reported on the work of several investigators in examining soils which are normally unsaturated. No theory to date has been proposed that fully reflects the flow behavior through these soils. Most attempts to represent unsaturated flow have been based on modifications of Darcy's law. The main modification necessary is one to reflect the negative pore pressures possible when air is introduced into the media. Many investigators have taken this factor into account by combining Darcy's law with the law of continuity and basing k on the volumetric water content. When these changes are made the following equation results:

$$v = -k(\theta) \frac{\partial \psi}{\partial x} \quad (2.4)$$

where

- v = velocity of flow
- $k(\theta)$ = permeability as a function of the volumetric water content, θ
- $\frac{\partial \psi}{\partial x}$ = gradient of potential or total head, ψ , in the x direction
- ψ = $z + u$
- z = elevation head
- u = pore pressure in height of water

In this modified form certain assumptions must be made which may result in serious problems and limit the use of the equation. Two such assumptions are: (1) light overburden and applied pressures and (2) no soil structure or fissures. The first severely limits the range of applicability when applying the results to field behavior. The second limits the laboratory determination of $k(\theta)$, as a structure is present in soils and the removal of in situ stresses will cause it to be altered. As a consequence most engineers fall back on semi-empirical methods for the evaluation of the permeability of unsaturated soils.

Mitchell and Younger (1967) have examined the work of many investigators in regards to the permeability of fine grain soils. They report that non-Darcy flow is common in these types of materials and that no consensus of opinion exists as to the cause. Several of the papers reviewed attribute the varying permeabilities to the alternate plugging and unplugging of void space. It is still argued whether this action is due to the migration of fine particles under stress or the effect of minute air bubbles in the material. Mitchell and Younger attribute much of this fluctuation in permeability to experimental effects in

measuring k such as leakage, swelling, consolidation, or variation in the fluid.

Growth of bacteria and other organisms has been found to influence flow behavior (Gupta and Swartzendruber, 1962). Growth of organisms can change the flow rate by blocking the flow paths with both the organisms themselves and with gaseous by-products or by changing the structure of the material through decomposition. With respect to threshold gradients to initiate flow, Mitchell and Younger (1967) report that the Russian investigators have accepted and used the above concept for a number of years. In their study on kaolonite, it was found that a threshold value did exist below which no flow would take place. The exact cause of this threshold limit could not be established, but three possible reasons were advanced; (1) capillary action, (2) the irregular destruction of a quasi-crystalline structure, or (3) bacterial growth. Of these three possible reasons, (1) and (3) relate to the entrapment of air within the sample.

Miller and Low (1963) also performed a series of tests to establish whether or not a threshold value for flow exists and if so, the cause. In working with bentonite of different densities, they found varying threshold gradients. The higher thresholds were associated with the higher densities. By examining sodium and lithium saturated bentonite, they concluded that the water develops a quasi-crystalline structure and acts as a solid at low gradients.

For these tests, efforts were made to evacuate any air within the sample. The success of this could not be ascertained and, as such, air blockage could not be completely dismissed.

In working with organic soils, Arman (1969) found results similar to the above with fluctuations in the permeability of peat ranging up to 50,000 times the low value. A large part of this fluctuation was attributed to bacterial growth causing the formation of minute air bubbles which would partially block the void space. It was also found that the permeability was affected by the amount of organic matter. As the organic matter was increased to beyond 40 percent, it was found that the controlling factor was the permeability of the organic materials. It appeared not to matter what the composition of the inorganic fraction was. Permeability-time studies performed indicated that the permeability decreased considerably with time for the peat studied. This factor may be of such importance that long term consolidation of peat is controlled by a decrease in permeability under a relatively constant pore pressure rather than by the dissipation of excess pore pressure.

In summary, it is widely agreed that deviation from Darcy flow is common and permeability values will show a wide fluctuation. There is no consensus of opinion as to why this fluctuation occurs nor has an adequate theory been proposed which relates the flow to the gradients applied and the material properties.

CHAPTER III

SLUDGES STUDIED AND SAMPLE PREPARATION

To best correlate the results of this study to the sludges encountered within the pulp and paper industry, two types of sludge were selected for evaluation: one from an integrated pulp and papermill, the other from a secondary fiber mill. The organic portion of the first was composed of long fiber cellulose material and some wood chips, while the organic portion of the latter was made up entirely of small cellulose fibers. The remaining portions were essentially the same for both sludges, varying only in the relative amounts of constituent materials. All samples were indexed by their physical properties which included the specific gravity, consistency limits, percent organic matter, percent ash, and clay type. The test methods used to determine these properties are listed in Table 3.1. This chapter describes the sludge samples used and provides information on the sample preparation for the triaxial specimens and permeability samples.

3.1 Secondary Fiber Mill Sludge

The secondary fiber mill sludge best fits the definition of a high ash pulp and papermill sludge (Gillespie,

Table 3.1 Physical Property and Test Method

Physical Property	Test Method
Consistency (Atterberg) limits	
Liquid limit	ASTM D423-66
Plastic limit and plasticity index	ASTM D424-59
Shrinkage limit	ASTM D427-61
Ash content	ASTM D586-63
Organic content	Agronomy No. 9, Sec. 92-3.3
Clay identification	Agronomy No. 9, pp. 683-692
Specific gravity*	ASTM D854-58

* Oven-dried samples were used for sludges H-2 and C-1. For sludge H-1, the oven-dried weight was determined at the end of the test.

Gellman, and Janes, 1970), hence it was used for the major part of the test program. The first sample obtained of this sludge was grey in color and contained 28.3 percent solids by weight. The organic content was only 27.5 percent of the solids by weight indicating this sample was not typical of those sludges normally resulting from the operation of this type of mill. Later information established that cleaning operations were underway at the mill when this sample was taken. These cleaning operations resulted in the sludge containing an excessive amount of fillers and coatings. Because this sample was not typical, a second sample, more representative of the mill, was obtained for the project.

The second sample was also grey in color but contained

25.7 percent solids of which 43.6 percent was organic material. The organic matter in both samples was essentially the same being short cellulose fiber. The physical properties of both sludges are given in Table 3.2 which also includes the properties of the samples modified by lime or flyash. The symbols H-1 and H-2 will be used throughout this report to identify the first and second samples, respectively, of the secondary fiber mill sludge.

The admixtures used with the two sludges included a commercial lime, comparable to that used in the paper industry but obtained from a local supplier, and a flyash resulting from the incineration of coal and bark in boilers at a secondary fiber mill. The properties of this lime and flyash are given in Table 3.3, with a grain size distribution curve for the flyash given in Figure 3.1.

Preparation of the samples with different organic contents or admixtures required special procedures. It was desired to alter the organic content of the sludge without affecting the remaining constituents in order to simulate decomposition. This was done by washing the sludge through a U. S. Standard No. 16 sieve (openings of 0.0469 inches) and collecting both the wash water and the material remaining on the sieve. The wash water was placed in a closed container and allowed to stand undisturbed for about four days permitting the suspended solids to settle out. The clear water was then siphoned off to a point about two inches above the settled solids. Next, the remaining

Table 3.2 Physical Properties of the Sludge Materials

Sludge ¹	Atterberg limits ²		SL	Ash ³ Content %	Organic ⁴ Content %	Specific Gravity	Solids ⁵ Content % by wt.
	LL	PL					
H-1	162.3	74.8	47.6	79.9	27.5	2.19	28.3
H-2							
28 % Organic content	133.4	65.5	53.2	83.7	28.6	2.36	
35 % Organic content	151.1	85.3	61.1	73.8	34.7	2.29	
43 % Organic content	175.5	108.0	83.7	61.1	43.6	2.27	25.7
50 % Organic content	210.2	152.4	99.1	49.9	50.1	2.24	
43 % Organic + 10 % lime	155.3	127.3	94.8	63.9	40.2	2.34	
28 % Organic + 10 % lime	136.0	83.3	61.3	74.5	26.4	2.41	
43 % Organic + 10 % flyash	162.1	113.5	82.1	64.7	39.9	2.20	
C-1							
51 % Organic content	245.3	169.0	124.8	48.5	51.3	2.30	30.7
51 % Organic + 10 % lime	235.1	176.4	108.4	51.3	47.8	2.35	
51 % Organic + 10 % flyash	240.5	172.1	117.6	53.4	46.9	2.19	

¹ H -- Secondary fiber mill sludge, samples 1 and 2
C -- Integrated pulp and papermill sludge

² LL = Liquid limit. PL = Plastic limit. SL = Shrinkage limit

³ Test method ASTM D586-63.

⁴ Tests performed by staff of Soil Science Dept., Michigan State University.

⁵ Solids content of sludge obtained at mill.

Table 3.3 Properties of Lime and Flyash

<u>LIME</u>	Brand	Mississippi Hydrated Lime
	Source	Massour, Missouri
	Specific gravity	3.32
	Available calcium hydroxide	97.00%
	Available calcium oxide	73.40%
	Available calcium carbonate	2.04%
	Total calcium oxide	74.57%
	Total trace elements	1.68%
<u>FLYASH</u>	Specific gravity	1.92
	Liquid limit	53.2
	Plastic limit	49.7
	Plasticity index	3.5

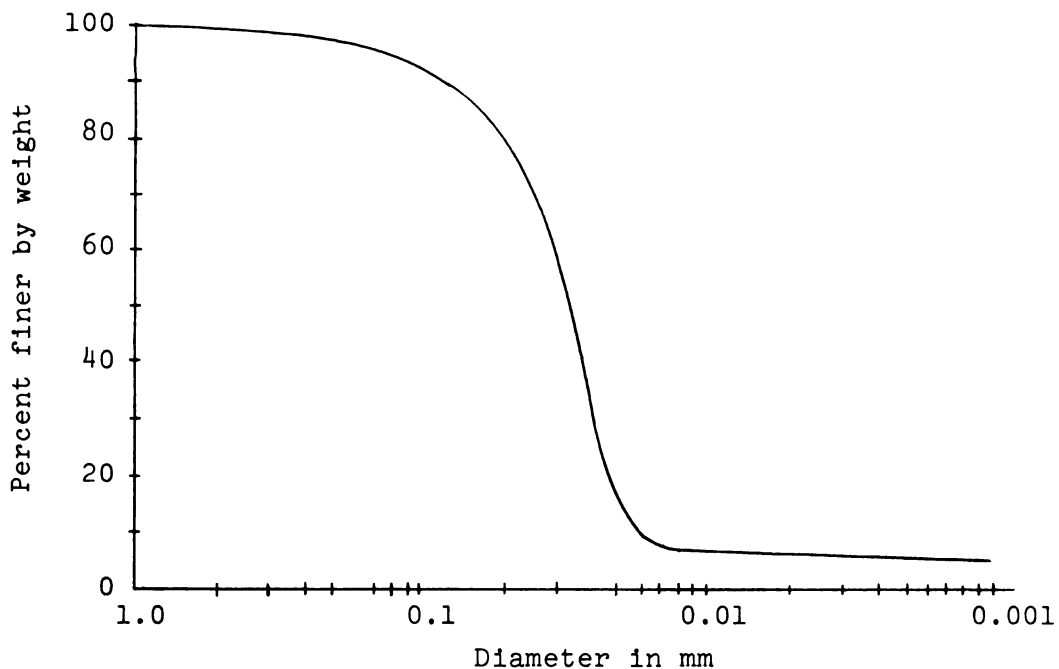


Figure 3.1 Grain Size Distribution Curve for Flyash Admixture

portion was brought to a consistency of about 40 percent solids by weight using an International model V, size 2 centrifuge for 30 minutes at 2500 rpm. An organic content determination was run on both the material collected on the sieve and on that washed through. Using these known values of organic content, mixtures were prepared to give the desired organic content. These mixtures (Table 3.2) were then checked for the actual percent of organic material. Since the openings on the No. 16 sieve are larger than the individual particles and fibers within the sludge, this process was not one of selective separation. The material retained on the sieve appeared to contain a full range of fiber size, the same as that washed through. Hence the fiber size within the modified samples was comparable to that in the natural sludge samples. The mixing referred to above was done by hand until the materials appeared to be well dispersed, then completed with a Hobart model A-200 electric mixer. The prepared mixtures were then stored in a refrigerator at 35° F in sealed plastic bags.

The lime and flyash samples were prepared by hand mixing the desired percentage by dry weight of the admixture with the sludge until it was well dispersed. Mixing was then completed using the Hobart mixer for four to five minutes. This material was also sealed in plastic bags and returned to the refrigerator for 24 hours before the test specimens were prepared.

3.2 Integrated Pulp and Papermill Sludge

The integrated pulp and papermill sludge was dark brown in color and contained some discrete particles of bark and wood chips. These particles ranged up to 15 mm in length and 2 mm in diameter. The solids content was 30.7 percent by weight of which 51.2 percent was organic material. This sludge would fall in the lower range of the high ash sludges. The symbol C-1 will be used throughout this report to identify this material. The physical properties of the sludge and its modifications with lime and flyash are given in Table 3.2. These modifications were prepared in a manner identical to that used for the secondary fiber mill sludge.

3.3 Triaxial Specimen Preparation

Triaxial specimens prepared with the secondary fiber mill sludge and the integrated pulp and papermill sludge would not retain their required shape as shown in Figure 3.2 until they had been dewatered to about 42 and 37 percent solids by weight, respectively. After dewatering by means of the centrifuge, remolded sludge samples were formed in a mold 7.13 cm high by 3.56 cm in diameter. Care was taken to work the sludge down into the mold and compact it so that any voids were small and any layering would be minimized. With the mold filled, the ends were carefully trimmed to be perpendicular to the sample axis. Next the mold was disassembled by pulling the sides directly away from the specimen such that no smear effects would result on the sides and interfere with drainage. The sample was then weighed,

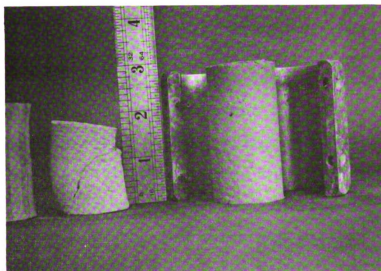


Figure 3.2 Triaxial Samples and Mold (left to right-- consolidated, failed, and new specimens)

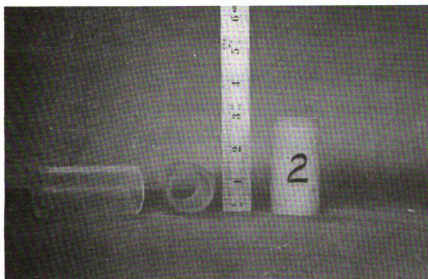


Figure 3.3 Permeability Sample and Mold

placed in an air tight container and returned to the refrigerator.

3.4 Permeability Sample Preparation

In preparing the permeability samples the sludge was first dewatered to the desired water content using the International centrifuge. This sludge was carefully worked into an acrylic plastic permeameter tube 2.81 inches long by 1.125 inches in diameter as shown in Figure 3.3. Care was taken to minimize the formation and size of voids and to fill these voids with the sludge fluid.

To establish base permeability curves it was necessary to remove the entrapped air and to prevent the formation of additional gas. The procedure for preparing such samples consisted of first treating the sludge with a biological sterilant (mercuric oxide) and then removing the previously entrapped air by subjecting the samples to a vacuum. The mercuric oxide was mixed with the sludge in such quantities that it formed a 0.5 percent solution by weight with the sludge fluid. Other concentrations were tried but it was found that this was the lowest concentration at which essentially all gas formation stopped. After a contact time of fifteen minutes, the sludge was placed in the centrifuge and dewatered to the desired solids content. The specimen was then formed as before and placed in a vacuum chamber at minus 10 psi. While in the vacuum, it was usually necessary to reform the sample as the escaping gas bubbles normally forced part of the sample out of the permeameter tube.

When no bubbles were observed moving out of the tube, the sample was removed from the vacuum, placed in an air tight container, and returned to the refrigerator until the test was to be run. This time period was never greater than two hours.

CHAPTER IV

LABORATORY EQUIPMENT AND TEST PROCEDURES

The triaxial test provides information on the strength and deformation characteristics of soil and sludge materials. The principal features of the triaxial apparatus are given in part II of THE MEASUREMENT OF SOIL PROPERTIES IN THE TRIAXIAL TEST by A. W. Bishop and D. J. Henkel (1962). The permeameter provides information on the ease with which water can flow through a soil or sludge in terms of permeability. Basic information on the apparatus and supplies is given in Chapter VI of SOIL TESTING FOR ENGINEERS by T. W. Lambe (1951). This chapter provides information on the laboratory equipment and test procedures used in this study on the high ash pulp and papermill sludges.

4.1 Triaxial Equipment

The initial stages of the research program involved very precise measurements of load, axial deformation, and pore pressure so as to minimize experimental error and observe the general sludge behavior under triaxial test conditions. A conventional triaxial cell (part II, Bishop and Henkel, 1962) for a 3 inch high by $1\frac{1}{2}$ inch diameter

sample size was modified to permit electronic measurement of load, axial deformation, and pore pressure. A schematic diagram of the system is shown in Figure 4.1 and pictured in Figures 4.2 and 4.3. The other modification was the installation of a 1000 cc buret to measure the large volume changes during consolidation of the high water content sludges. A Sanborn Linearsyn Differential Transformer (model 585DT-1000, 1 inch stroke) measured axial deformation, a Dynisco load transducer (model FT2-2C, 250 pound capacity) measured the axial load, and a Transducer Inc. pressure transducer (model GP-49F-250, 250 psi capacity) measured the pore water pressure at the sample base. All transducers were linear over the full range of loads, pressures, and displacements and, when calibrated, gave actual values on the recorder with no conversions needed. As the test program proceeded and the general behavior of the pulp and papermill sludges was determined, conventional triaxial equipment (Bishop and Henkel, 1962) was also used, measuring the load, pore pressure, and axial deformation with a proving ring, mercury manometer, and dial gage, respectively. Comparisons of results using this equipment to those determined with the electronic measurements showed excellent agreement, although the amount of work in performing the test was considerably more and some additional experimental error was involved.

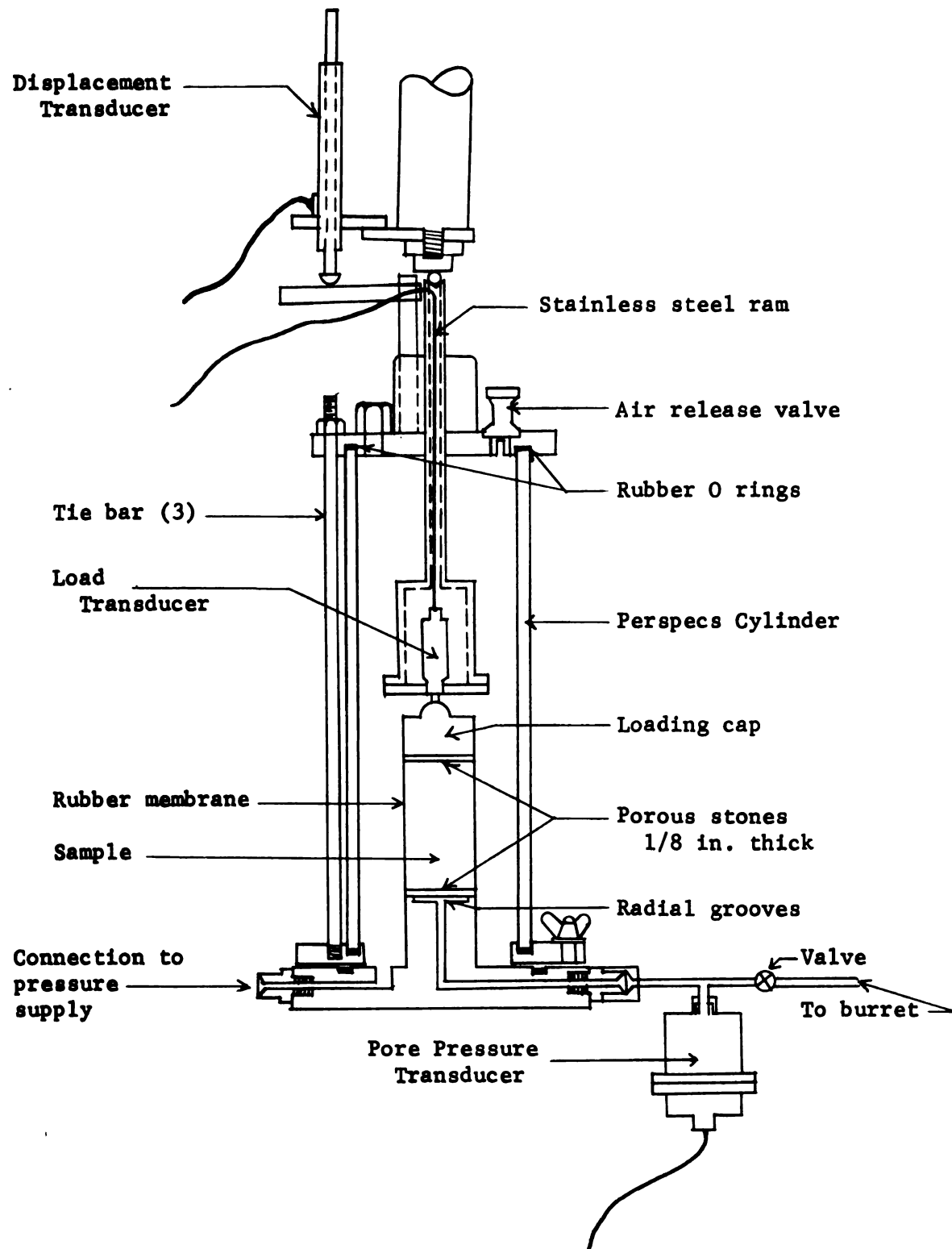


Figure 4.1 Diagrammatic Representation of the Modified Triaxial Cell

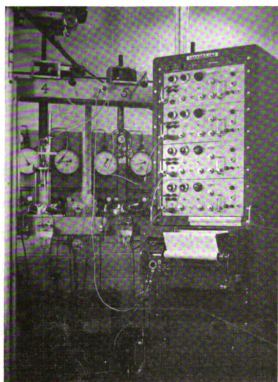


Figure 4.2 Triaxial Equipment and Recorder

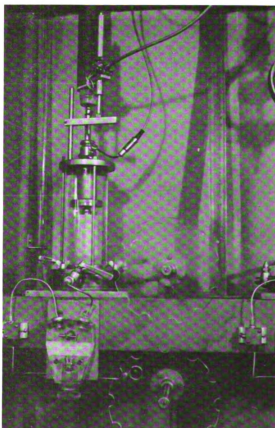


Figure 4.3 Modified Triaxial Cell with Sample

4.2 Triaxial Test Procedure

Sample preparation and test set ups were identical throughout the study and varied only slightly from a standard consolidated-undrained test for soil (Bishop and Henkel, 1962). Specimens were prepared the afternoon before the consolidation phase of the test was to begin. Since cold samples were easier to set up in the triaxial cell, the prepared samples were returned to the refrigerator for a minimum of two hours but never for more than four before setup was attempted. After removal from the refrigerator, side drains consisting of filter paper strips (Bishop and Henkel, 1962) 4 3/4 inches by 3 1/4 inches were wrapped around the sample and also around a porous stone placed at each end of the sample. This method permits both radial and end drainage to occur during consolidation. Next the sample was mounted on the cell pedestal, the loading cap placed on the top, and enclosed with two rubber membranes, Figure 4.4. Finally the cell was filled with water and a small quantity of oil and permitted to stand overnight to bring the sample to room temperature. The oil, floating at the top of the cell served a dual purpose in reducing frictional forces between the ram and the cell and in reducing leakage around the ram due to the greater viscosity of the oil.

The consolidation phase of the test varied in time depending upon the composition of the sample. So that both straight line portions of the volume change versus square

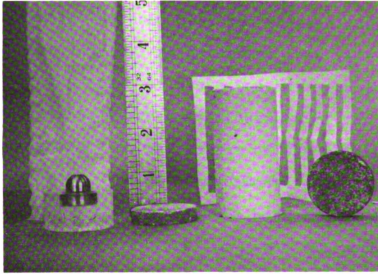


Figure 4.4 Triaxial sample, porous stones, loading cap, paper side drains, and protective membranes

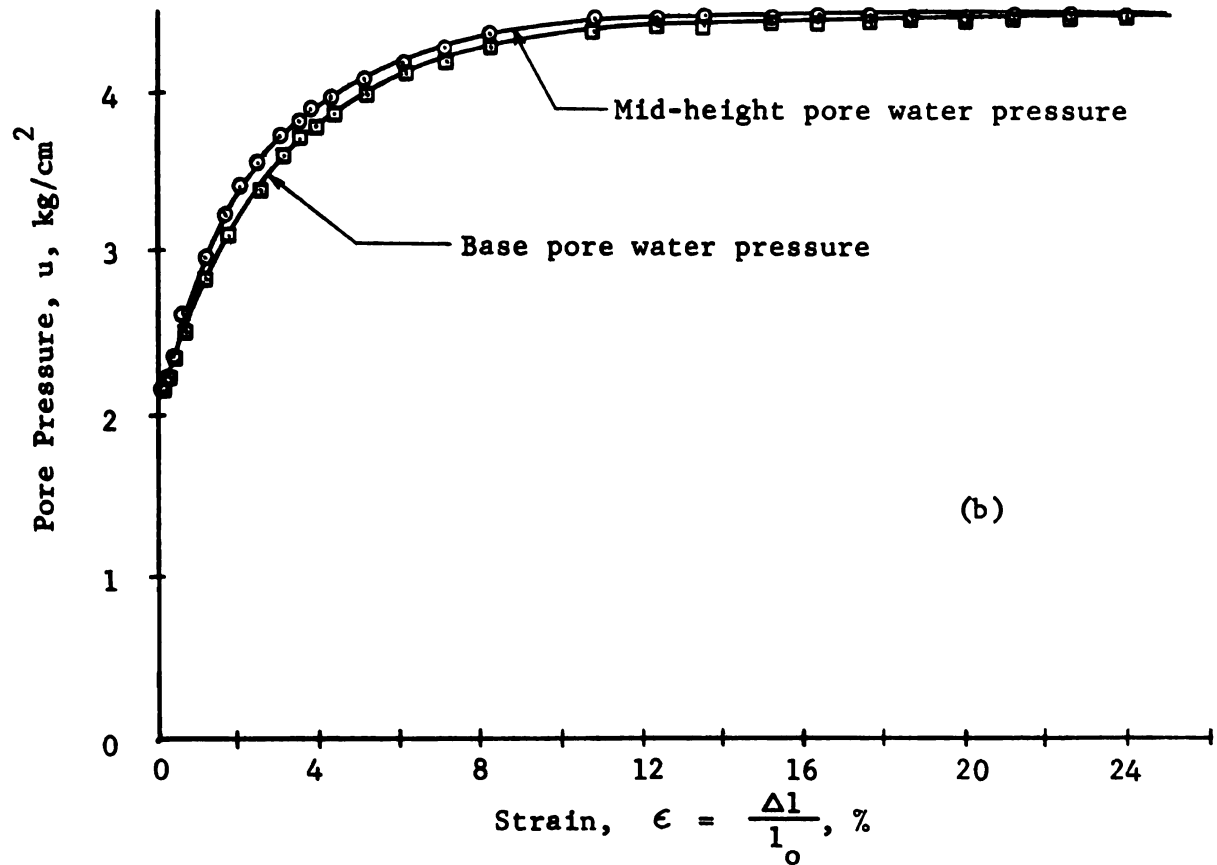
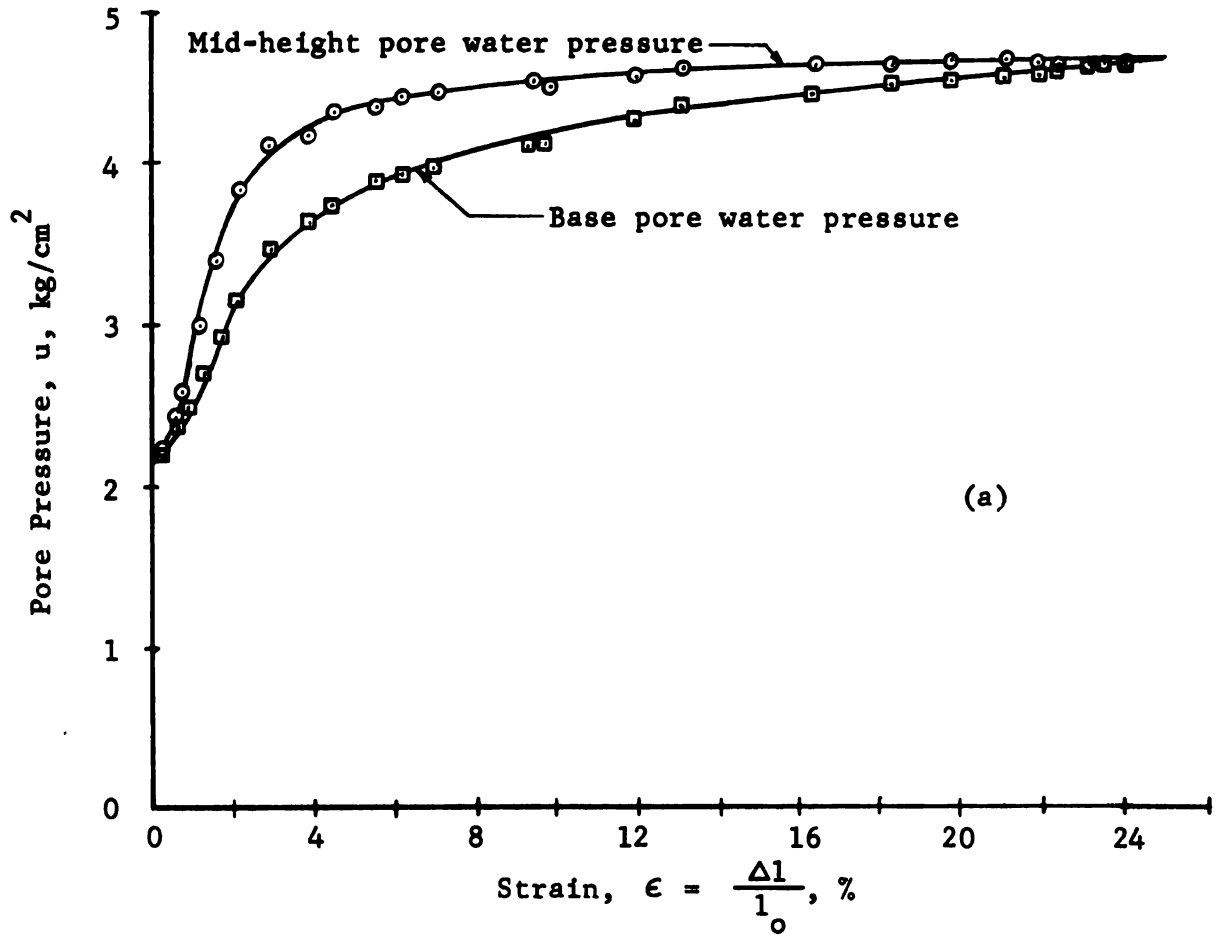
root of time plot could be well established, the consolidation phase was continued as long as 72 hours in some tests. The maximum time for 100 percent consolidation in any test was 266 minutes or approximately $4\frac{1}{2}$ hours. When the consolidation phase was completed, the cell pressure was increased by 20 psi with a 20 psi backpressure. This backpressure served to insure complete saturation and was maintained for 12 hours. After this 12 hour period, the cell pressure was increased an additional 10 psi and the increase in pore pressure recorded in order to determine the pore pressure coefficient B. With the pore pressure stabilized, the sample was then failed under undrained conditions by increasing the axial load. Pore pressure measurements were recorded during this part of the test.

In order to minimize the time required for each test,

samples were deformed at the fastest rate possible while still permitting the pore pressure to equalize itself throughout the sample. To determine this rate of deformation, a special series of tests was run with the pore pressure measured with a probe at midheight of the sample and at the porous stone at the bottom of the sample for several deformation rates. These measurements gave the time lag for equalization of pore pressure between the center of the sample and the ends. Figure 4.5 gives the results for one such series of tests using the strain rates of 0.010, 0.005, and 0.001 inches per minute. This data showed that a strain rate of 0.005 inches per minute satisfactorily allowed for pore pressure distribution and reduced the time lag effects to a position of minor importance. Hence, the time required to fail a sample or reach at least 25 percent strain was approximately $2\frac{1}{2}$ hours.

4.3 Permeability Equipment

The variable head permeameter is best suited for permeability measurements in relatively impervious materials. In order to establish the effects on the permeability of air entrapped in the sludge, a variable head permeameter was modified so that a backpressure could be applied to the sample. This equipment is shown schematically in Figure 4.6 and pictured in Figures 4.7 and 4.8. It consisted of a standard falling head permeameter (Soiltest model K-620) on which the fittings were changed to accept $1/8$ inch inside diameter plastic tubing, pressure rated to 150 psi. This



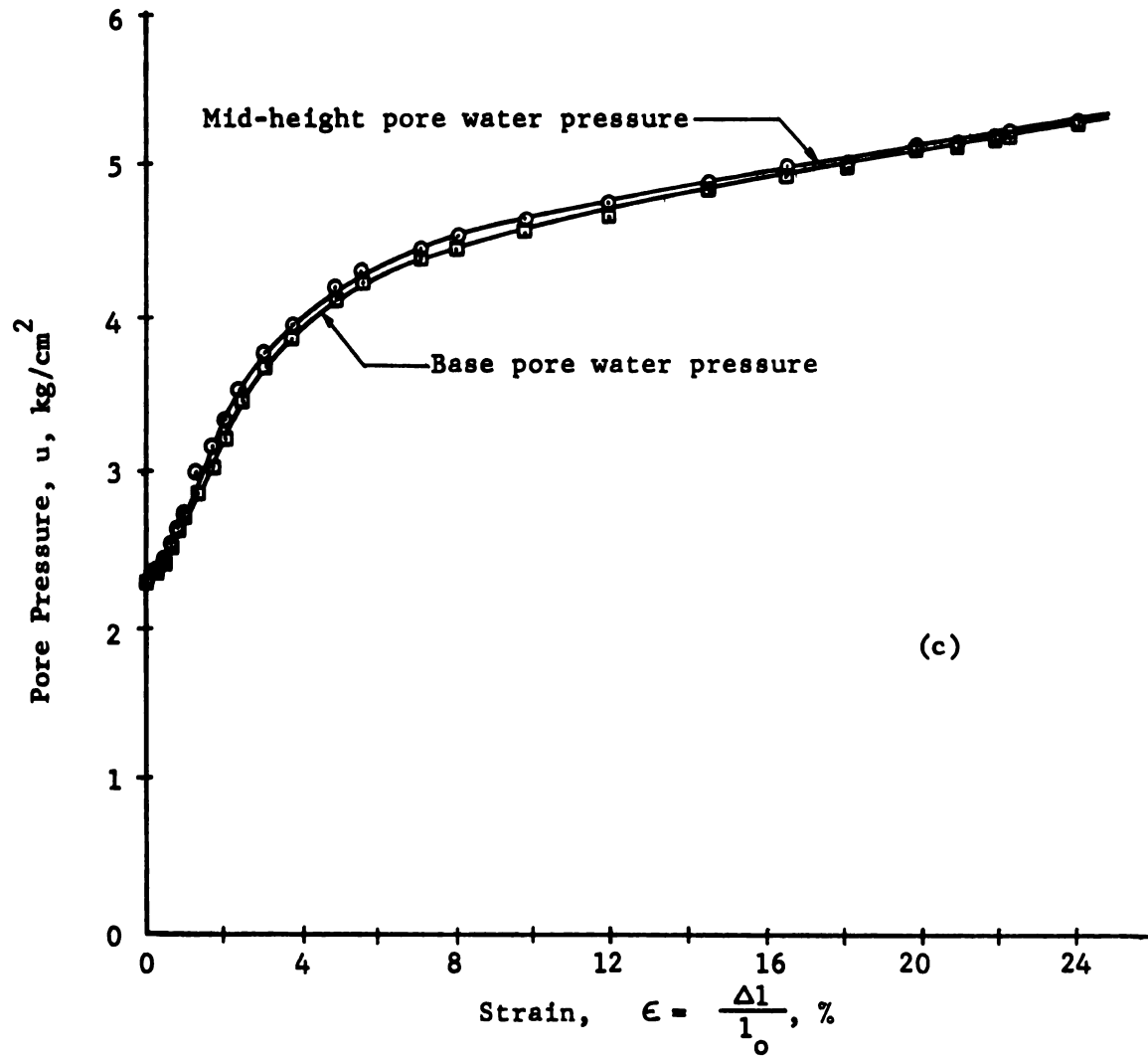


Figure 4.5 Measured Pore Pressures at Mid-height and at the Base of Sludge Sample (a) strain rate of 0.010 in/min (b) strain rate of 0.005 in/min (c) strain rate of 0.001 in/min

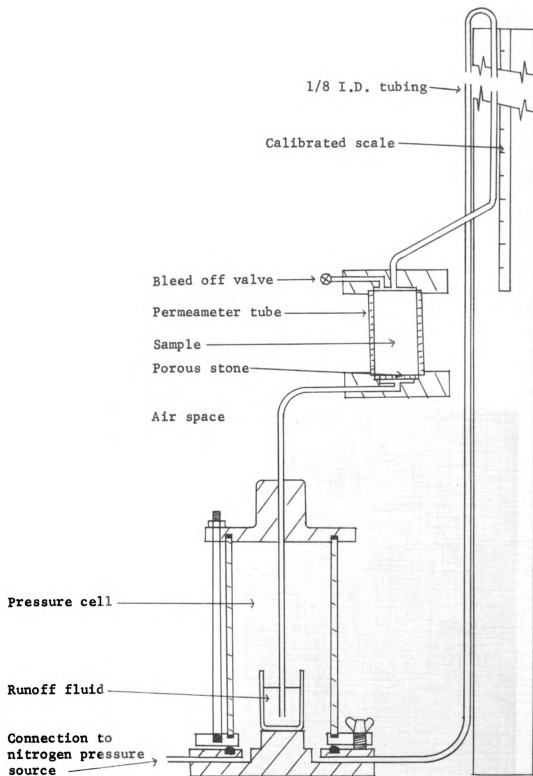


Figure 4.6 Diagrammatic Representation of Permeability Equipment

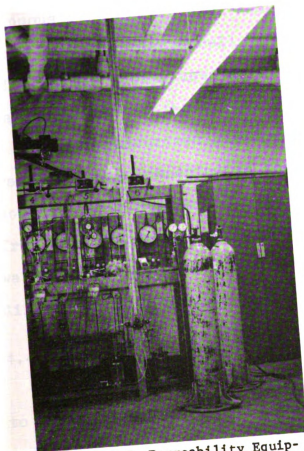


Figure 4.7 Permeability Equipment

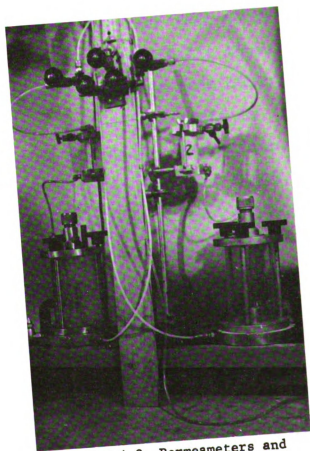


Figure 4.8 Permeameters and Pressure Cells

tubing connected to the top of the permeameter and ran continuously upward 10 feet along a calibrated backing and back down into a pressure cell. To facilitate filling that portion of the tubing used as a standpipe, a larger container was connected to the system by a series of valves. Finally, a tank of pressurized nitrogen equipped with a low pressure regulator was connected to the cell and served as a pressure source. This system was capable of backpressures ranging from 0 to 100 psi or an equivalent head of 231 feet of water. The water in the standpipe provided for the pressure difference or hydraulic gradient for the test.

4.4 Permeability Test Procedures

Identical procedures were followed for each test so as to minimize any difference in the results, especially those due to temperature variations. Liquid extracted from other portions of the same sludge was used as the flow media in an attempt to minimize any change in the sludge composition. The base of the permeameter was first filled with the fluid to the top of the porous stone and the bottom clamped shut. Next, the sample was put in place and the permeameter reassembled. The fluid was then permitted to flow down on the sample and force the air out through the top valve. With the air removed and the bottom tube clamped, 10 cm of liquid was forced into the upper tube. The sample was then allowed to set two hours to bring it to room temperature. With the sample at room temperature, the standpipe was filled to a point 10 cm above the desired water head and the

bottom tube opened. Time zero was taken at the point where the 10 cm overfill had passed through the sample. Flow was then continued until the final head in the standpipe was reached.

In those tests where a backpressure was required, the desired pressure was placed on the sample when the upper tube was filled to the initial 10 cm mark. This pressure was then held constant for the entire test with the exception of that period when the standpipe was filled. For this short period it was necessary to release the pressure. Application of the backpressure caused a small expansion in the standpipe resulting in a change in cross sectional area. Hence, a calibration curve for tube diameter versus pressure was needed and is given in Appendix D.

4.5 Water Retention Procedures

Preparation of the four samples for determination of their water retention characteristics was identical and done in a manner that comparisons between specimens could be made. Distilled, deionized water was mixed with the sludge to form a fluid mixture. This mixture was then placed in a metal ring 7.62 cm in diameter and 4.65 cm high. The ring had one end covered with four layers of gauze and was resting on a metal screen (openings 0.25 x 0.25 in). The mixture inside the ring was free to drain and as water moved out and the material settled, more was added. The water content at which the ring was filled and no water was draining out was taken as the initial state with zero

tension. The samples were next subjected to different tensions by means of either a water tension table or a pressure container system (Agronomy No. 9). Each pressure was maintained for 24 hours after which time the change in air volume was determined by means of a volumetric gas equalization system (Agronomy No. 9).

CHAPTER V

EXPERIMENTAL RESULTS

The experimental results of the test program are presented in two sections. The first section covers the triaxial phase of the project and includes information on the shear strength of the three natural sludges, sludge H-2 with different organic contents, and sludges H-2 and C-1 with 10 percent lime or flyash. The results are summarized by typical stress-strain curves, $\bar{p}$ - q plots giving the cohesion and angle of internal friction, and the relationships of the water content and undrained shear strength to consolidation pressure. The second section covers the permeability tests on the natural sludges H-2 and C-1, sludge H-2 with different organic contents, and sludges H-2 and C-1 with the addition of 10 percent lime or flyash. The results are presented in terms of permeability versus the average head (backpressure plus hydraulic head).

5.1 Triaxial Tests

Consolidated-undrained triaxial tests with pore pressure measurements were used for evaluation of the shear strength parameters. Initially, only the single triaxial cell equipped to measure the axial load, axial displacement,

and pore water pressure with electronic sensors was used. This instrumentation permitted measurements to 0.01 pound, 0.0001 inch, and 0.01 psi, respectively. As the general behavior of the sludge materials was established, conventional triaxial equipment was also used (Chapter IV). A minimum of three triaxial tests and usually more were used to establish the failure line. Test results are presented in terms of the k_f failure line from which the cohesion $\bar{c}$ and the angle of internal friction $\bar{\phi}$ are computed. Water content and unconfined compressive strength are plotted against the consolidation pressure for each test series.

5.1.1 Shear Strength for Natural Sludges

For the purpose of this study, natural sludges are defined as those sludges at the same organic content as when sampled at the mill and with no addition of lime or flyash. The physical properties of the three natural sludges, C-1, H-1, and H-2, are given in Table 3.2. Stress-strain curves were similar for the three. Several typical curves, in terms of axial strain versus stress difference ($\bar{\sigma}_1 - \bar{\sigma}_3$) are shown in Figure 5.1. Since a peak stress difference was not reached, failure was taken equal to 20 percent axial strain. A summary of the individual test results is given in Table 5.1. Complete test data is included in Appendix A.

The Mohr failure envelope and the k_f line are given in Figures 5.2(a), 5.3(a), and 5.4(a) for the three natural sludges. Trigonometric transformations for the two methods

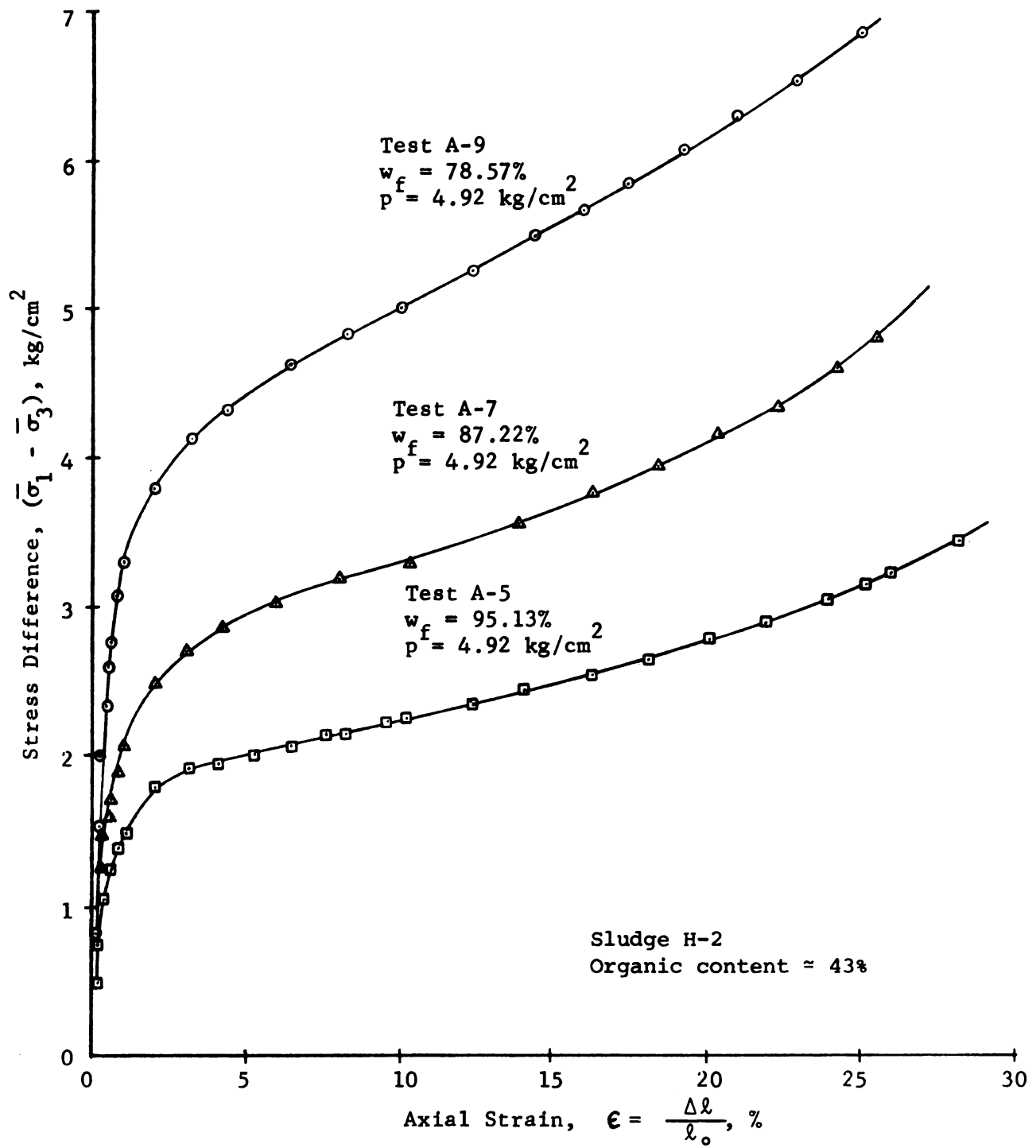


Figure 5.1 Typical Stress-strain Curves for Sludge H-2, 43% organic matter

Table 5.1 Summary of Triaxial Test Results on the Natural Sludges

Sludge	Test No.	Consolidation Pressure kg/cm ²	Water Content %	Undrained Strength kg/cm ²	$\bar{\sigma}_{1f}$ kg/cm ²	$\bar{\sigma}_{3f}$ kg/cm ²	A_f
H-1	A-1	0.70	71.38	1.05	2.34	0.24	0.33
	A-2	1.40	67.62	2.04	4.35	0.26	0.27
	A-3	2.11	59.51	2.34	5.06	0.39	0.35
H-2	A-4	0.70	111.69	0.83	1.74	0.08	0.37
	A-5	1.41	95.13	1.38	2.97	0.20	0.43
	A-6	2.11	85.87	1.82	3.92	0.28	0.50
	A-7	2.11	87.22	2.05	4.45	0.36	0.43
	A-8	2.81	80.40	2.60	5.62	0.42	0.46
	A-9	3.51	78.57	3.07	6.53	0.40	0.39
	A-10	4.92	67.88	5.14	11.19	0.90	0.39
C-1	A-11	1.50	104.59	1.71	3.54	0.12	0.30
	A-12	2.50	99.44	2.31	4.53	-0.10	0.25
	A-13	3.00	97.71	3.18	6.66	0.30	0.34
	A-14	3.50	95.13	4.01	8.43	0.41	0.34
	A-15	4.00	89.47	3.23	6.74	0.28	0.56
	A-16	4.92	94.39	3.85	7.82	0.13	0.62

Failure is represented by 20 percent axial strain

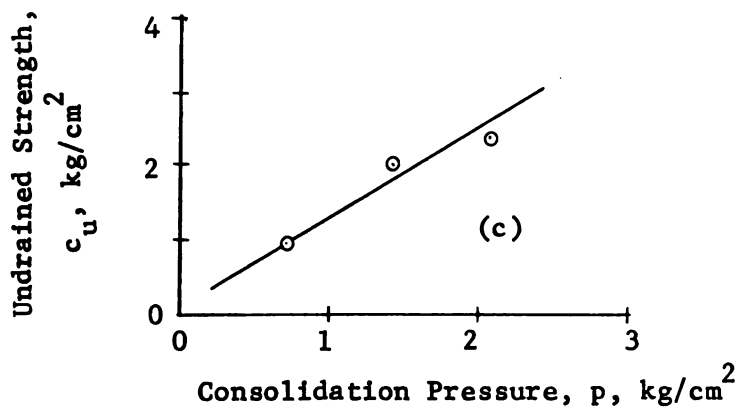
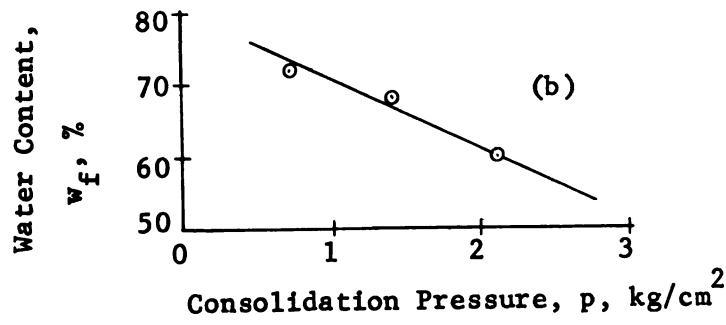
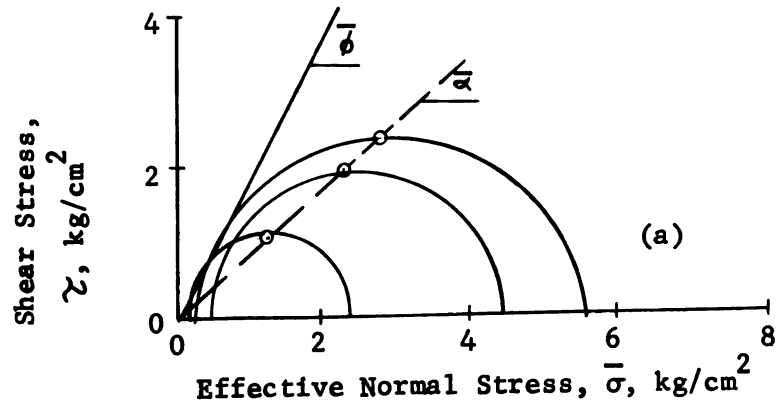


Figure 5.2 Consolidated-undrained Test Results for Sludge H-1
 a) Mohr envelope and k_f rupture line b) Water content
 c) Undrained strength

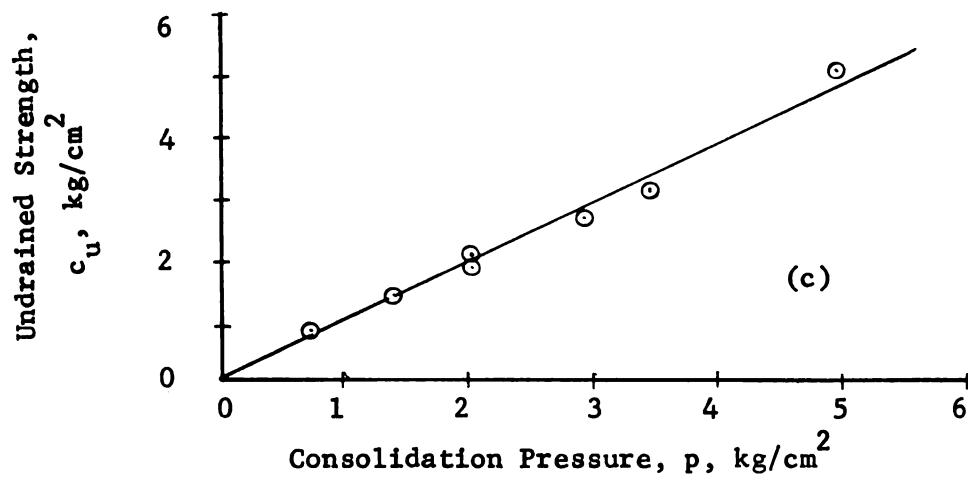
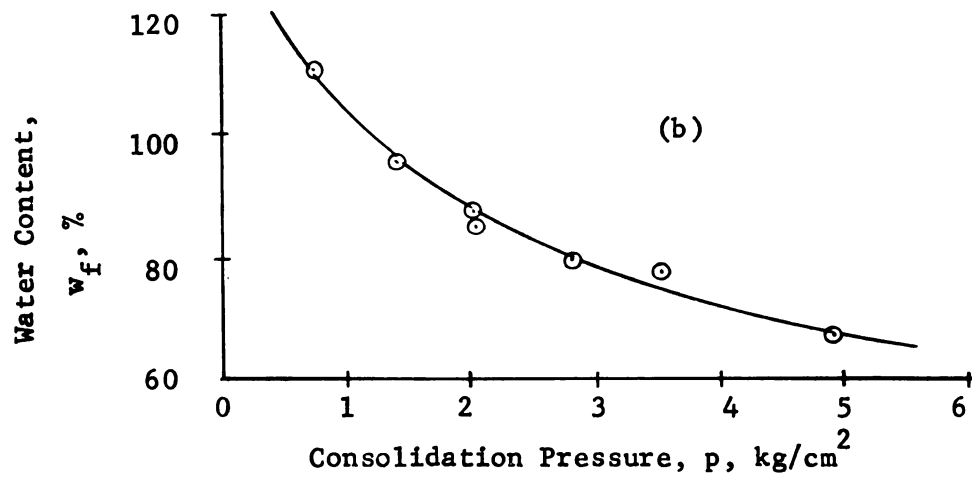
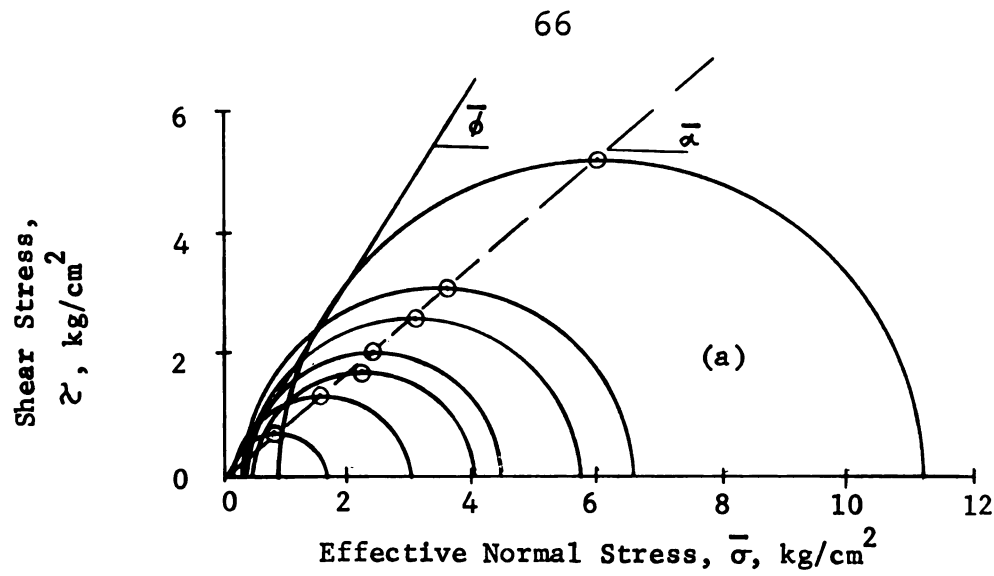


Figure 5.3 Consolidated-undrained Test Results for Sludge H-2, 43% organic matter a) Mohr envelope and k_f rupture line b) Water content c) Undrained strength

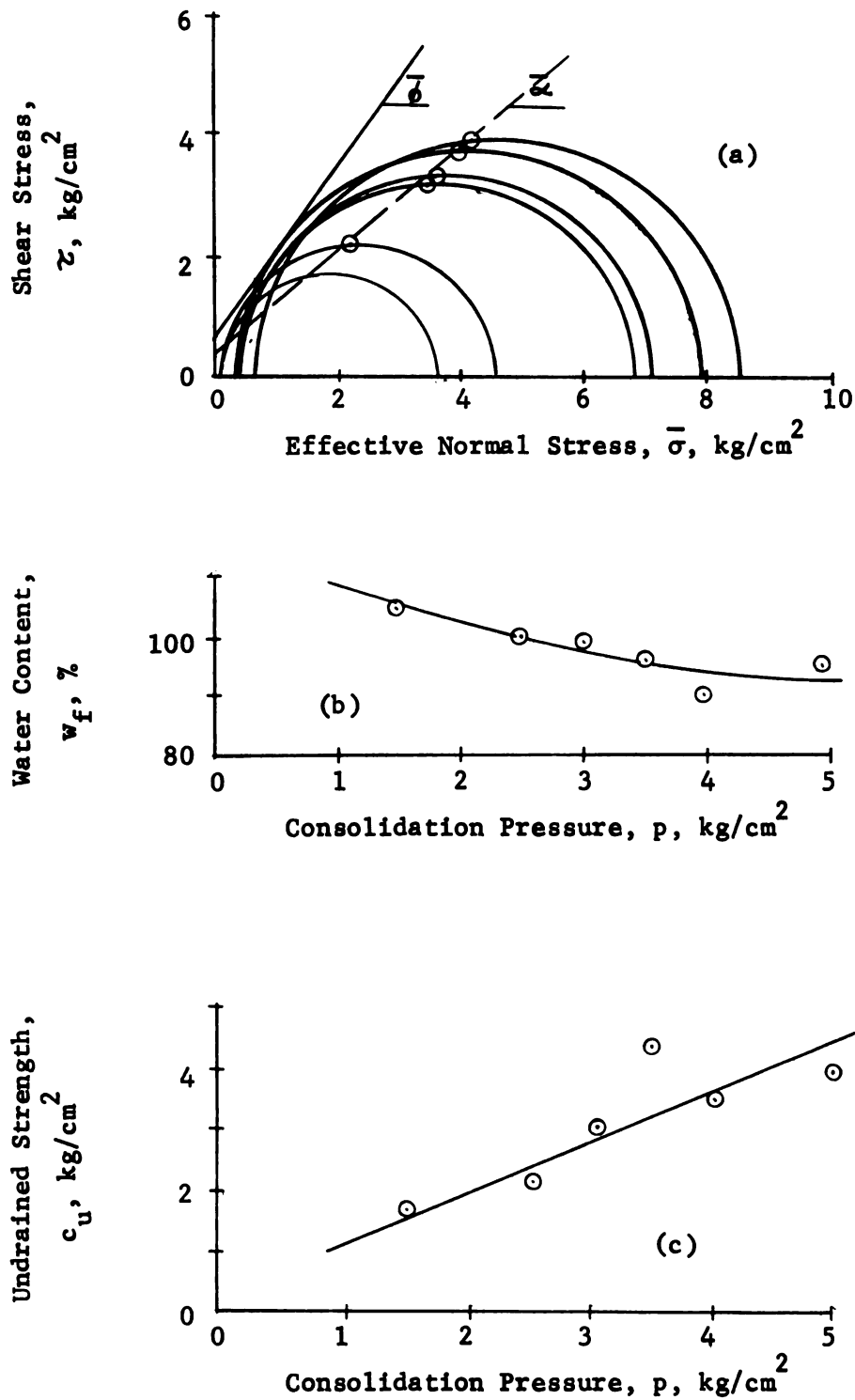


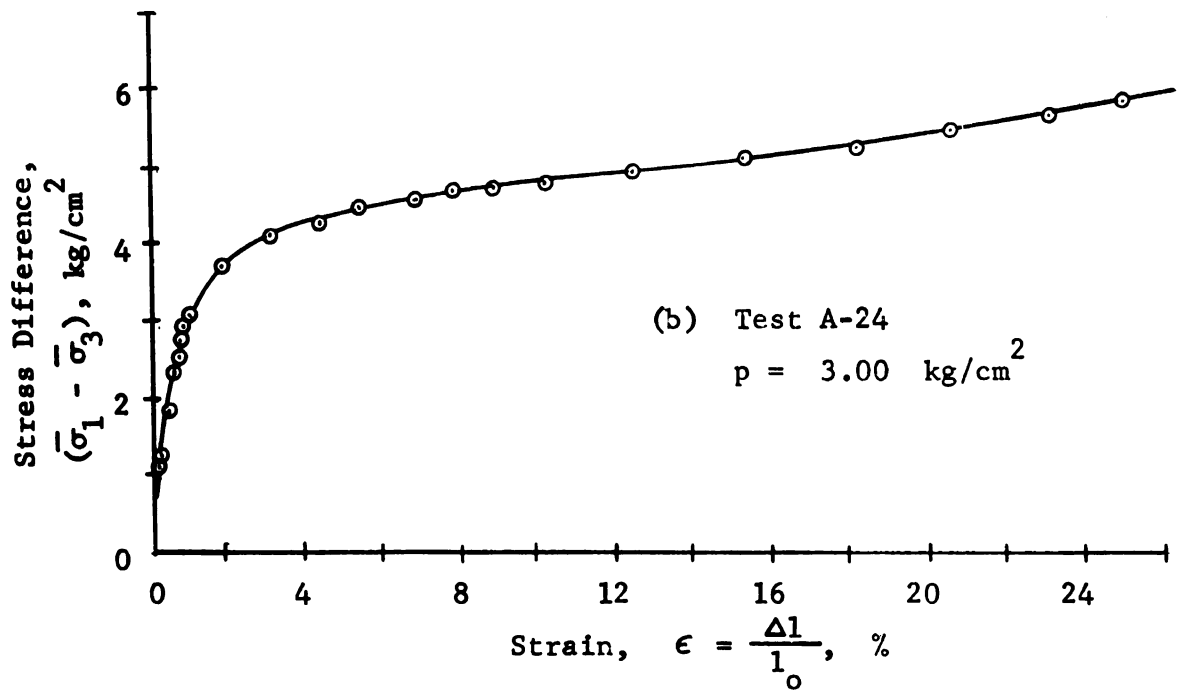
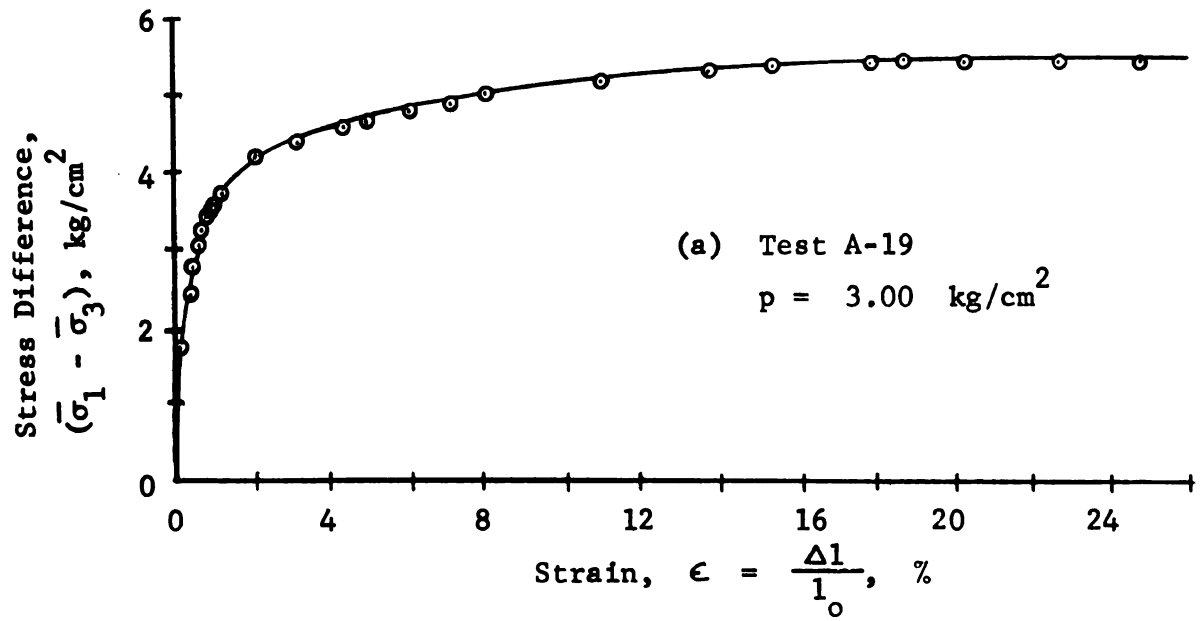
Figure 5.4 Consolidated-undrained Test Results for Sludge C-1 a) Mohr envelope and k_f rupture line b) Water content c) Undrained strength

of presentation are given in Figure 2.10. Since the k_f failure line can be more accurately determined, the Mohr envelope is omitted in subsequent figures. The water content and undrained strength versus consolidation pressure are also given in Figures 5.2, 5.3, and 5.4.

5.1.2 Shear Strength for Different Organic Contents

The organic content of sludge H-2 was altered by washing the material through a U. S. Standard No. 16 sieve to separate the organic fiber and inorganic material. These fractions were recombined to provide samples with four different organic contents. The physical properties of these samples are given in Table 3.2. Typical stress-strain curves are given in Figure 5.5 for the four different organic contents. A peak strength value was not reached when plotting the stress difference or principal stress ratio against axial strain, hence, failure was again defined at 20 percent axial strain. A summary of the tri-axial test results for the different organic contents is given in Table 5.2 with complete data given in Appendix A.

The shear strength in terms of the k_f line is shown in Figures 5.6(a), 5.7(a), 5.8(a), and 5.9(a). Figure 5.8 represents the natural sludge H-2. These plots clearly show that the angle of internal friction increases with an increase in organic content. Plots of water content and undrained compressive strength versus consolidation pressure are also included in Figures 5.6, 5.7, 5.8, and 5.9.



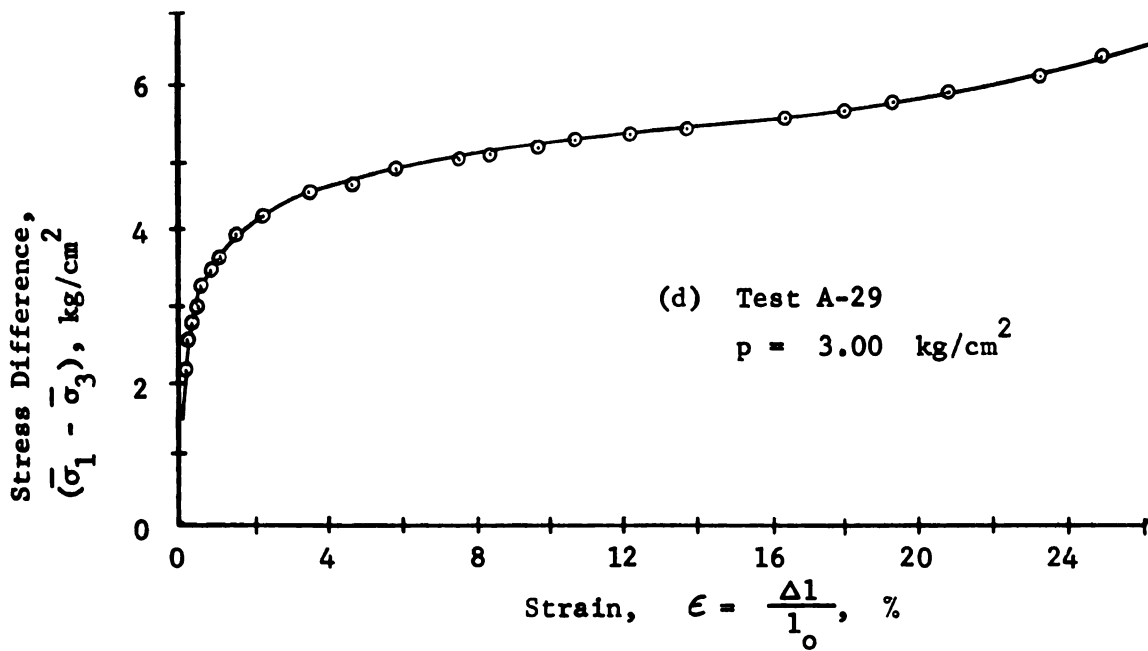
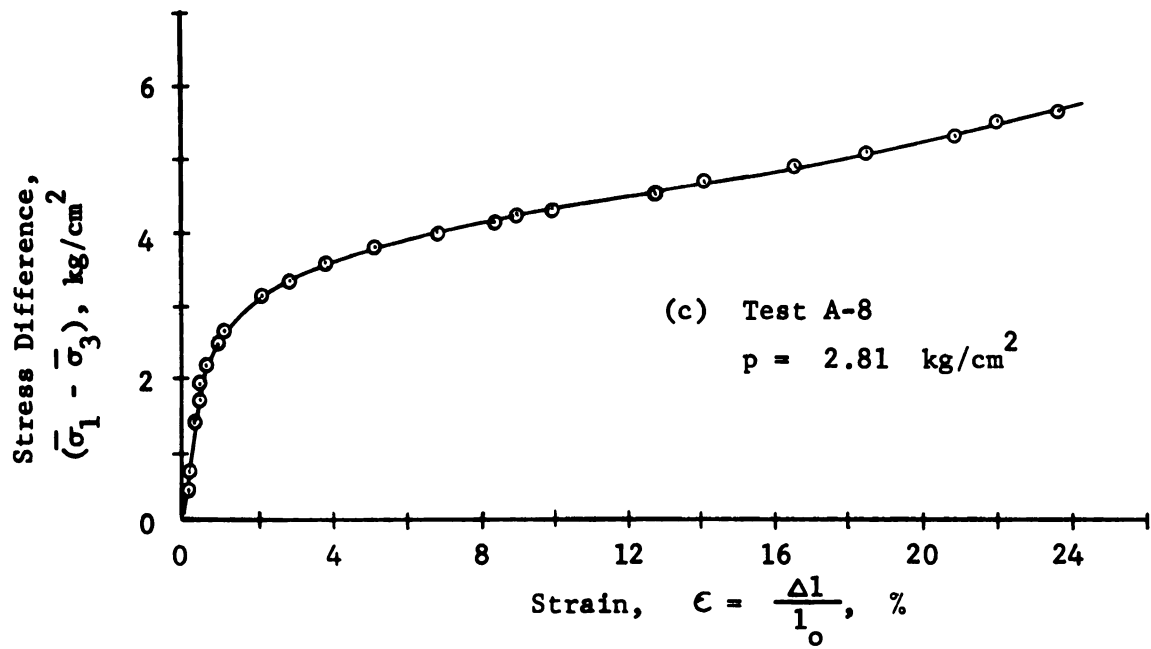


Figure 5.5 Typical Stress-strain Curves for Sludge H-2 (a) 28% organic matter (b) 35% organic matter (c) 43% organic matter (d) 50% organic matter

Table 5.2 Summary of Triaxial Test Results on Sludge H-2 with Different Organic Contents

Sludge ¹	Test No.	Consolidation Pressure kg/cm ²	Water Content %	Undrained Strength kg/cm ²	σ_{1f}^2 kg/cm ²	σ_{3f}^2 kg/cm ²	A _f
H-2, 28%	A-17	1.00	66.96	1.52	3.36	0.32	0.22
	A-18	2.00	63.60	2.08	4.69	0.52	0.29
	A-19	3.00	62.51	2.72	6.04	0.61	0.42
	A-20	4.00	58.25	2.92	6.91	1.06	0.49
	A-21	4.92	55.94	4.03	10.24	2.19	0.34
H-2, 35%	A-22	1.00	81.81	1.46	3.01	0.09	0.28
	A-23	2.00	72.65	3.81	4.30	0.29	0.42
	A-24	3.00	68.25	2.73	5.86	0.41	0.46
	A-25	4.00	65.62	3.01	6.71	0.69	0.50
	A-26	4.92	61.32	4.28	9.48	0.91	0.46
H-2, 43%	A-4	0.70	111.69	0.83	1.74	0.08	0.37
	A-5	1.41	95.13	1.38	2.97	0.20	0.43
	A-6	2.11	85.87	1.82	3.92	0.28	0.50
	A-7	2.11	87.22	2.05	4.45	0.36	0.43
	A-8	2.81	80.40	2.60	5.62	0.42	0.46
H-2, 50%	A-9	3.51	78.57	3.07	6.53	0.40	0.39
	A-10	4.92	67.88	5.14	11.19	0.90	0.39
	A-27	1.00	109.35	1.08	2.18	0.01	0.46
	A-28	2.00	101.12	1.92	3.97	0.13	0.44
	A-29	3.00	90.09	2.91	6.07	0.24	0.48
H-2, 50%	A-30	4.00	79.90	3.30	7.05	0.46	0.54
	A-31	4.92	74.90	4.57	9.52	0.38	0.49

¹Percentage figure represents the approximate amount of organic matter, see Table 3.2.
Failure is represented by 20 percent axial strain

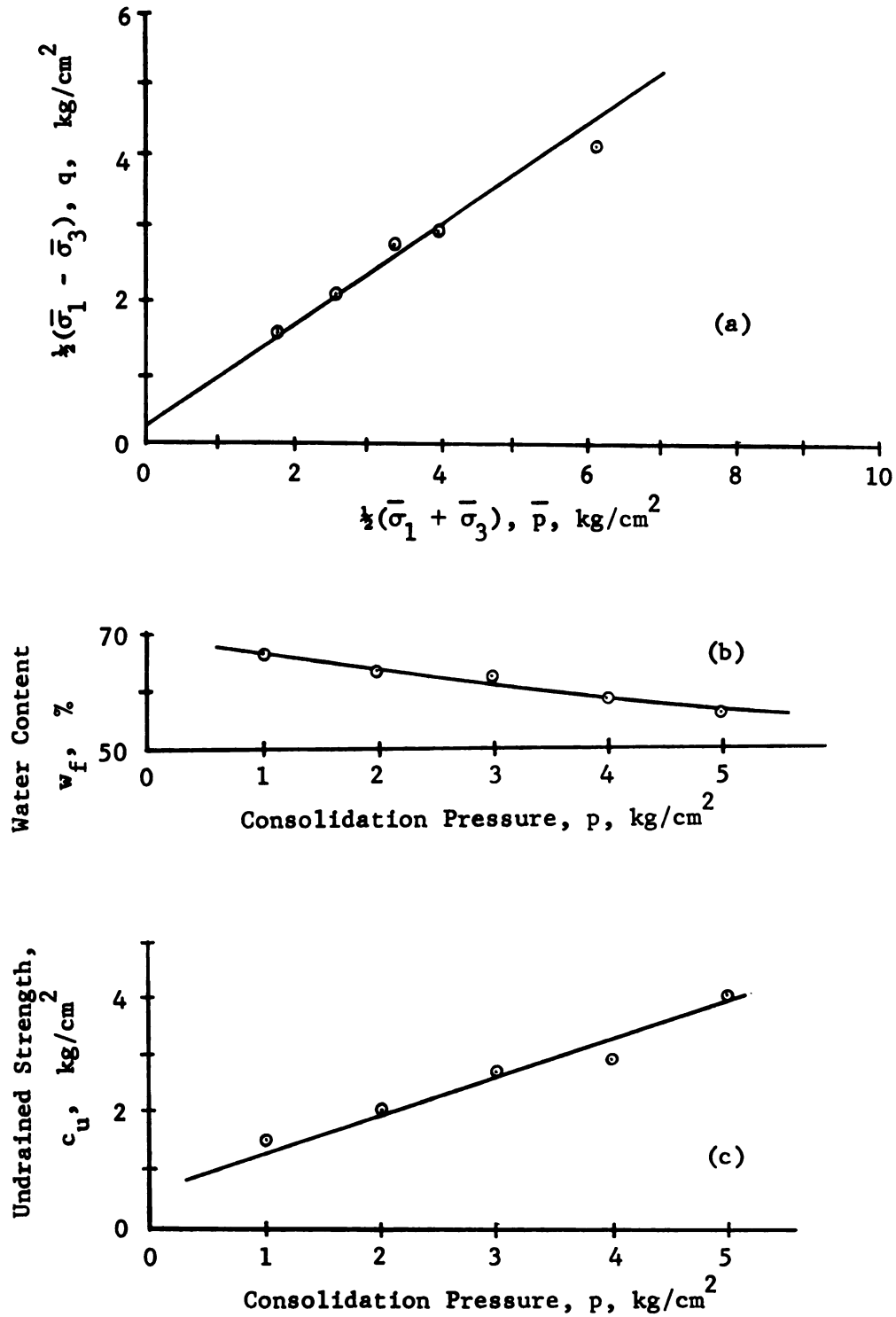


Figure 5.6 Consolidated-undrained Test Results for Sludge H-2, 28% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

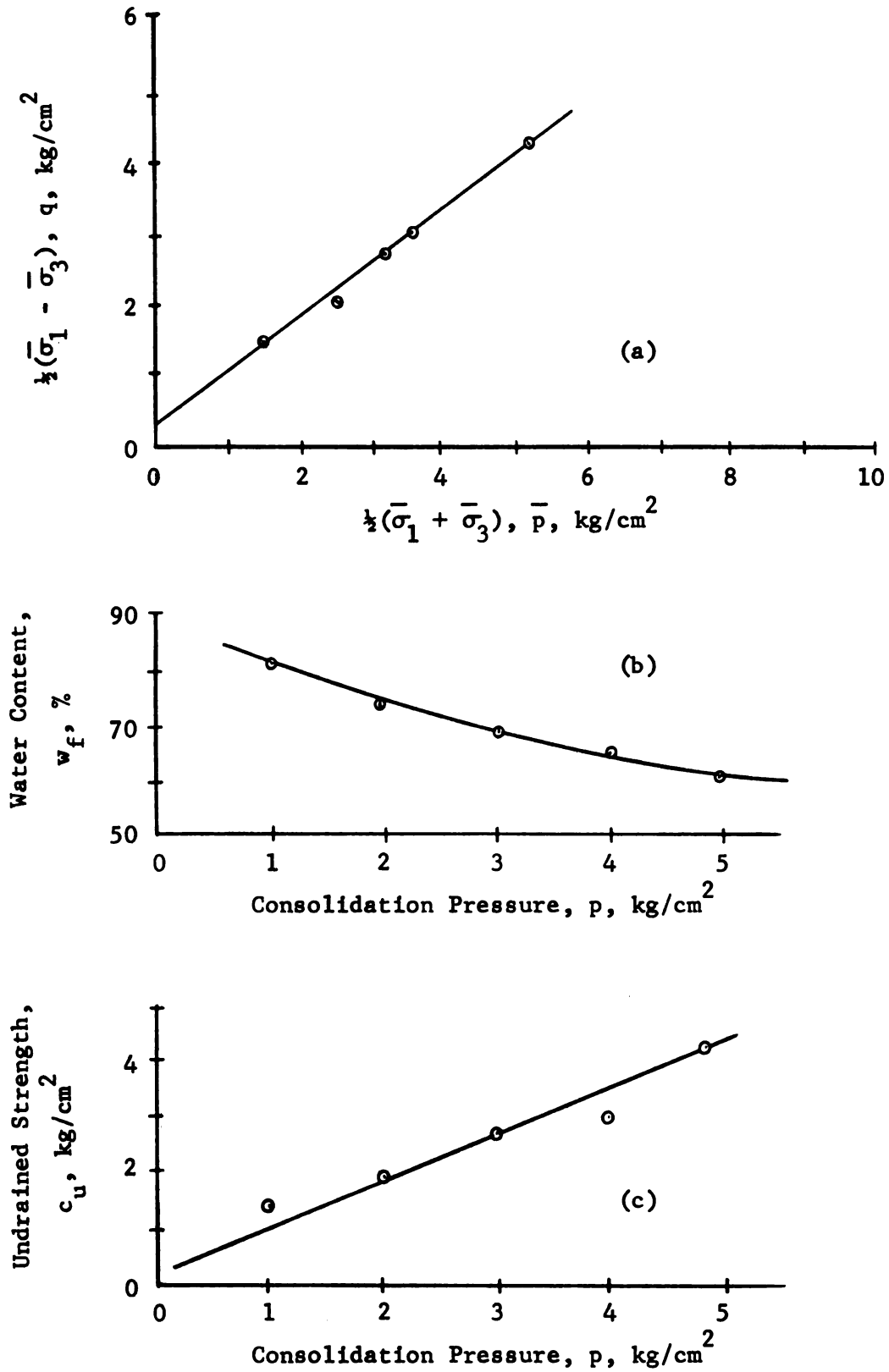


Figure 5.7 Consolidated-undrained Test Results for Sludge H-2, 35% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

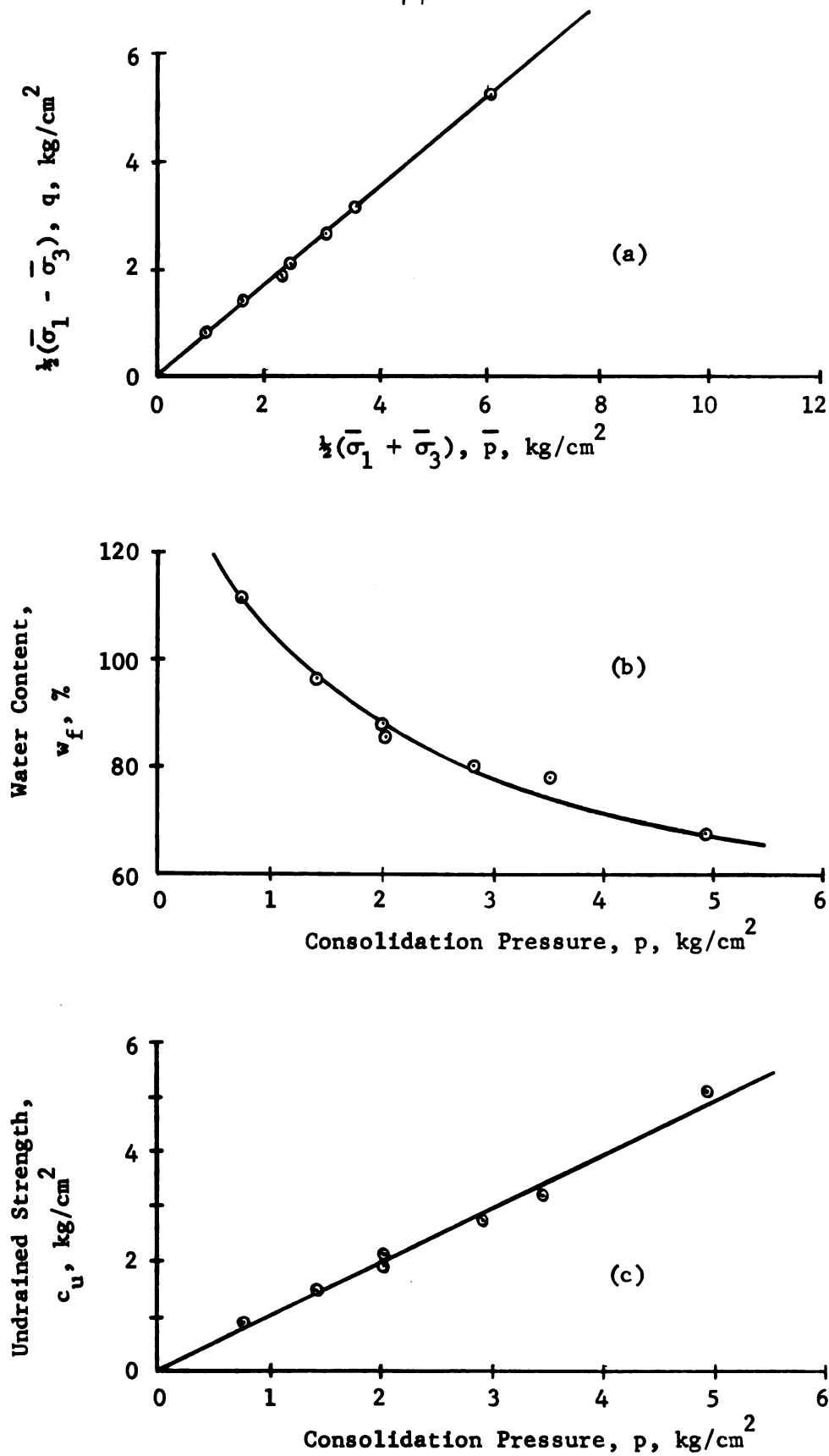


Figure 5.8 Consolidated-undrained Test Results for Sludge H-2, 43% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

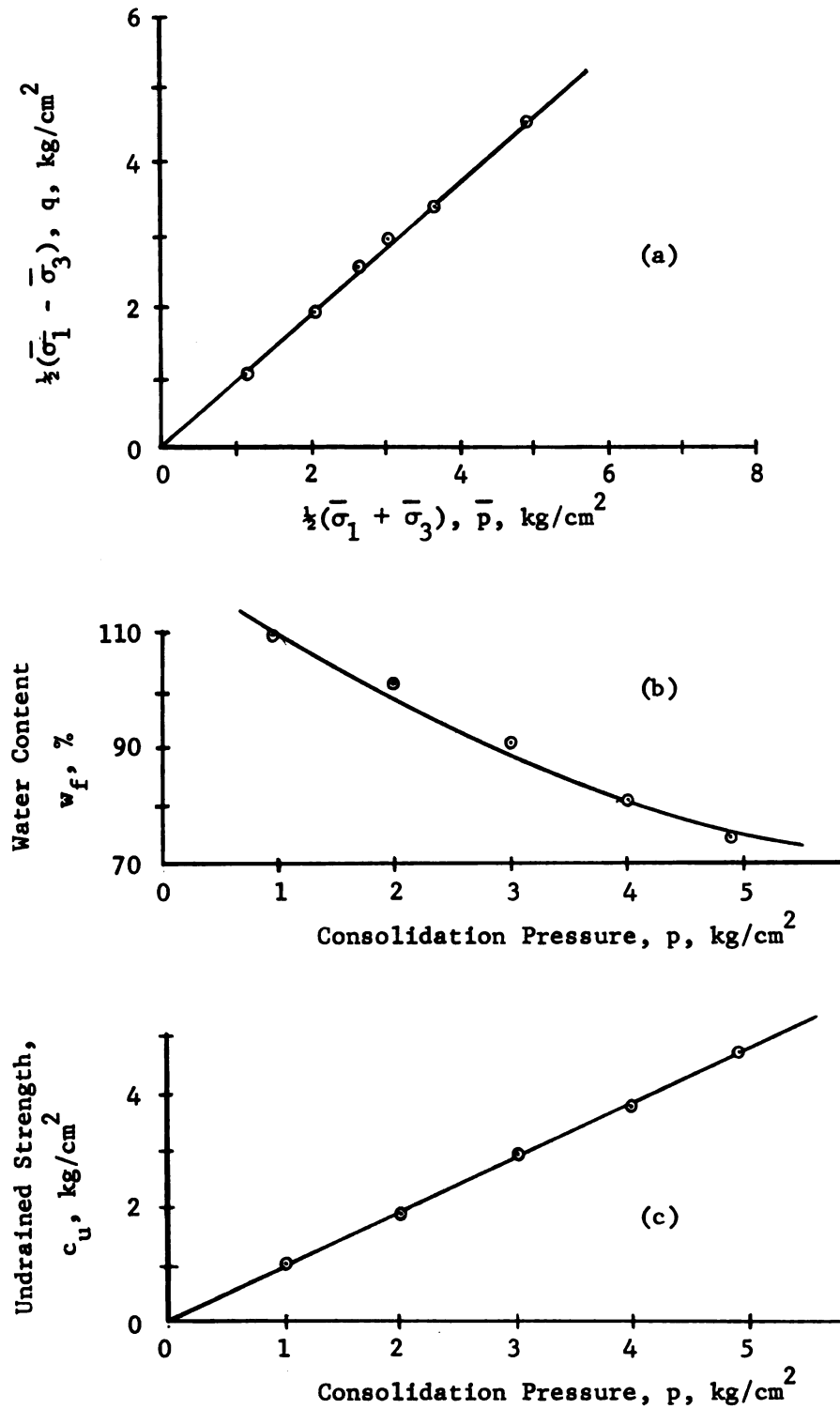


Figure 5.9 Consolidated-undrained Test Results for Sludge H-2, 50% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

5.1.3 Shear Strength With Additions of Lime or Flyash

Ten percent additions of lime or flyash were combined with sludges H-2 and C-1 for the purpose of determining if any beneficial effects result on the shear strength and permeability. The physical properties of the sludge-admixture combinations are given in Table 3.2. A 10 percent addition of lime by dry weight represents a value slightly greater than what would normally be added at the mill for increasing sludge dewaterability. It would, however, give a good indication of whether or not the lime was having a significant effect on the sludge behavior and if further investigations in this area were warranted. This series of tests also included the evaluation of the lime addition to sludge H-2 modified to 28 percent organic matter. A summary of the triaxial tests on the sludges with lime or flyash added are given in Table 5.3 and 5.4, respectively. Information on the shear strength in terms of the k_f line, water content, and undrained compressive strength is given in Figures 5.10 thru 5.14. Complete test data is given in Appendix A. A summary of values for the cohesion $\bar{c}$ and the angle of internal friction $\bar{\phi}$ for all the samples studied is given in Table 5.5.

5.2 Permeability Tests

The permeability of pulp and papermill sludges is of importance in the engineering problems of seepage, settlement, stability, and drainage. Analytical treatment of these problems requires a relationship between the hydraulic

Table 5.3 Summary of Triaxial Test Results on Sludges with Lime Added

Sludge ¹	Test No.	Consolidation Pressure kg/cm ²	Water Content %	Undrained Strength kg/cm ²	$\bar{\sigma}_{1f}$ kg/cm ²	$\bar{\sigma}_{3f}$ kg/cm ²	A_f
H-2, 43%	A-32	0.70	111.80	1.16	2.35	0.03	0.26
	A-33	1.50	102.04	1.61	3.30	0.08	0.27
	A-34	2.00	92.51	2.22	4.57	0.12	0.41
	A-35	2.90	89.21	3.79	7.96	0.38	0.31
	A-36	3.50	77.45	4.27	9.14	0.61	0.45
	A-37	4.92	79.67	4.74	10.24	0.75	0.44
H-2, 28%	A-38	1.00	97.23	1.35	2.98	0.27	0.21
	A-39	2.00	87.23	1.89	4.24	0.46	0.41
	A-40	3.00	81.07	2.59	5.70	0.52	0.48
	A-41	4.00	77.75	2.95	6.78	0.87	0.54
C-1	A-42	1.00	113.79	1.78	3.57	0.00	0.16
	A-43	2.00	102.12	2.59	5.45	0.27	0.35
	A-44	3.00	94.46	3.89	7.94	0.16	0.40
	A-45	4.00	89.78	3.13	6.77	0.51	0.57
	A-46	5.00	81.09	3.37	7.22	0.47	0.65

¹ Percentage figure represents the approximate amount of organic matter, see Table 3.2.

Failure is represented by 20 percent axial strain

Table 5.4 Summary of Triaxial Test Results on Sludges with Flyash Added

Sludge	Test No.	Consolidation Pressure kg/cm ²	Water Content %	Undrained Strength kg/cm ²	$\bar{\sigma}_{1f}$ kg/cm ²	$\bar{\sigma}_{3f}$ kg/cm ²	A_f
H-2	A-47	1.00	90.21	1.21	2.48	0.06	0.36
	A-48	2.00	78.20	2.16	4.48	0.17	0.42
	A-49	3.00	72.13	2.93	6.25	0.39	0.46
	A-50	4.00	67.62	3.14	6.74	0.47	0.54
	A-51	4.92	62.81	3.96	8.64	0.71	0.53
C-1	A-52	1.00	105.38	1.36	2.80	0.08	0.31
	A-53	2.00	92.40	3.92	8.03	0.19	0.22
	A-54	2.50	86.57	3.44	7.46	0.58	0.29
	A-55	3.00	81.84	3.34	6.98	0.31	0.41
	A-56	3.50	75.70	3.28	6.33	-0.24	0.57
	A-57	4.00	70.14	3.17	6.76	0.41	0.55
	A-58	5.00	62.25	3.13	6.70	0.44	0.71

Failure is represented by 20 percent axial strain

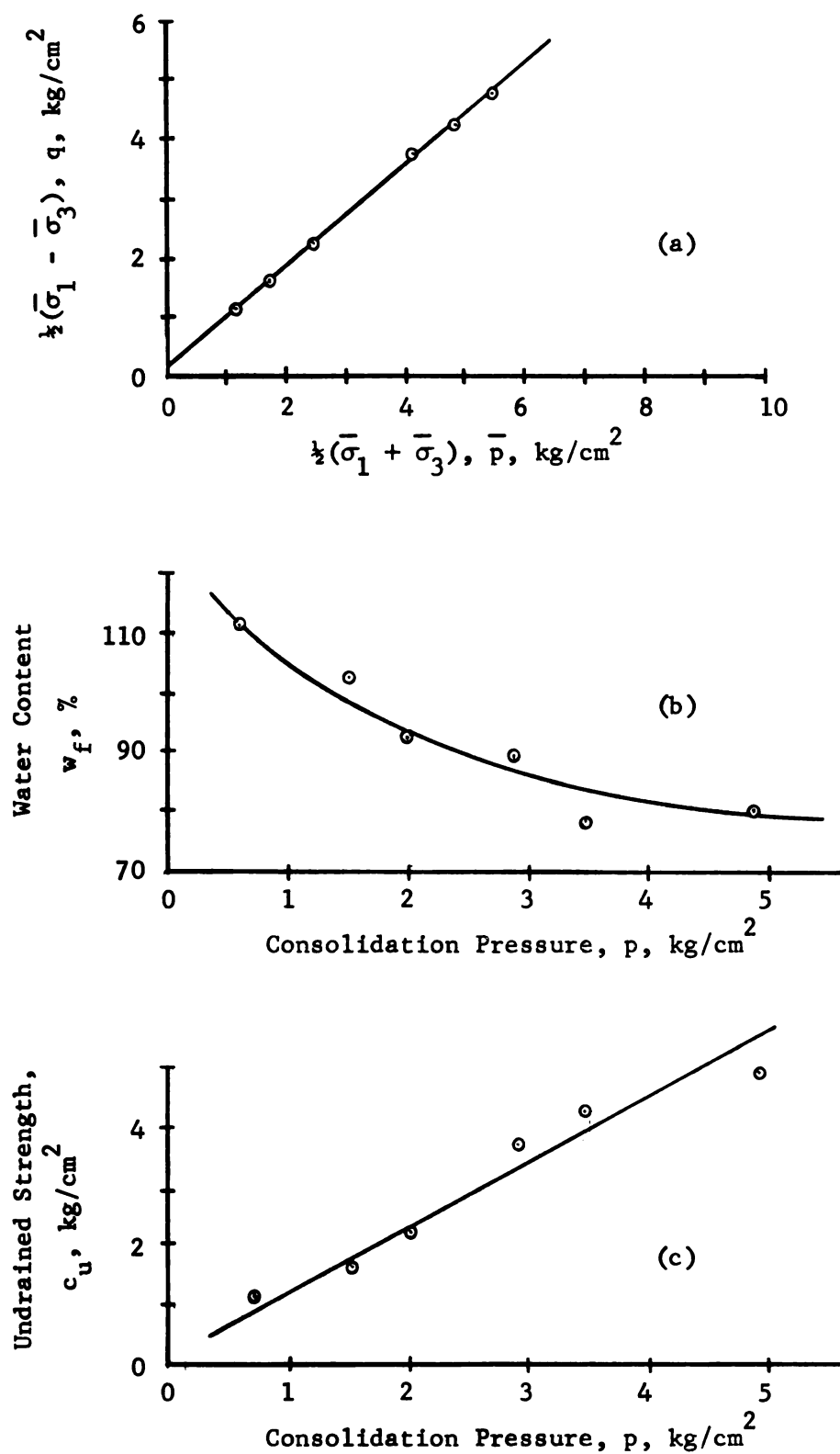


Figure 5.10 Consolidated-undrained Test Results for Sludge H-2 with 10% Lime Added, 43% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

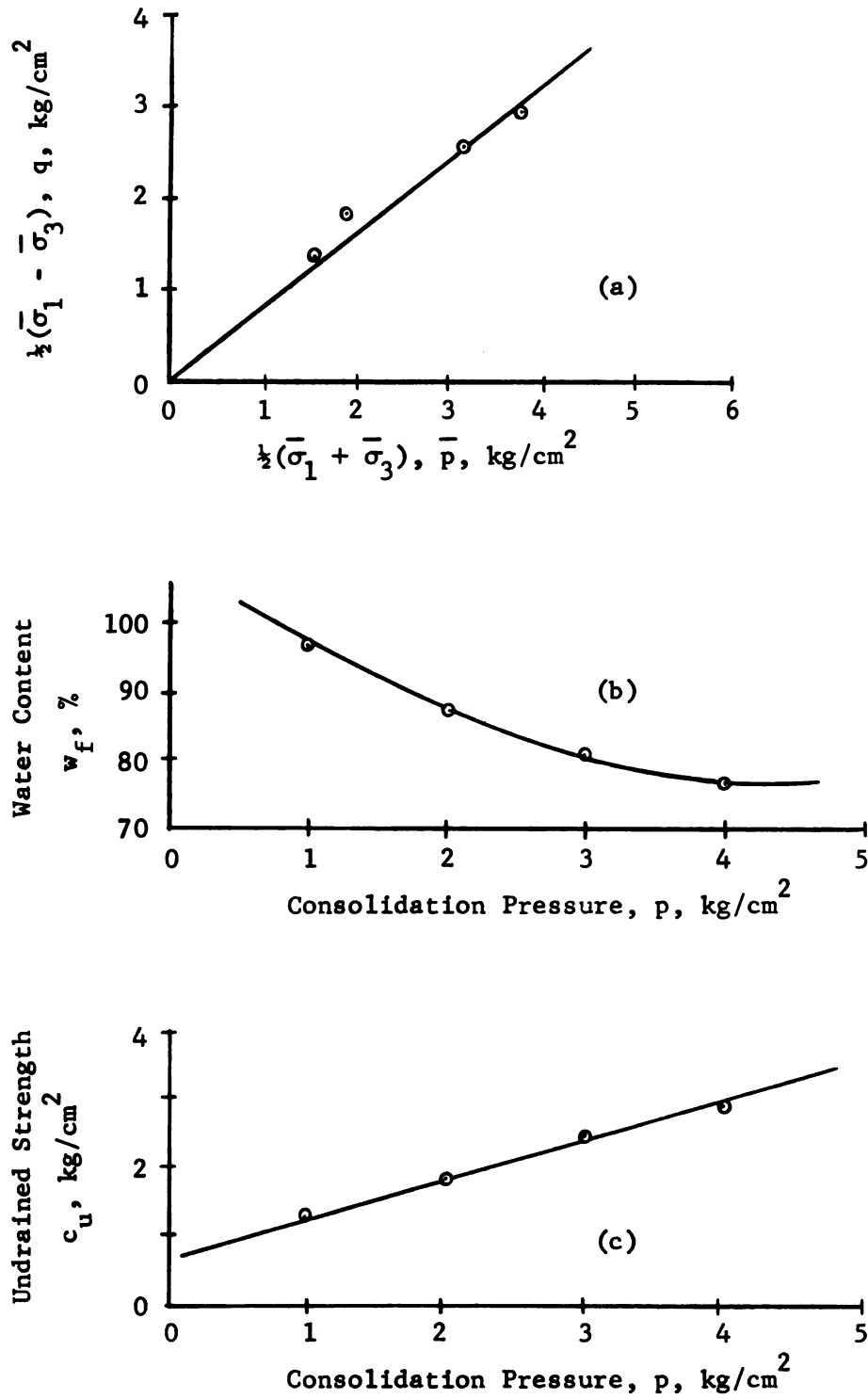


Figure 5.11 Consolidated-undrained Test Results for Sludge H-2 with 10% Lime Added, 28% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

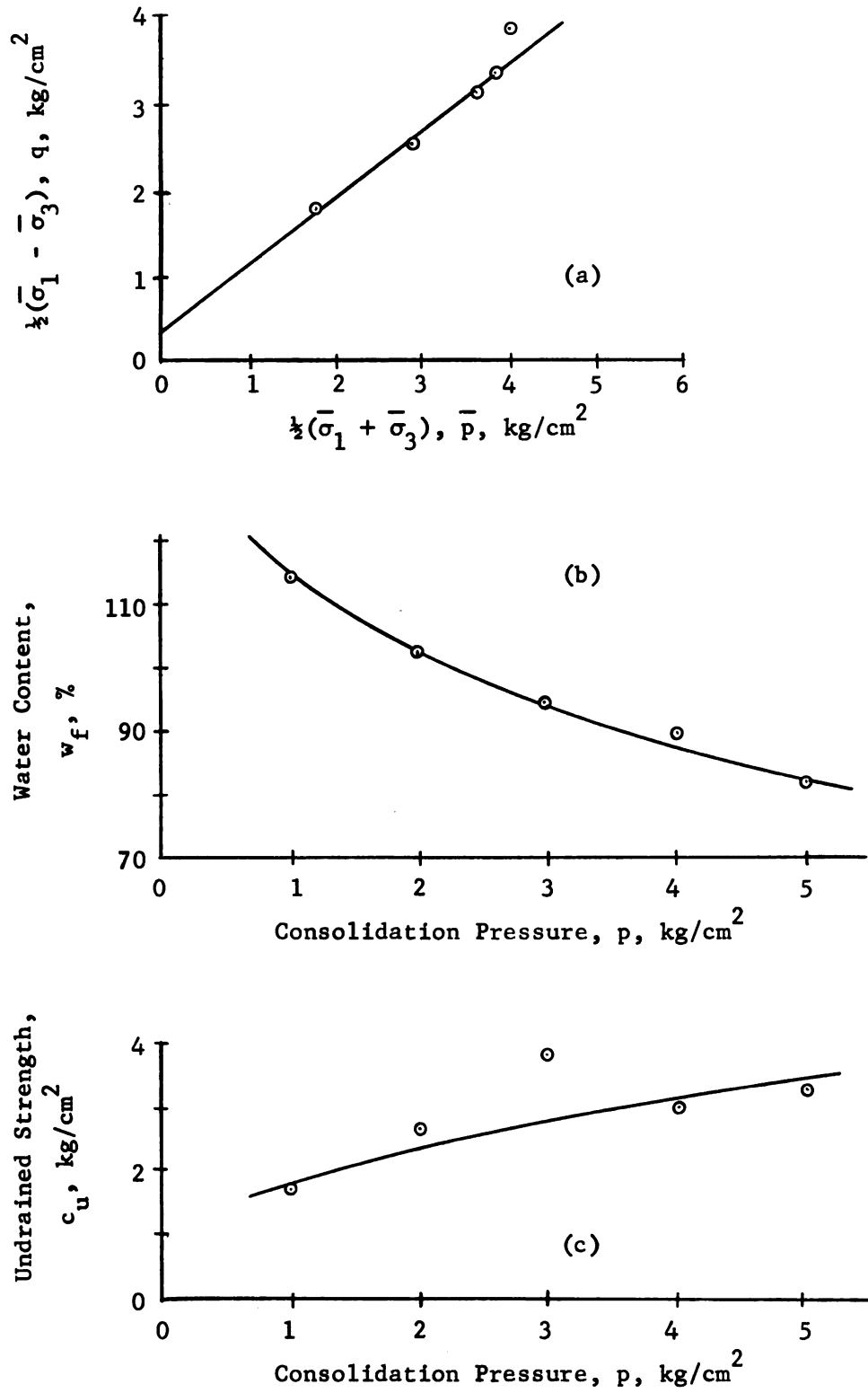


Figure 5.12 Consolidated-undrained Test Results for Sludge C-1 with 10% Lime Added (a) k_f rupture line (b) Water content (c) Undrained strength

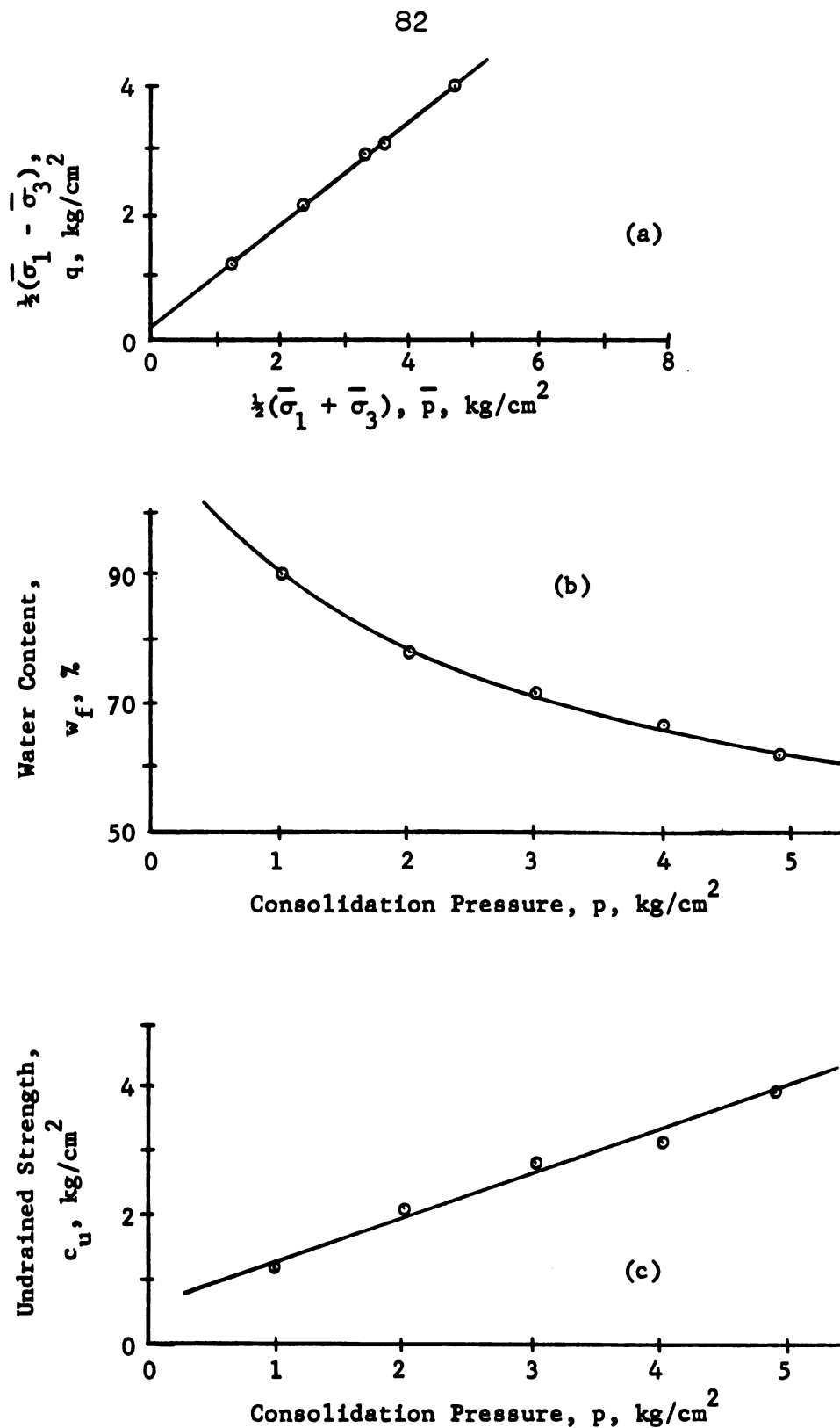


Figure 5.13 Consolidated-undrained Test Results for Sludge H-2 with 10% Flyash Added, 43% organic matter (a) k_f rupture line (b) Water content (c) Undrained strength

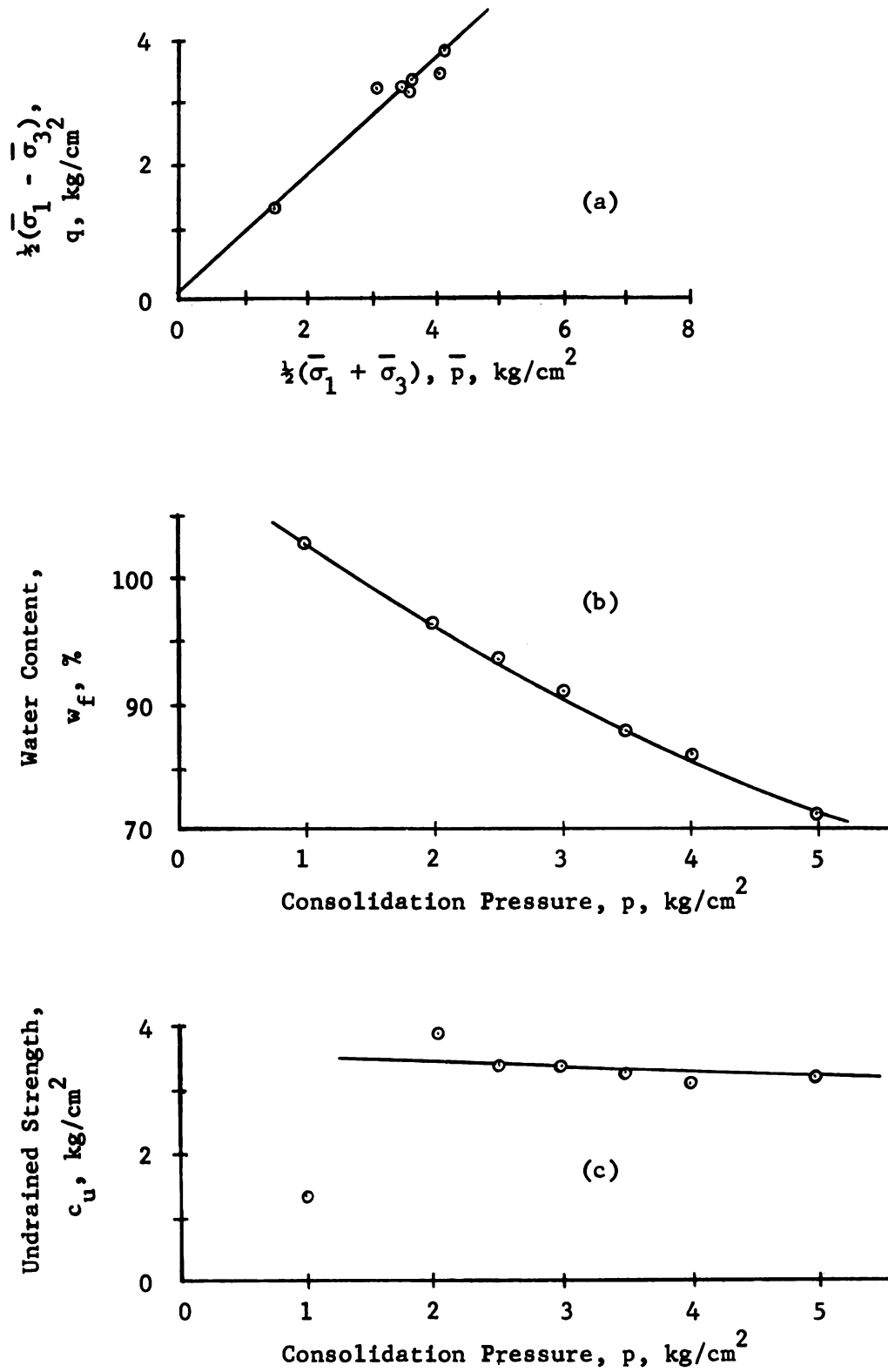


Figure 5.14 Consolidated-undrained Test Results for Sludge C-1 with 10% Flyash Added (a) k_f rupture line (b) Water content (c) Undrained strength

Table 5.5 Summary of $\bar{\phi}$ and $\bar{c}$ Values for the Triaxial Tests

Sludge	$\bar{\phi}$	$\bar{c}$
H-1	58.7 degrees	0.0 kg/cm ²
H-2		
28 % organic matter	44.3	0.3
35 % organic matter ¹	51.4	0.3
43 % organic matter	58.5	0.0
50 % organic matter	63.4	0.0
43 % organic + 10 % lime	58.9	0.2
28 % organic + 10 % lime	55.2	0.0
43 % organic + 10 % flyash	54.1	0.2
C-1	59.7	0.2
10 % lime added	57.4	0.2
10 % flyash added	64.1	0.1

¹ Natural sludge H-2

flow rate and hydraulic gradient as given by Darcy's law. It was found that the constant of proportionality or permeability was dependent on several variables including the presence of small air bubbles trapped within the sludge mass, the average head or backpressure, the organic content, and the presence of either lime or flyash. Test results are presented in terms of the permeability, k , versus the average head on an element midheight of the sample.

5.2.1 Flow Through Natural Sludges

Permeability relationships for natural sludges H-2 and C-1 are given by the lower curve in Figures 5.15 and 5.16. The applied backpressures for these tests ranged from 0 to almost 240 feet of water. When tests were started at low hydraulic gradients with either a low backpressure or the absence of such, it was observed that to initiate flow it was necessary to increase the hydraulic gradient to some critical value. Once flow had started, it would continue at the lower hydraulic gradients. The hydraulic gradients required to initiate flow at the different backpressures are given in Table 5.6 for the natural sludges.

Since it appeared that small air bubbles trapped within the sludge were having a marked effect on the permeability at the lower backpressures, another series of tests was run on the sludges after they had been treated with a sterilant (mercuric oxide) and/or subjected to a vacuum before testing. The resulting permeabilities were greatly increased as shown by the upper curves in Figures 5.15 and 5.16.

Table 5.6 Hydraulic Gradient Required to Initiate Flow

Sludge	Backpressure	Hydraulic gradient
H-2	0 psi	7.56 - 11.77
	10	6.16 - 8.97
	20	3.36 - 4.76
	30	1.96 - 4.76
	40 and above	0
C-1	0	3.36 - 7.57
	10	1.96 - 5.32
	20 and above	0

Complete permeability data is given in Appendix B.

Permeability tests conducted at several solids contents for sludge H-2 are summarized in Figure 5.17. This three-dimensional plot, which includes the influence of backpressure, shows that the permeability is decreased substantially with a slight increase in solids content. At 57.8 percent solids by weight the permeability was in the order of 1×10^{-8} cm/sec. Figure 5.18 presents similar results for sludge C-1, only in a two-dimensional form. All the curves show the same characteristic shape but the degree of fluctuation is less. Complete permeability data is given in Appendix B.

5.2.2 Influence of Organic Content on Flow

Permeability tests were conducted on the modified organic content samples of sludge H-2 for solids contents of 25.7, 34.2, 40.25, and 50.18 percent by weight. The results of these tests are summarized in Figure 5.19 with complete data given in Appendix B. These figures show that

with a decrease in organic content the permeability also decreases.

5.2.3 Influence of Lime or Flyash Admixtures on Flow

Natural sludges H-2 and C-1 were examined to determine what effects the addition of lime or flyash would have on the drainage characteristics previously determined. The addition of 10 percent lime by dry weight gave some improvement in permeability as shown in Figures 5.20 and 5.21. This increase in permeability becomes more evident when comparisons are made on the basis of different solids contents as given in Figures 5.22 and 5.23.

In assessing the effects of the lime on the sludge behavior, the pretreatments with a sterilant and/or vacuum were also performed and evaluated. The permeabilities after such treatments are given in Figures 5.24 and 5.25. The drop in permeability values at the larger heads in Figure 5.25(a) is the result of the low solids content as a decrease in total volume was noted as the head was increased. These figures show that the effects of the sterilant and vacuum are opposite to those found without lime added.

The variations in permeability examined with the addition of the lime admixture were also examined with the addition of 10 percent flyash (dry weight basis). The results of these tests are summarized in Figures 5.26 thru 5.30. The permeability is slightly increased, but proportionately, not as much as with the addition of lime. The results of the pretreatments were similar to those obtained

on the natural sludges.

5.2.4 Water Retention of Sludge

The ability of the sludge to retain or hold water under a given tension or suction is shown by the water retention curves in Figure 5.31. These curves represent sludge H-2 at two organic contents and natural sludge H-2 with 10 percent lime or flyash added. The water holding capacity is reduced with either the lowering of organic content or with the addition of lime or flyash.

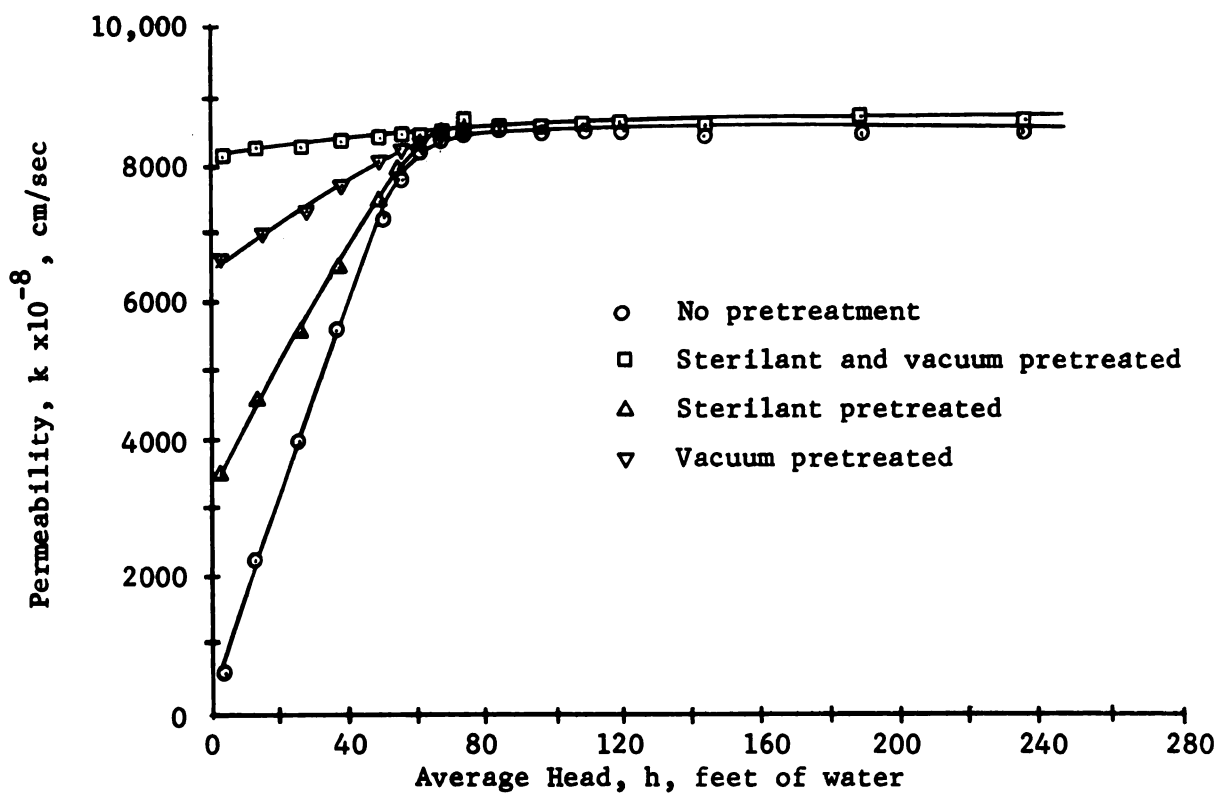


Figure 5.15 Permeability of Sludge H-2 with Varying Average Head

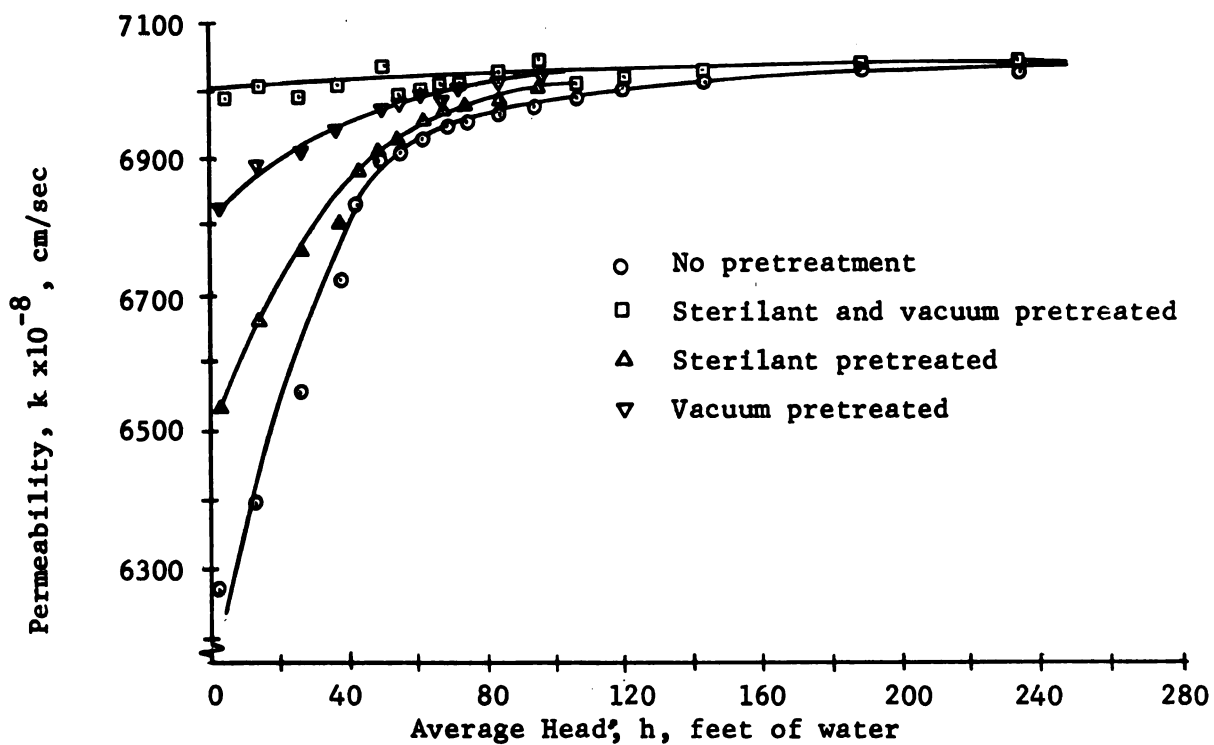


Figure 5.16 Permeability of Sludge C-1 with Varying Average Head

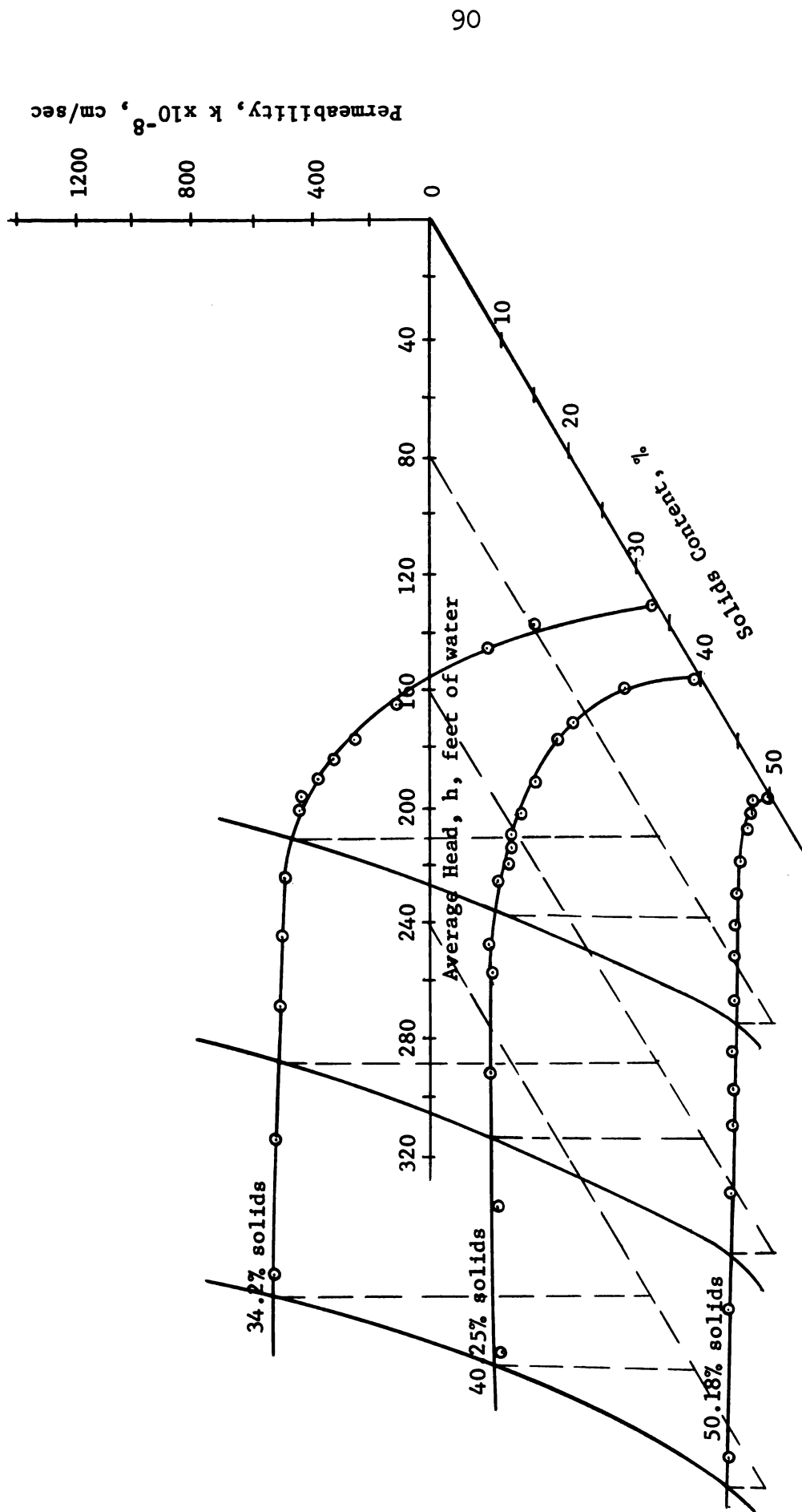


Figure 5.17 Permeability, Solids Content, and Average Head for Sludge H-2

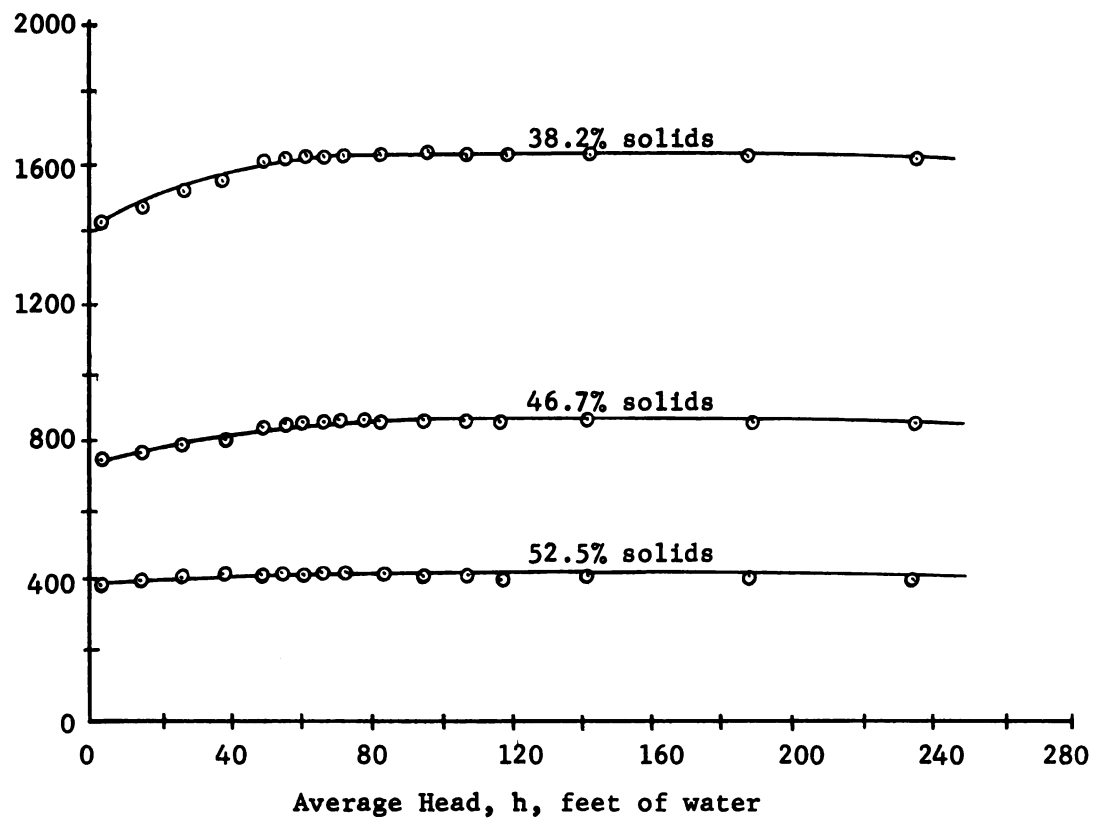
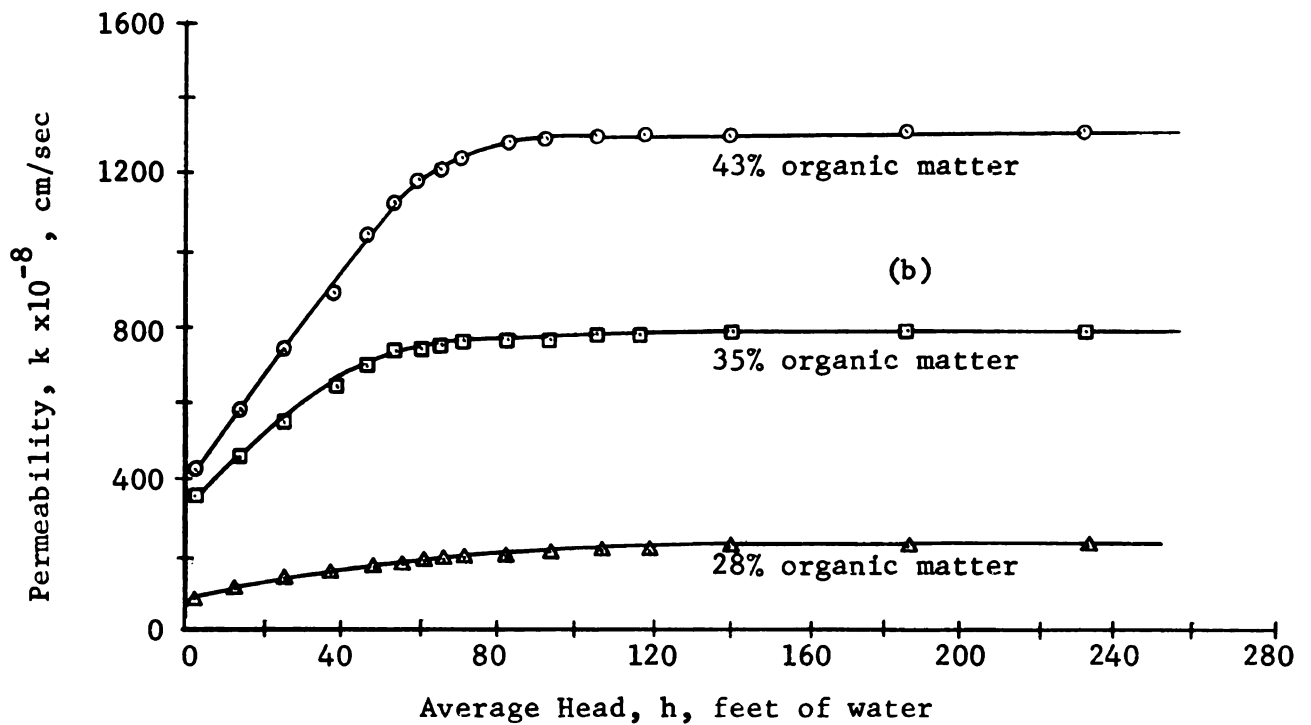
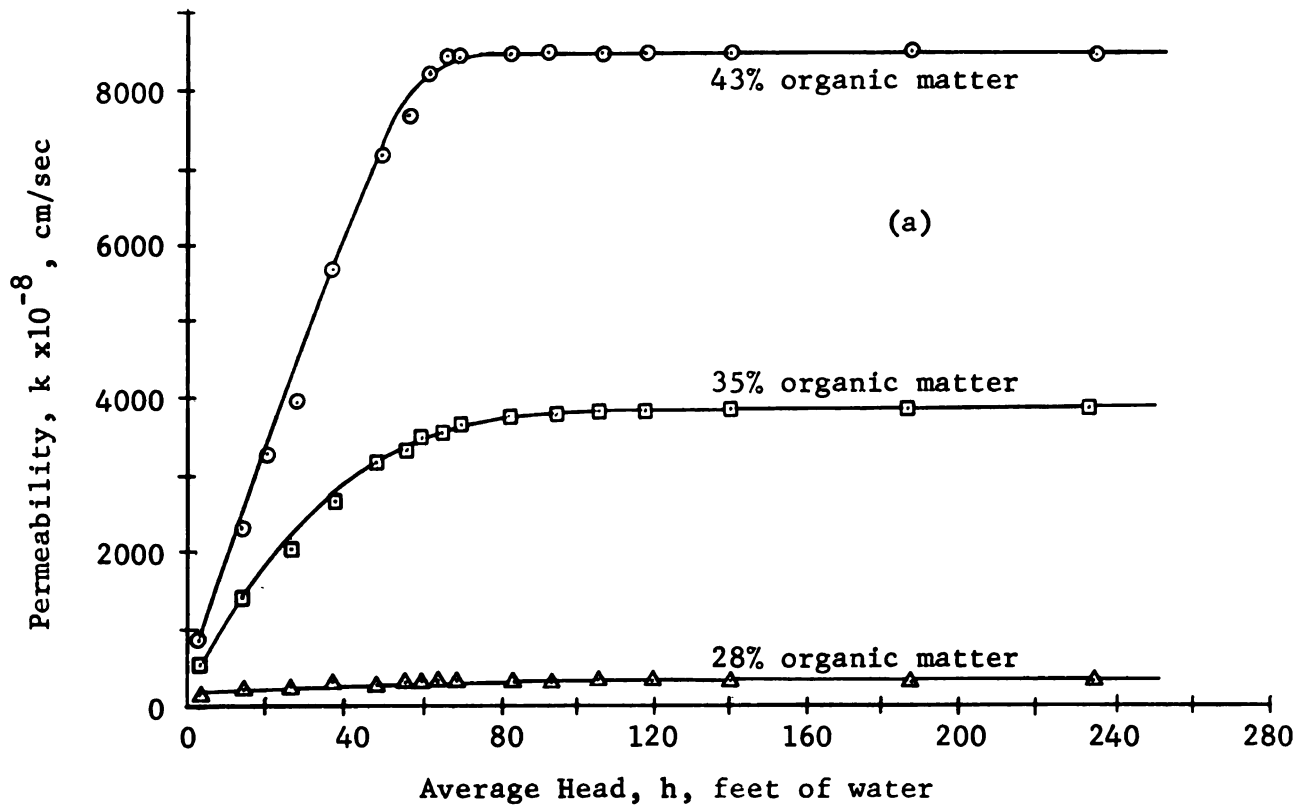


Figure 5.18 Permeability, Solids Content, and Average Head for Sludge C-1



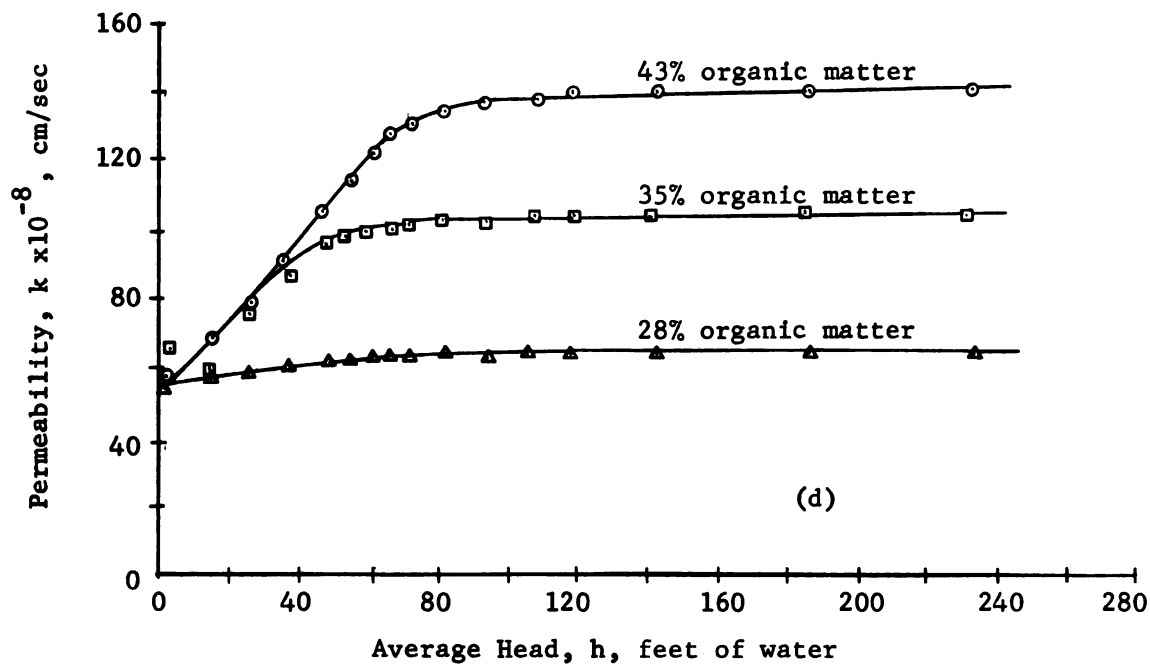
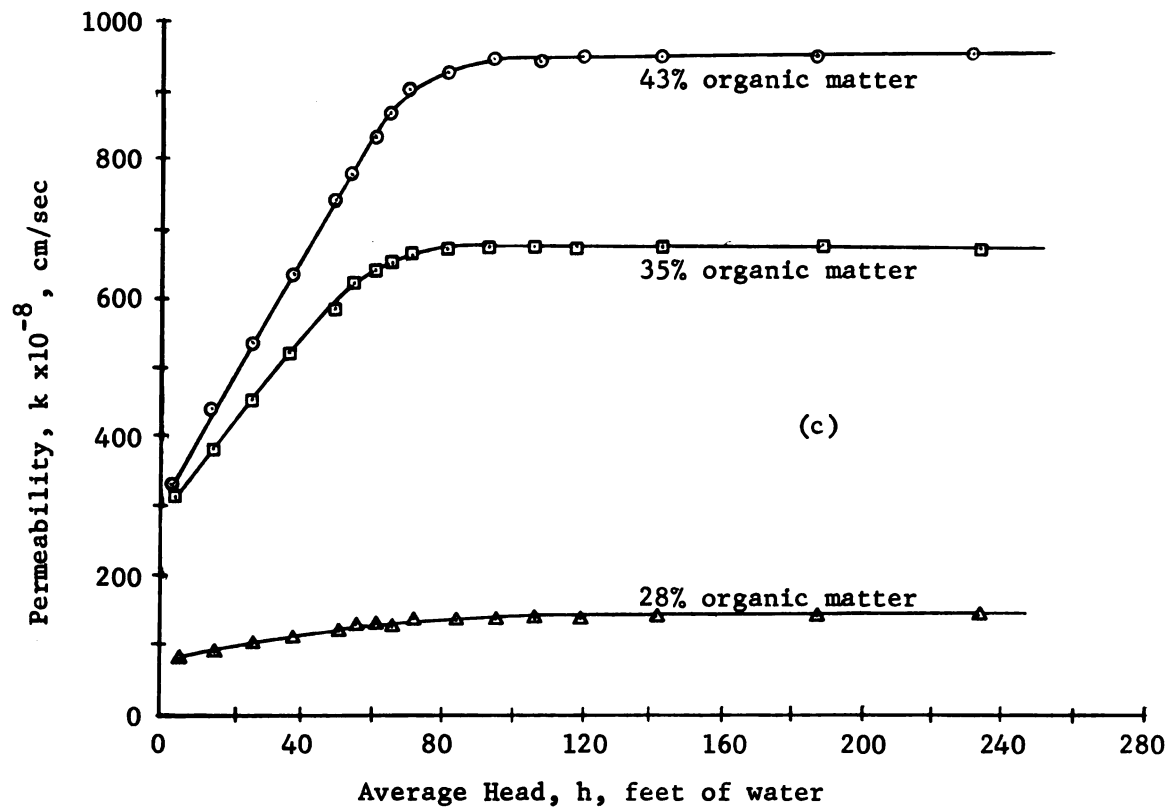


Figure 5.19 Change in Permeability with Change in Organic Content
 (a) 25.7% solids (b) 34.2% solids (c) 40.25% solids
 (d) 50.18% solids

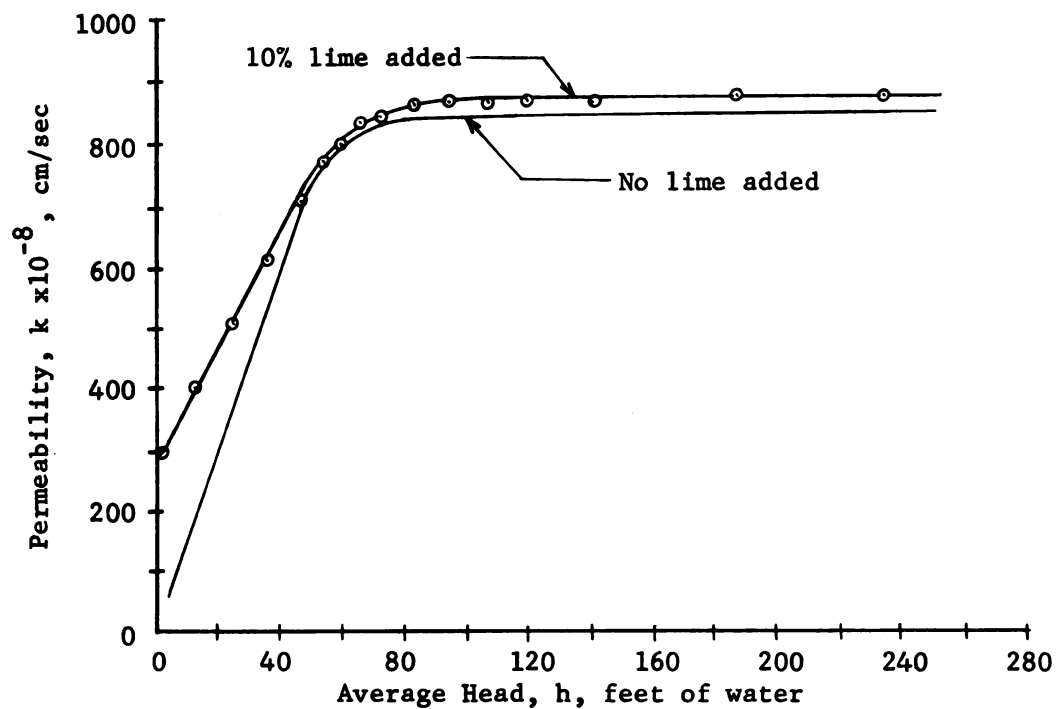


Figure 5.20 Permeability of Sludge H-2 with 10% Lime Added

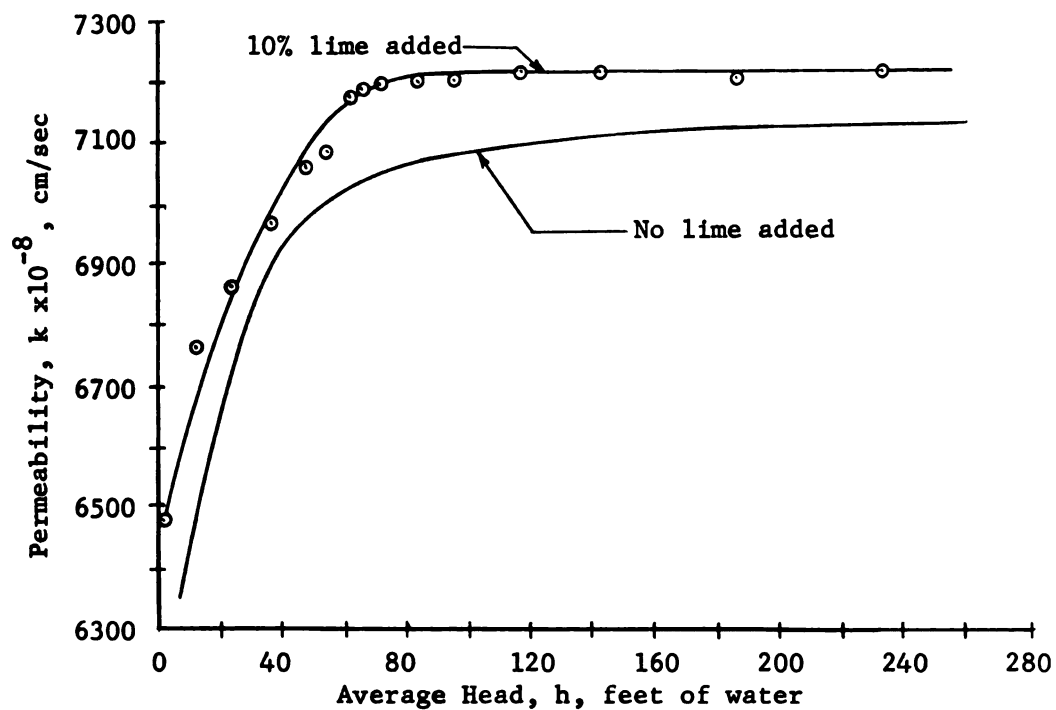


Figure 5.21 Permeability of Sludge C-1 with 10% Lime Added

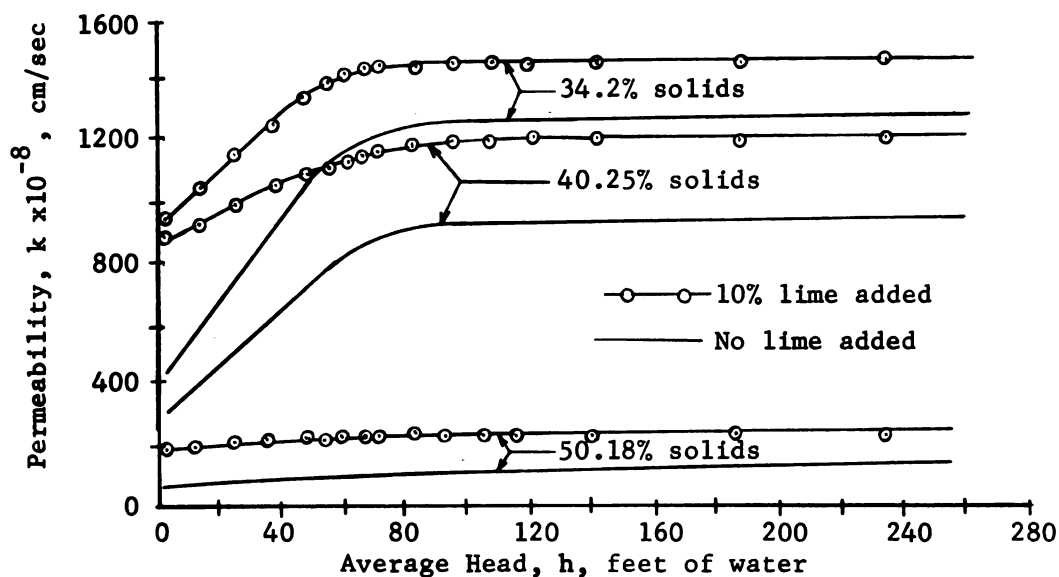


Figure 5.22 Permeability of Sludge H-2 with 10% Lime Added at Three Solids Contents

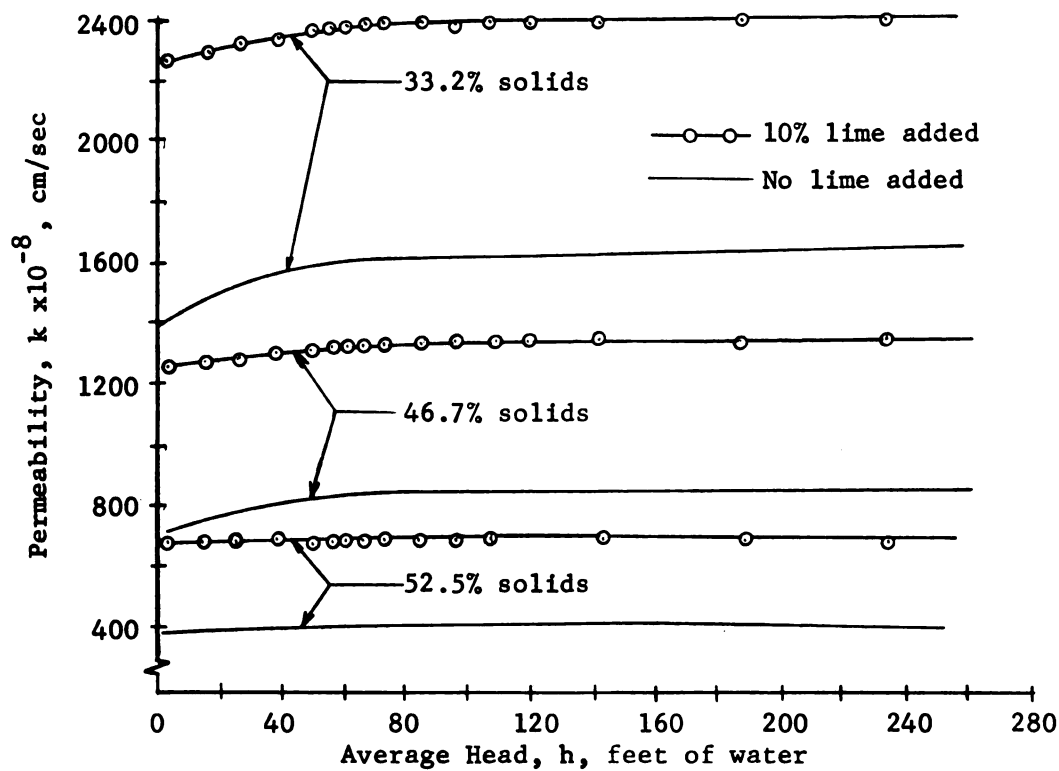


Figure 5.23 Permeability of Sludge C-1 with 10% Lime Added at Three Solids Contents

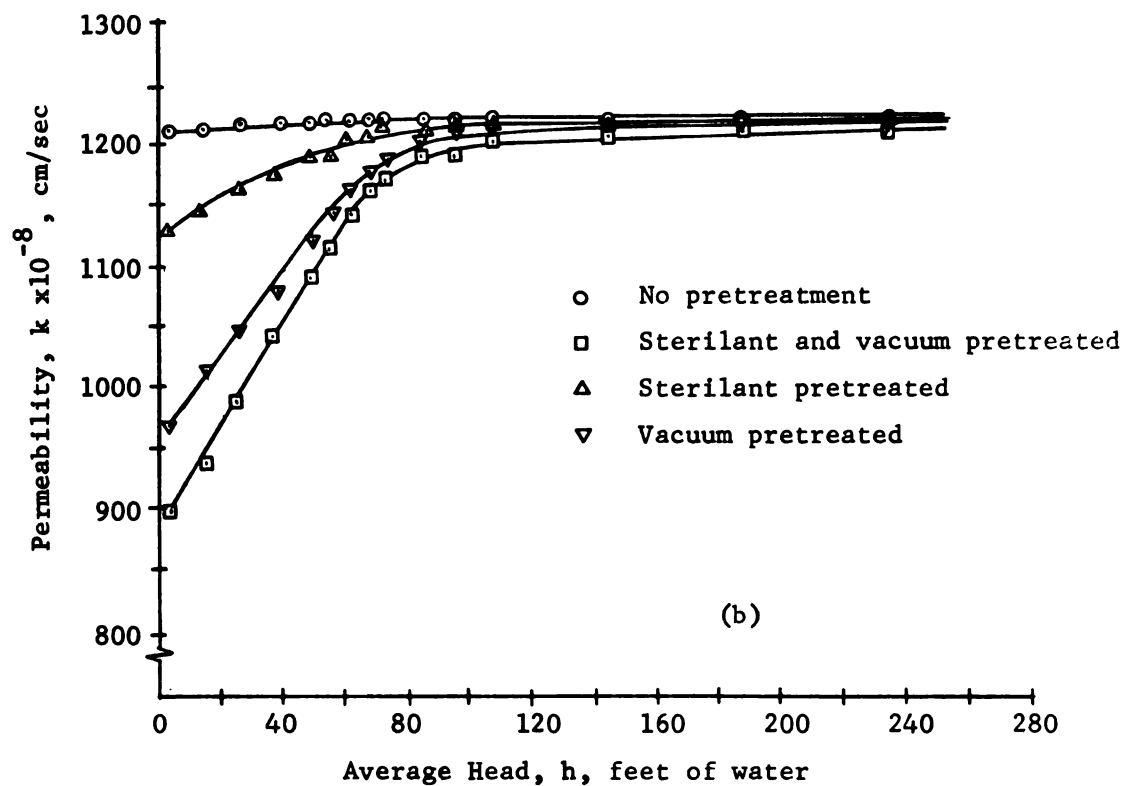
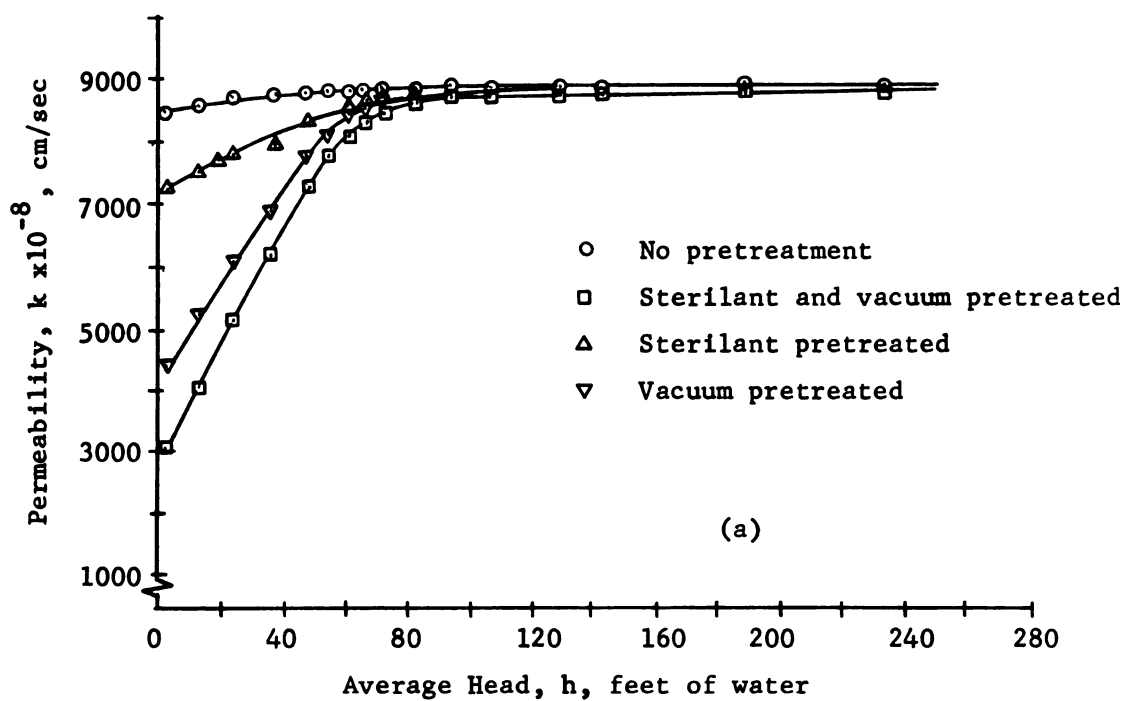


Figure 5.24 Permeability of Sludge H-2 with 10% Lime Added and Pretreated (a) 25.7% solids (b) 40.25% solids

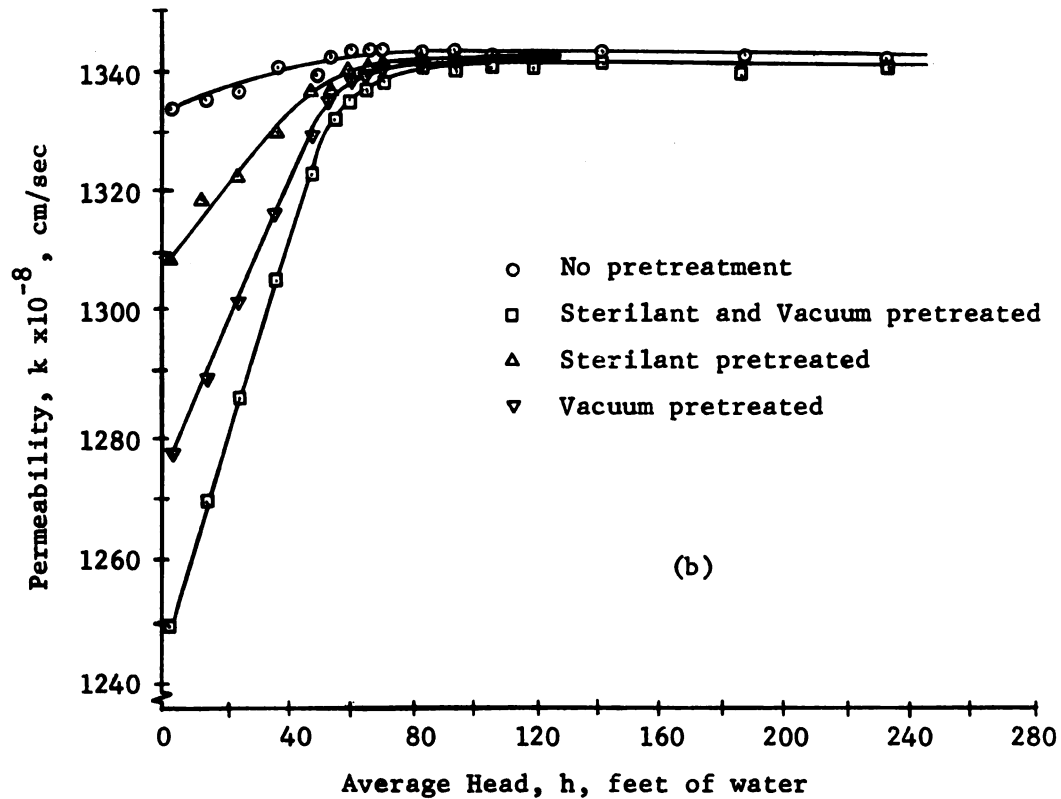
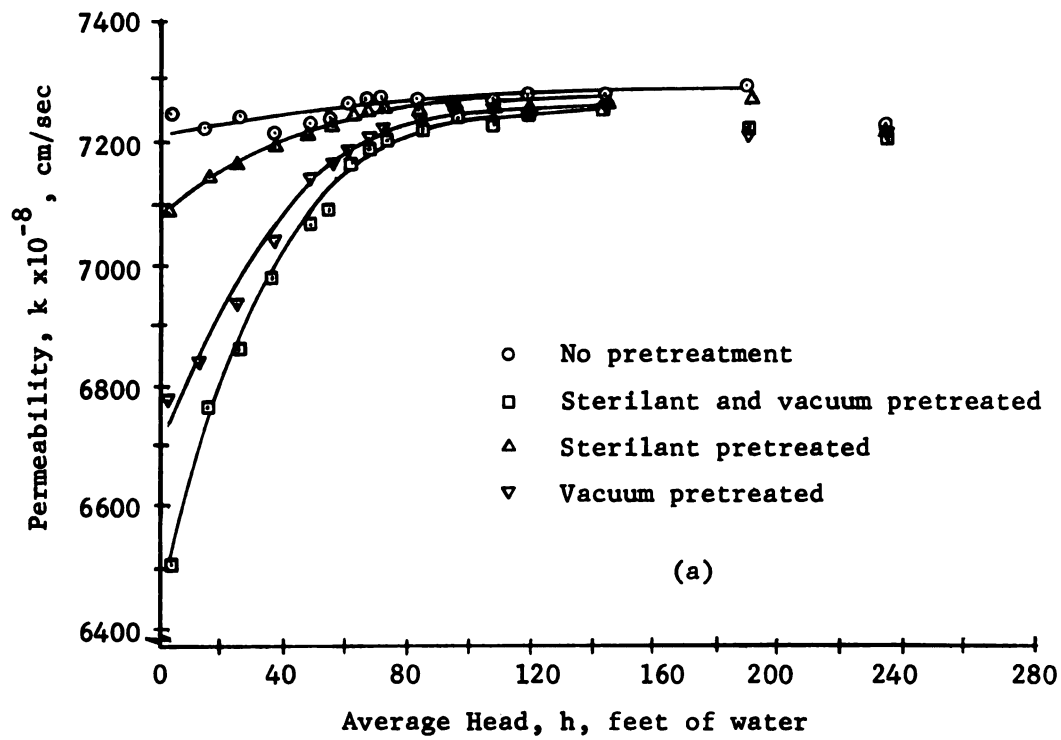


Figure 5.25 Permeability of Sludge C-1 with 10% Lime Added and Pretreated
(a) 30.7% solids (b) 46.7% solids

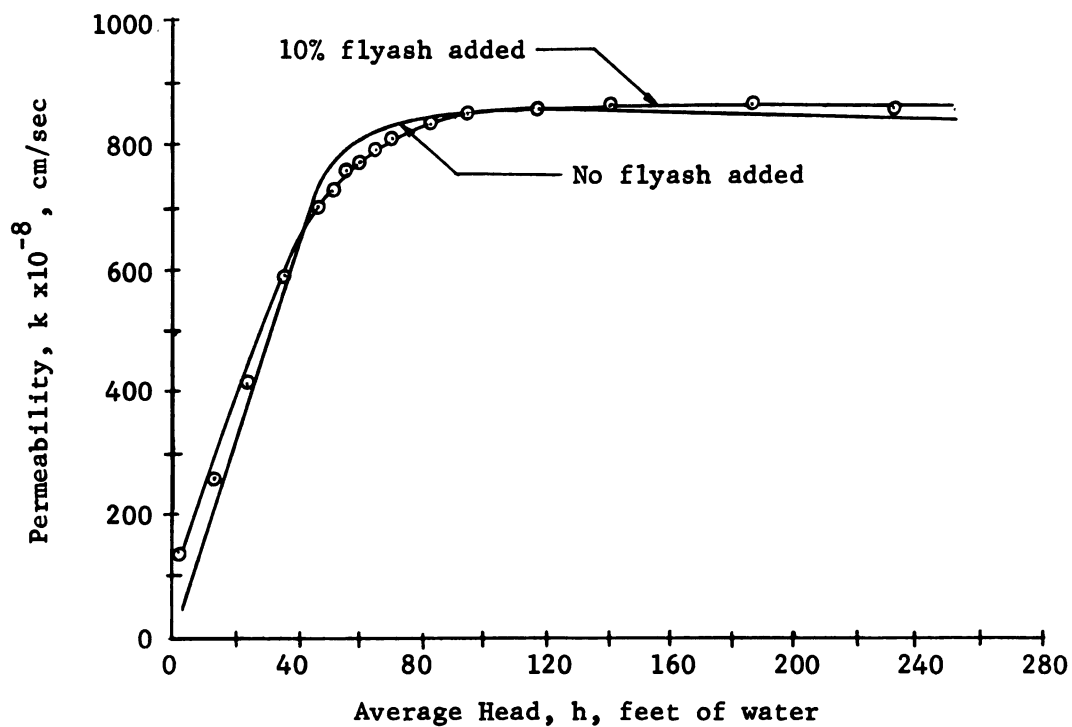


Figure 5.26 Permeability of Sludge H-2 with 10% Flyash Added

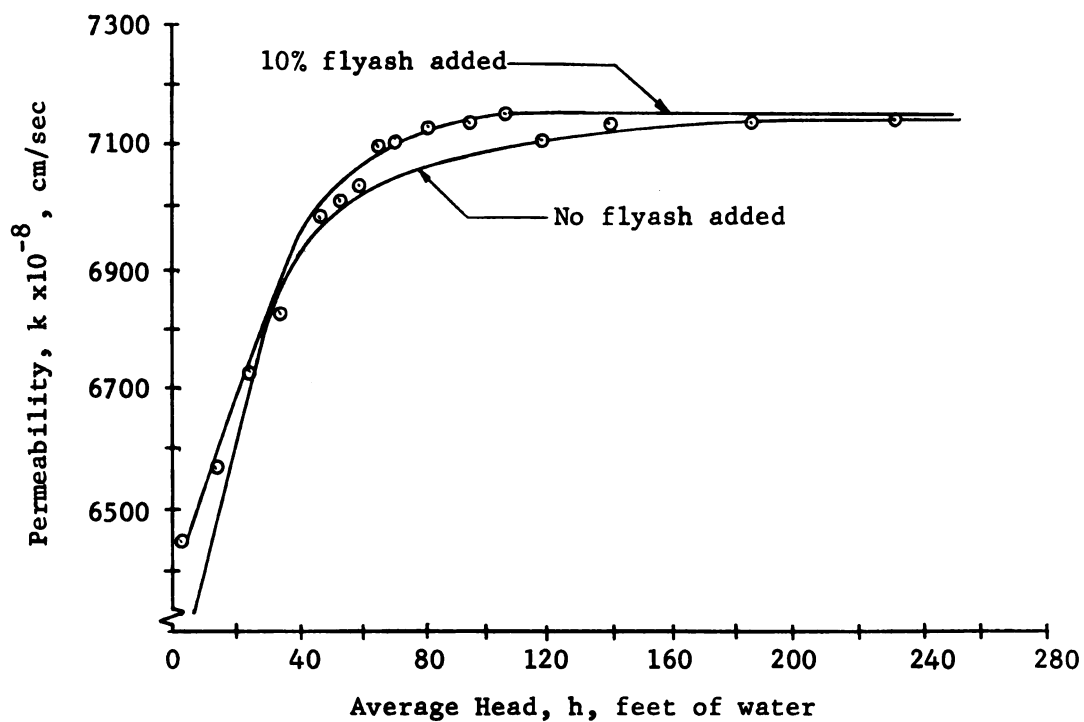


Figure 5.27 Permeability of Sludge C-1 with 10% Flyash Added

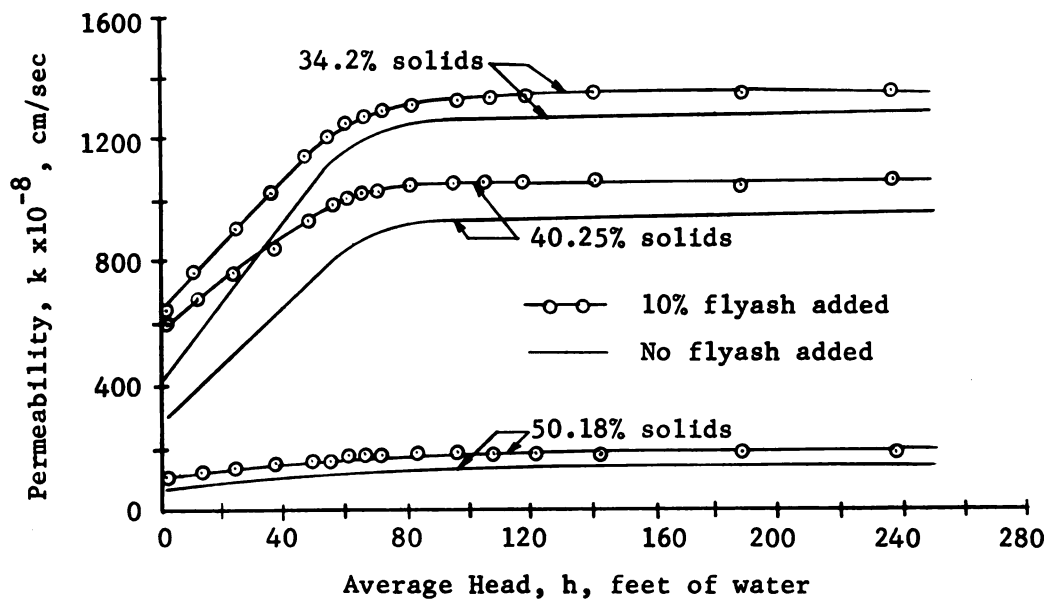


Figure 5.28 Permeability of Sludge H-2 with 10% Flyash Added at Three Solids Contents

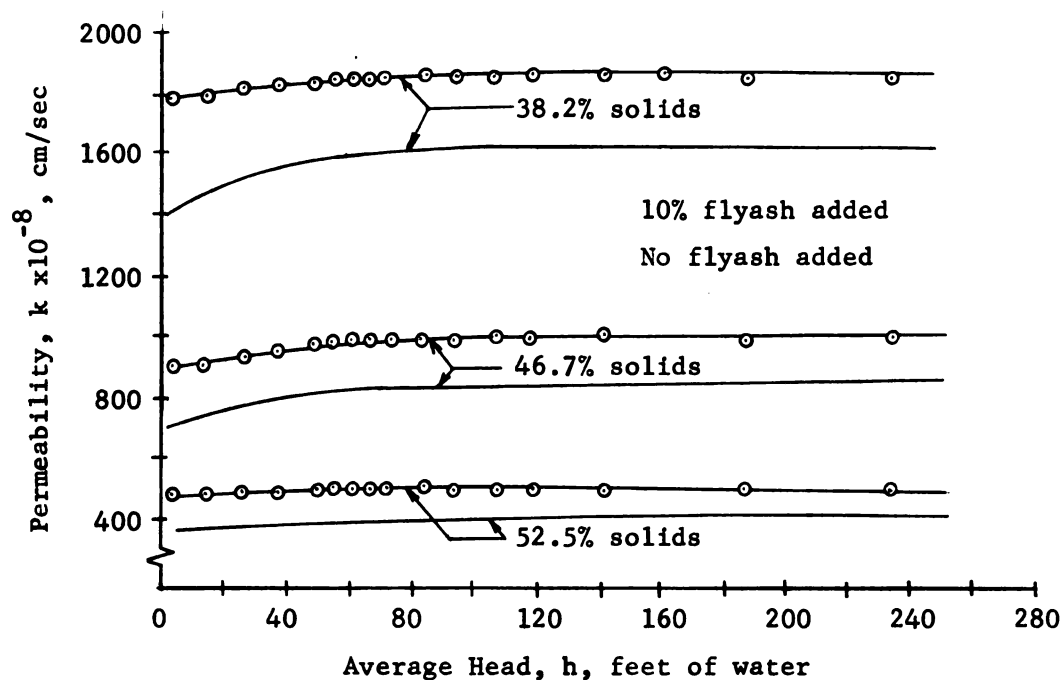


Figure 5.29 Permeability of Sludge C-1 with 10% Flyash Added at Three Solids Contents

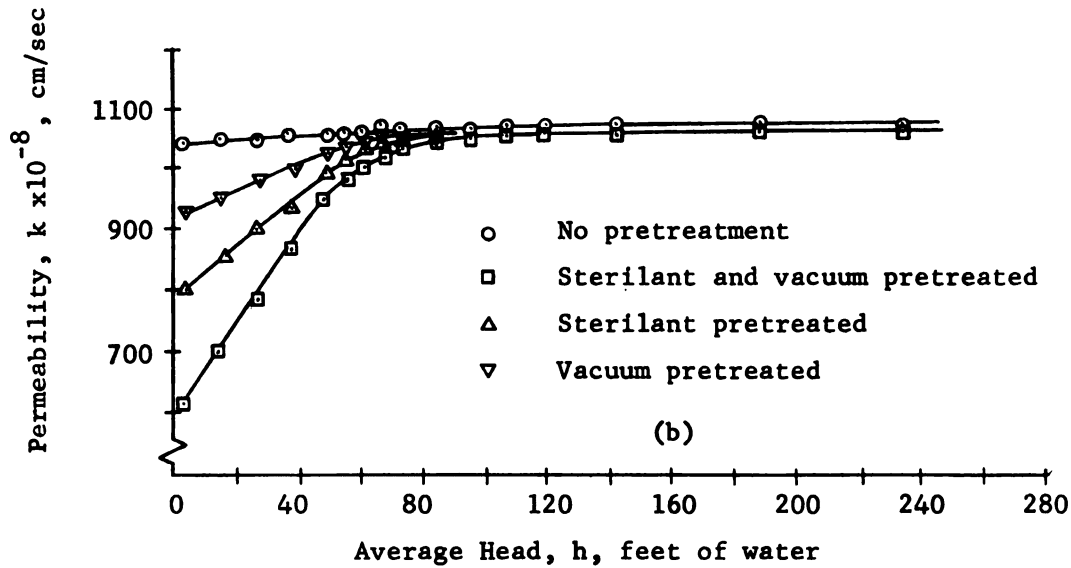
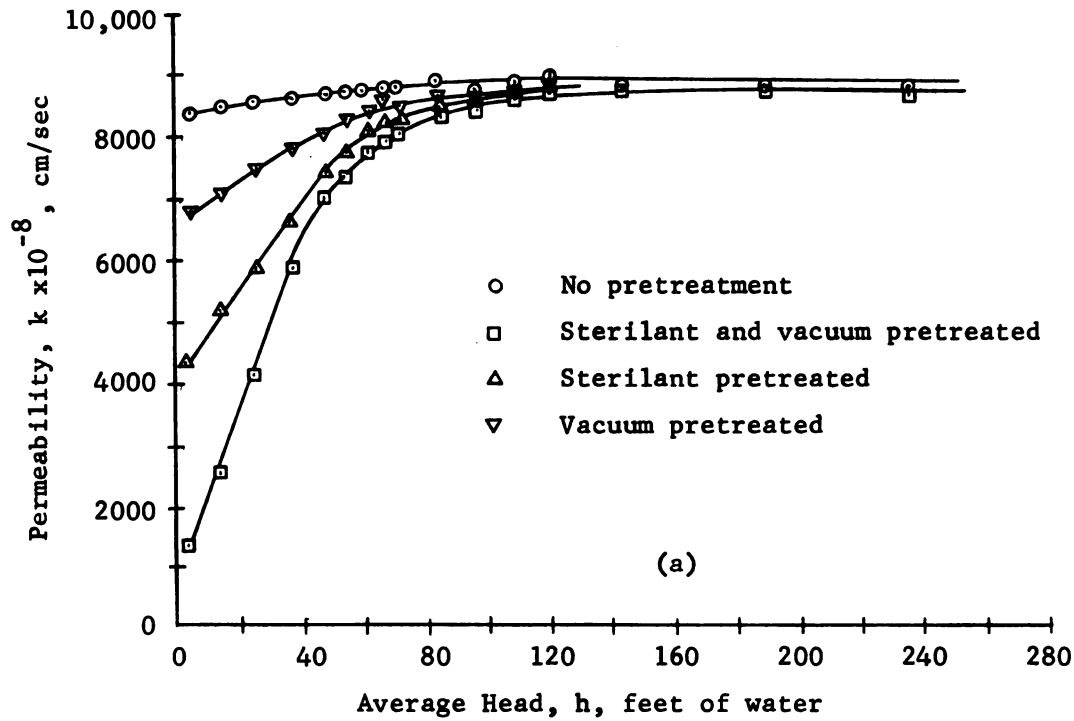


Figure 5.30 Permeability of Sludge H-2 with 10% Flyash Added and Pretreated (a) 25.7% solids (b) 40.25% solids

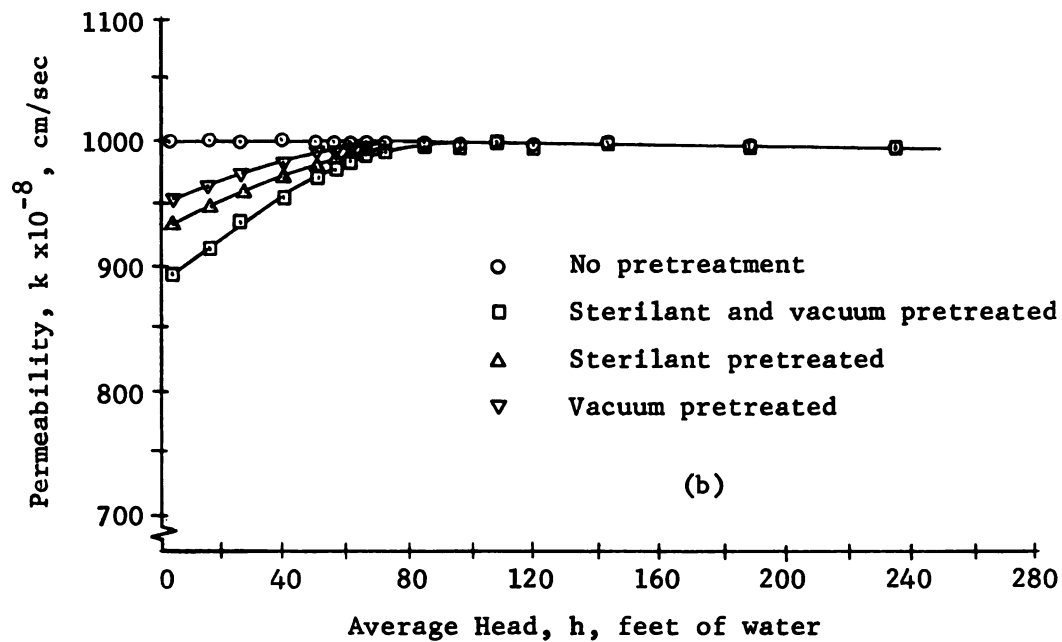
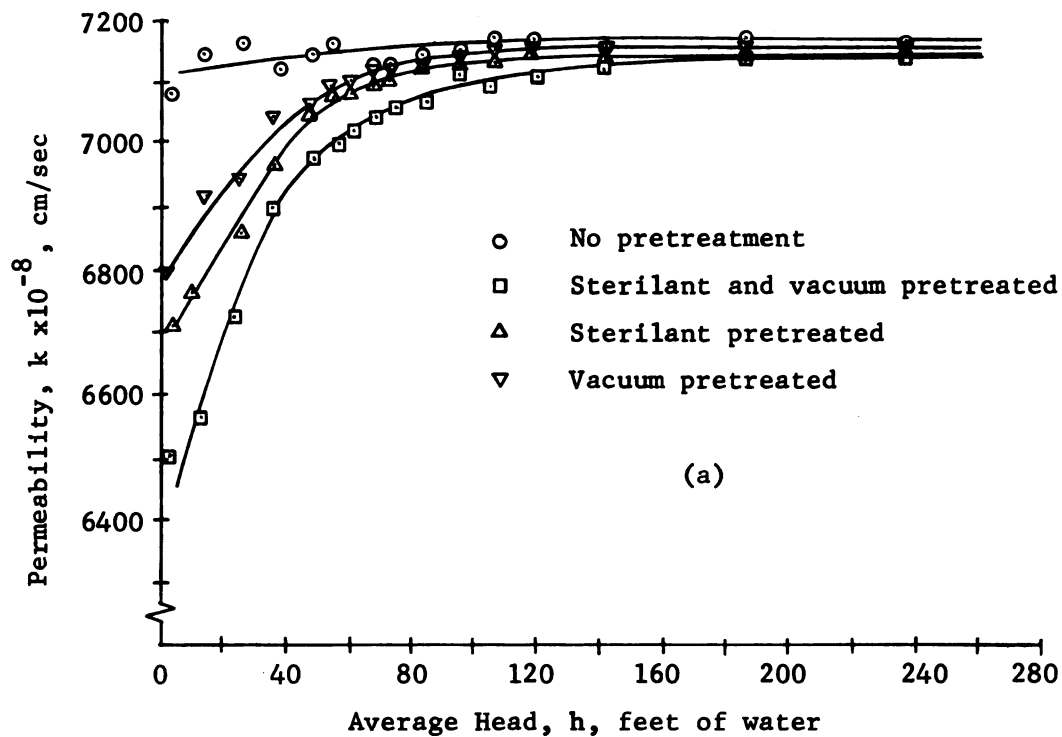


Figure 5.31 Permeability of Sludge C-1 with 10% Flyash Added and Pretreated (a) 30.7% solids (b) 46.7% solids

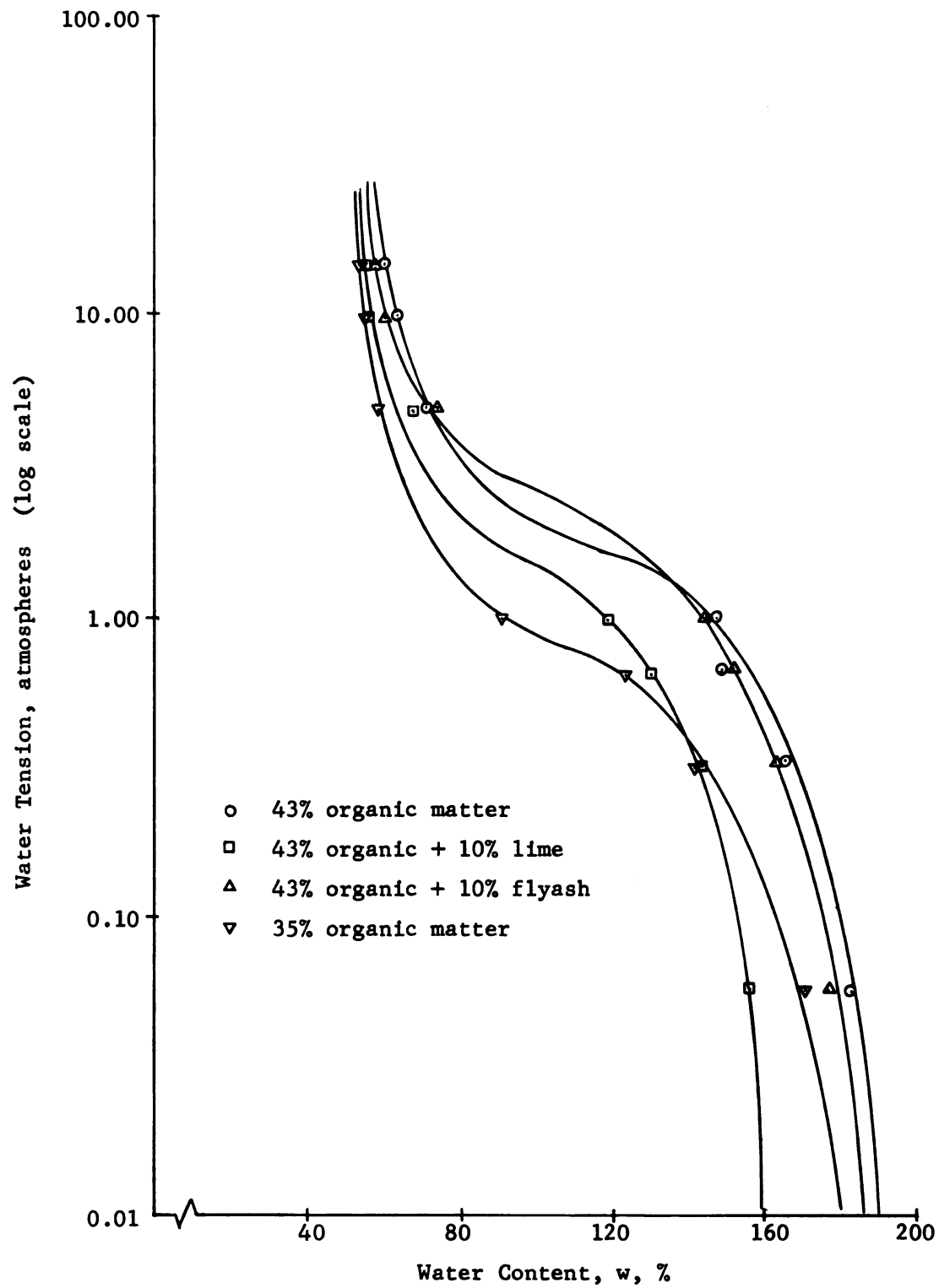


Figure 5.32 Water Retention Characteristics for Sludge H-2

CHAPTER VI

DISCUSSION AND INTERPRETATION OF RESULTS

This discussion and interpretation of results is subdivided into two sections, shear strength and permeability. Each section considers the natural sludges, the consequences of changing the organic content such as may occur during decomposition, and the influence of lime or flyash additives. Related information on the undrained strength, pore pressure parameters, and water retention characteristics of the sludge are included in the appropriate section.

6.1 Shear Strength

6.1.1 Natural Sludges

The typical stress-strain curves of Figure 5.1 for sludge H-2 show a sharp increase in stress at low strains followed by a more gradual increase at higher strains. No peak strength value is reached with strength continuing to increase for strains of 25 percent or more. Scott (1963) points out that this behavior is typical of remolded clays where the particles are randomly oriented and have few interparticle contacts. Technically this means that large deformations will occur as the sludge develops its resistance to applied loads and in design problems, deformation or

settlement may be the controlling factor rather than stability.

The water content of dewatered sludges is unusually high in comparison to inorganic soils that are normally encountered in engineering practice. As sampled, the water content of sludges H-2 and C-1 were 387 and 322 percent, respectively. Strength improvements in these sludges will be dependent on the reduction of their water content. Figures 5.2, 5.3, and 5.4 include curves showing changes in the water content and undrained strength in relationship to the all-around consolidation pressure. These curves show relationships similar to what is expected for inorganic soils (Bishop and Henkel, 1962). The ratio c_u/p appears to be constant, its value depending on the sludge composition. This means for a uniform sludge deposit the undrained strength should increase linearly with depth. Data presented by Mazzola (1969) gave some indications of this behavior where the sludge strata appeared to be uniform as shown by the consistency limits.

Sludge specimens prepared for the triaxial tests were remolded such that no preferred orientation existed between the fibers or clay particles. Consolidation under an all around pressure would not greatly alter this general random orientation. These conditions may not be fully representative of field sludge deposits in which consolidation takes place only in the vertical direction (one-dimensional). This anisotropy, with respect to fiber and particle

orientation, expected in field deposits was not considered in this study. In addition, there are reasons to doubt that the solid phase in a sludge can be considered as incompressible as for inorganic soils. Laboratory methods which would permit consideration of the compressibility of the solid phase are not yet available.

For purposes of engineering design, numerical values must be assigned to the shear strength of the sludge. Parameters are required which will reflect the change in shear strength with variations in stress and loading history. Conventional practice in soil mechanics uses the Mohr-Coulomb theory (Terzaghi and Peck, 1967; Wu, 1966) which gives the shear strength in terms of a cohesion component and a frictional component (Equation 2.1). Using effective normal stresses, experimental results on the natural sludges are given in Figures 5.2(a), 5.3(a), and 5.4(a). The cohesion component approximates zero. The angle of internal friction for these sludges is exceptionally high when compared to those for inorganic soils but is comparable to those found for peat and muskeg. These high values indicate that for practical problems the sludge can develop sufficient shear strength but this development will be accompanied by large deformations. Thus the governing factor in design will be the deformation characteristics of the sludge.

Adams (1961) has established that the coefficient of earth pressure at rest for peat is exceptionally low and

that it decreases with increasing effective consolidation pressure. Jaky (1944) has suggested that experimental values for K_0 are represented by the relationship

$$K_0 = 1 - \sin \bar{\phi} \quad (6.1)$$

where $\bar{\phi}$ is the angle of internal friction. If this expression is approximately correct for the natural sludges, K_0 would be close to zero. This finding would have implications in stability analysis involving bearing capacity and in the development of shearing resistance on failure surfaces.

The pore pressure parameters A and B (Bishop and Henkel, 1962) were for the consolidated-undrained tests. For fully saturated sludges B equals unity within the limits of experimental determination. Values for A at failure (20 percent strain) are summarized in Table 5.1 and show a range from 0.25 to 0.62.

6.1.2 Organic Content

The organic content of the sludge influences both the consistency limits and the shear strength parameters. Data included in Table 3.2 shows that both the liquid limit and plastic limit were decreased for sludge H-2 when the organic content was reduced. This correlates with the decrease in water retention shown in Figure 5.32 for a reduction in organic content. The range in water contents in which the sludge can be considered plastic (plasticity index) changed only slightly with the reduction in organic content. This shows that the plasticity of the sludge is not dependent on the organic fiber. The fiber does interfere with the

mechanical test procedures used for the determination of the liquid and plastic limits and thus throws some uncertainty on these values.

A comparison of stress-strain curves for samples with different organic contents is shown in Figure 6.1. These curves show a smaller increase in strength at the larger axial strains with a lower organic content. This behavior may be the result of the amount of fibers since it was also observed in sample preparation that the higher organic content sludge samples would maintain the test specimen shape at a lower solids content.

Values for the angle of internal friction and cohesion (effective stress basis) are summarized in Table 5.5. Considering sludge H-2, the organic content has been plotted against the angle of internal friction in Figure 6.2. This point representation indicates a linear relationship between the two over the range of organic contents studied and shows a considerable increase in friction angle with an increase in organic content. At the lower organic contents, the angle of internal friction should approach a value representative of the non-organic constituents in the pulp and papermill sludges. In sludge H-2 this component was primarily kaolinite clay. Gibbs, et al. (1960) reports the ϕ for kaolinite to be approximately 25 degrees. The value obtained for the sludge by extending the linear relationship to the ϕ axis (22.8°) is in close agreement with this. For comparison, a data point for muskeg (Adams, 1965) is shown

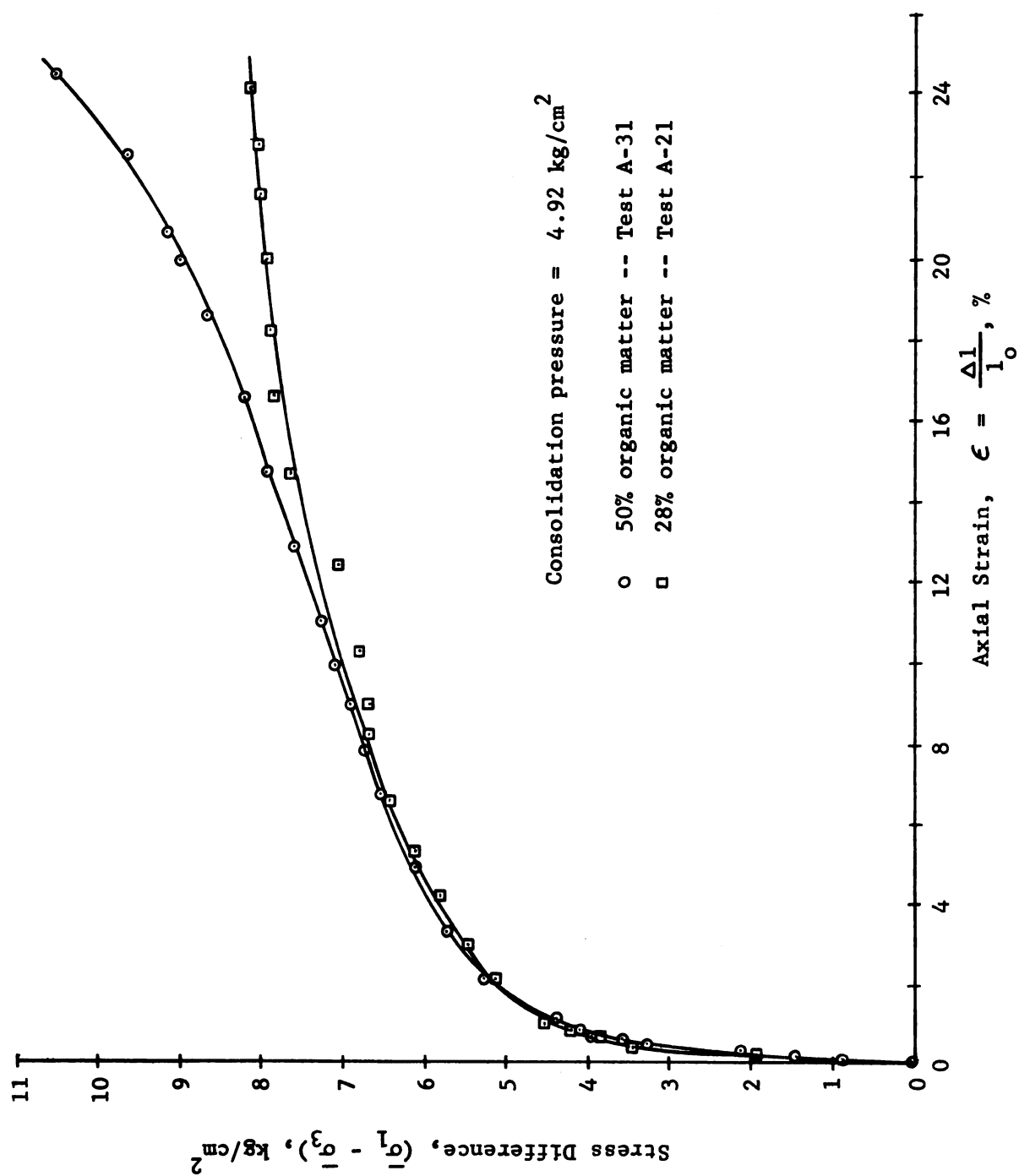


Figure 6.1 Organic Content and Stress-strain Behavior, Sludge H-2

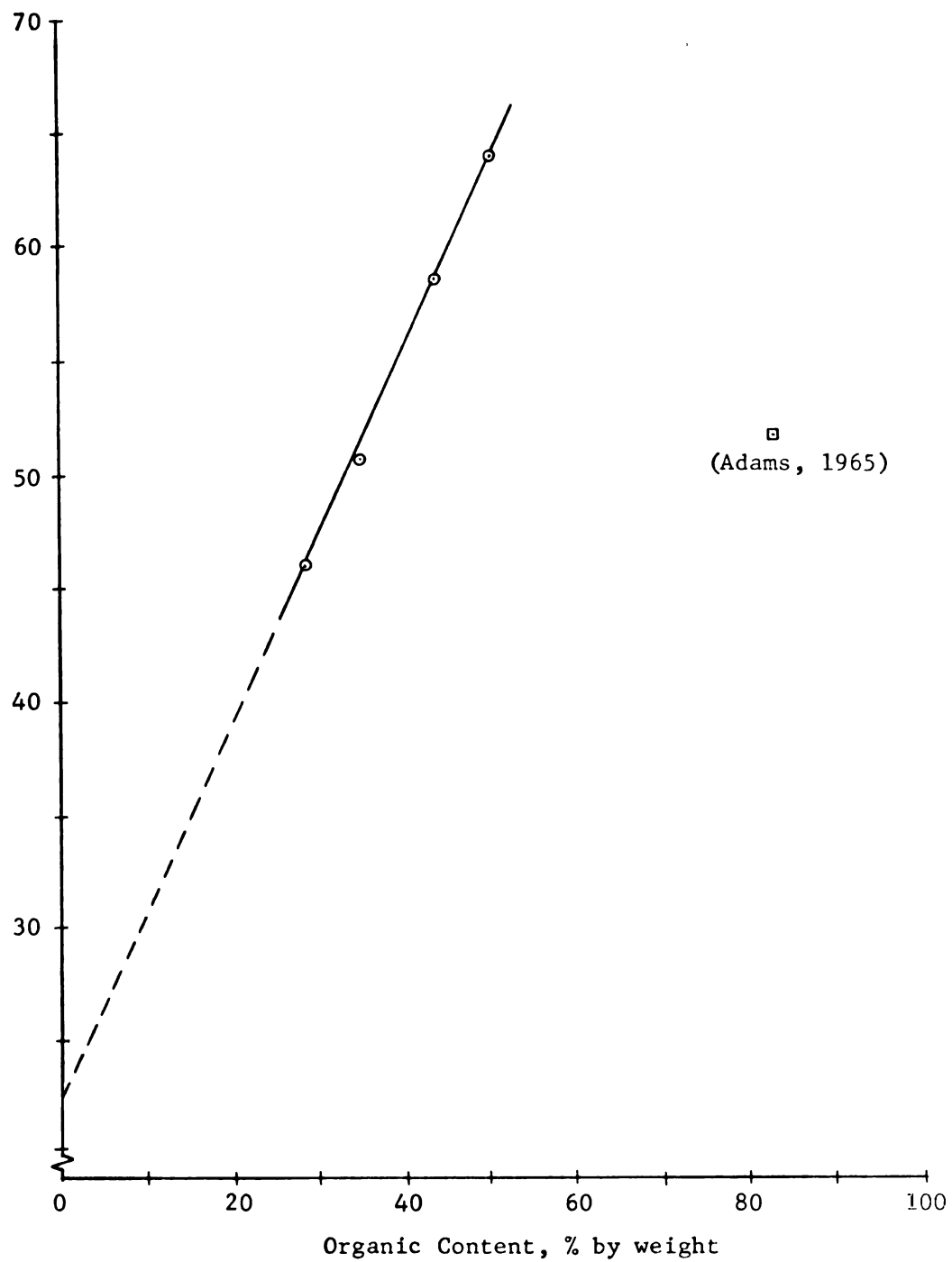


Figure 6.2 Organic Content and Angle of Internal Friction $\bar{\phi}$, Sludge H-2

assuming that the organic content equals one minus the ash content. It may be that the friction angle would continue to increase to some peak value and then decrease. If sludge decomposition is represented by a decrease in organic fiber content, then for the same effective normal stress, the frictional aspects of the shear strength will decrease due to the reduction in the angle of internal friction. This may not be as serious as it appears since cellulose decomposition requires the presence of available nitrogen (Umbreit, 1962) which has been reported lacking in pulp and papermill sludges. Mazzola (1969) observed very little decomposition visually in sludge samples representing ages of 1 and 12 years taken in the same deposit. Natural sludge C-1, with a higher organic content, has close to the same ϕ as does natural sludge H-2. Longer and larger diameter fibers and the presence of organic material in sludge C-1 may be responsible for similar ϕ values at different organic contents. The large ϕ value for sludge H-1 with a low organic content, may be related to the size of the organic fiber present. It was so small that visual observations were not recorded. Small values for the cohesion $\bar{c}$ were found for sludge H-2 at the lower organic contents and for natural sludge C-1. It is possible that some preconsolidation during sample preparation or small experimental error during the triaxial test could be responsible.

Water content - consolidation pressure curves are included for each series of triaxial test data given in

chapter 5. A comparison of these water contents for different organic contents is given in Figure 6.3. With increasing organic contents, the reduction in water content is greater for the same increase in consolidation pressure. At the same time, the higher organic contents are responsible for a greater water retention at a given consolidation pressure as shown in Figure 5.32. As the organic content increases, the effective pore space must be increased such that the free water can drain more readily. The relative proportions of interstitial water and water of imbibition must increase with an increase in organic content.

Undrained shear strengths for the different organic contents are compared in Figure 6.4 for the range of consolidation pressures used in the triaxial tests. Experimental error appears to hide most of the influence of the organic content on c_u . The higher organic contents appear to give the greater undrained strength for the higher consolidation pressures. At lower consolidation pressures, the lower organic content sludge gave the greater undrained strength. This behavior may be a consequence of the relatively greater reduction in water contents for the higher organic content sludges.

6.1.3 Lime and Flyash Admixtures

Lime or flyash admixtures were combined with the pulp and papermill sludge to determine whether improvements in the shear strength parameters would result. Data from Table 3.2 shows that the plasticity index of natural sludge

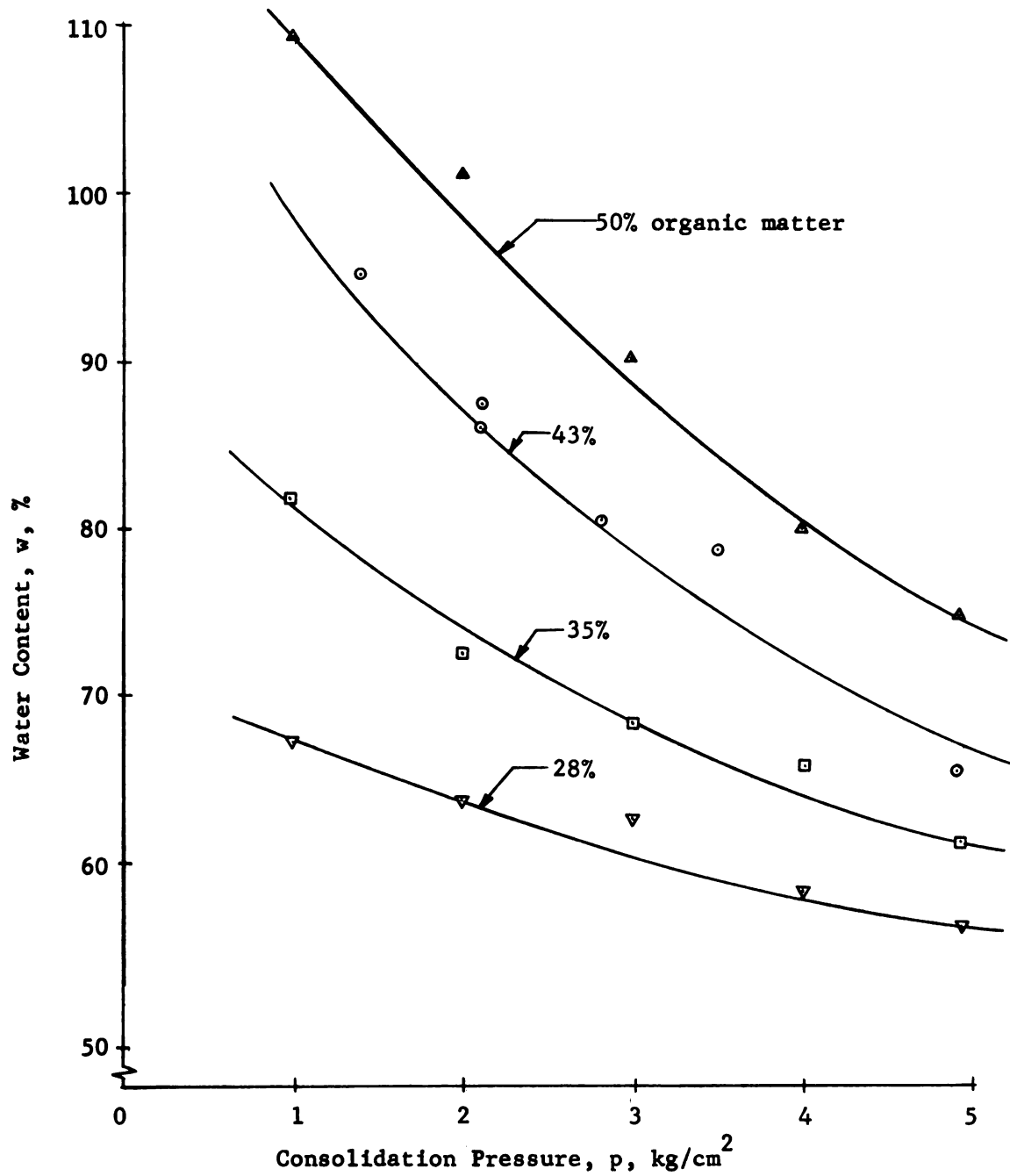


Figure 6.3 Water Contents after Consolidation in the Triaxial Cell at Different Organic Contents

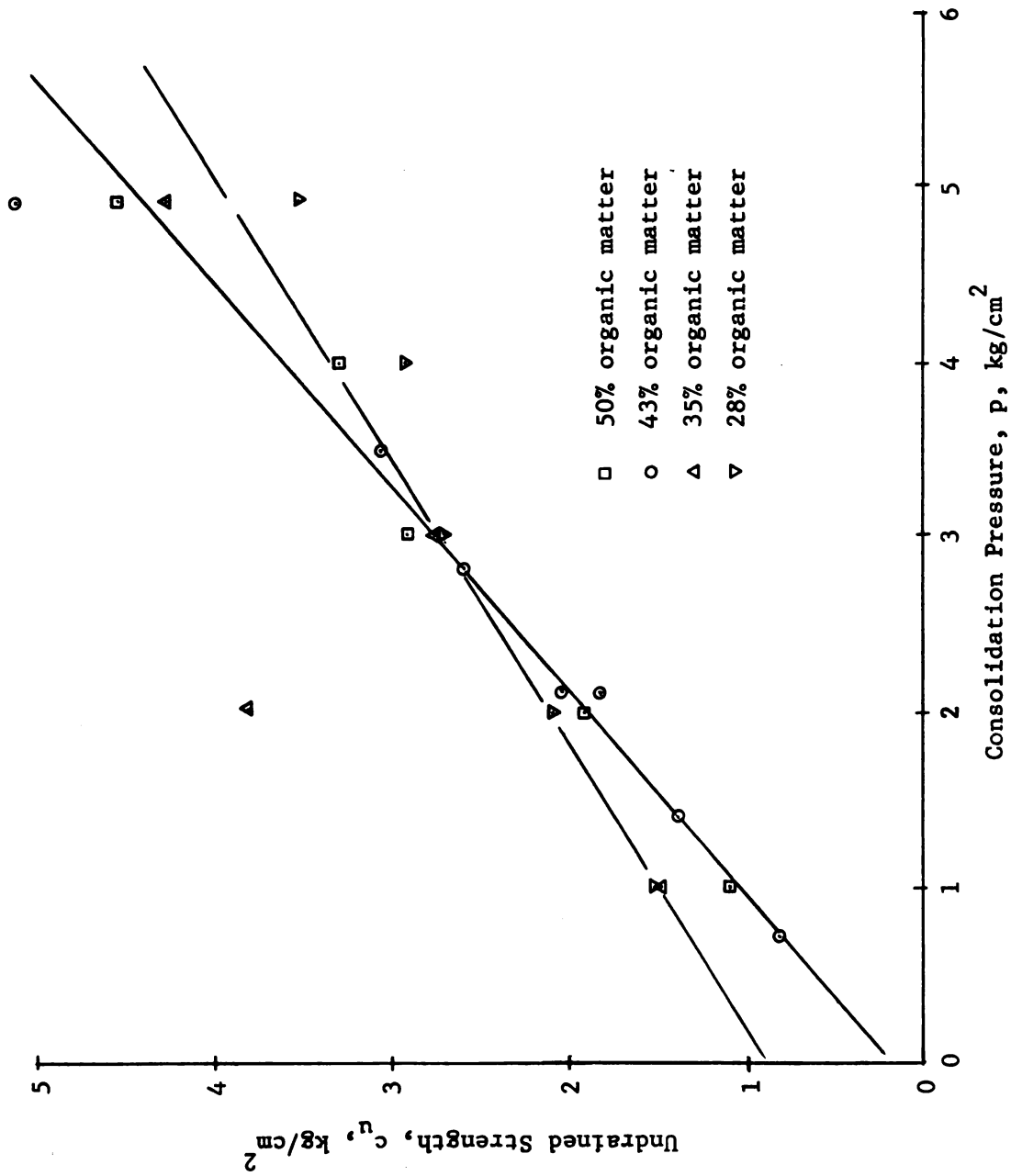


Figure 6.4 Undrained Strengths after Consolidation in the Triaxial Cell, Sludge H-2 at Different Organic Contents

H-2 was reduced from 67 to 28 by addition of 10 percent lime by dry weight. The shrinkage limit was increased. These changes are generally attributed to cation exchange, flocculation, and agglomeration in lime-soil mixtures (Thompson, 1966). Addition of flyash to sludge H-2 was not as effective as the lime in reducing the plasticity index and had little effect on the shrinkage limit.

Comparisons of the k_f lines are made in Figure 6.5 for natural sludge H-2 with 10 percent lime or flyash added. Any real changes in the angle of internal friction are not evident. These results tend to indicate that ϕ for the sludge is independent of combinations with either lime or flyash. A small cohesion value $\bar{c}$ was observed for each series of tests which included admixtures. Undrained shear strengths included in Figures 5.10 thru 5.14 show a greater scatter than when no admixtures were used. This may be due to variations in completion of any reactions of the lime or flyash with the sludge. Some increase in undrained strength for natural sludge H-2 is apparent. The results presented in Figure 5.14(c) indicate that for sludge C-1 plus 10 percent flyash the undrained strength has been altered. Cementation would alter the c_u versus p relationship as shown. The relative short period (four days) between sample preparation and shearing might limit the development of increased strengths. The presence of organic matter will also retard the strength producing lime-soil pozzolanic reaction (Thompson, 1966).

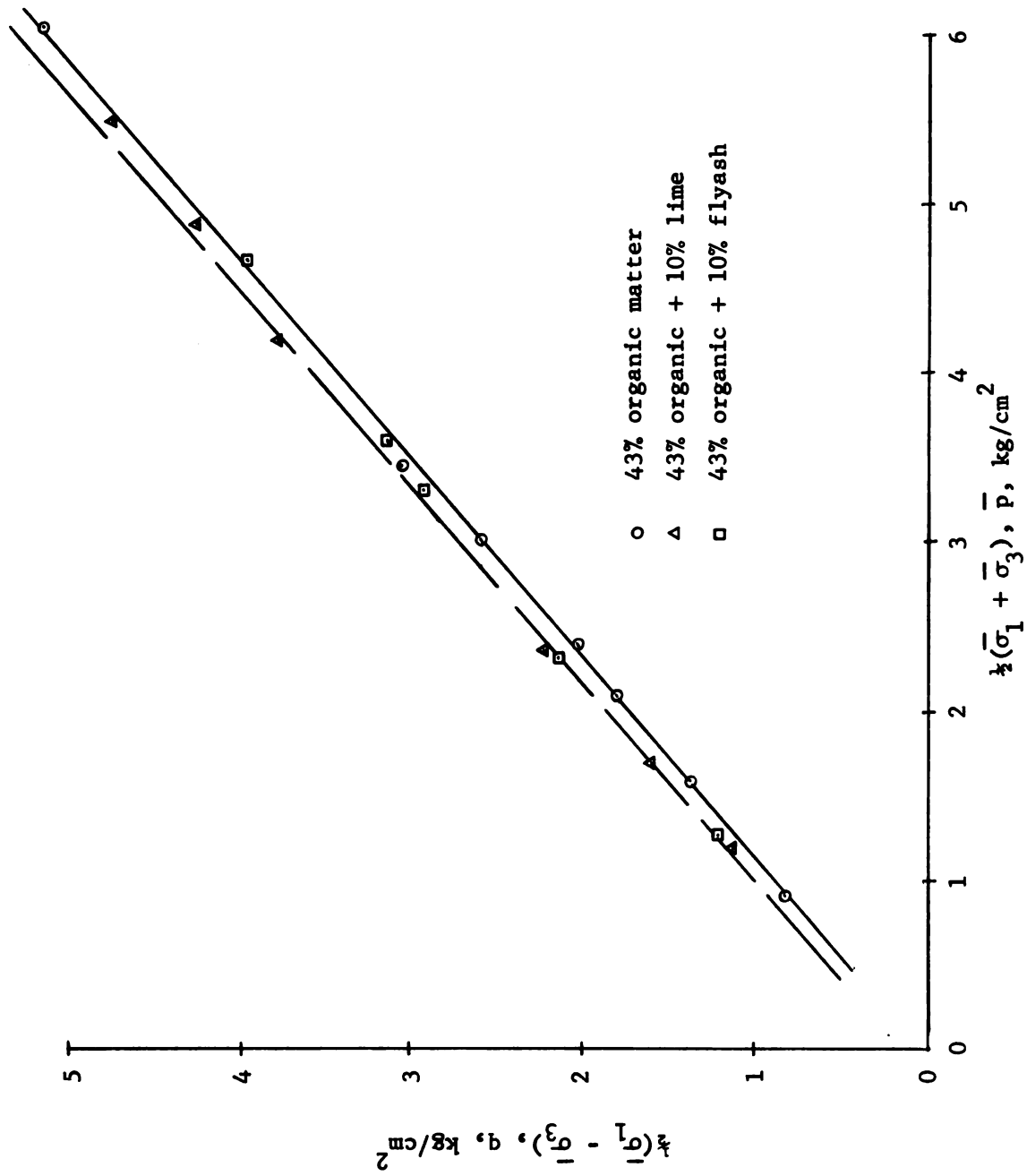


Figure 6.5 k_f Line for Natural Sludge H-2 Compared to k_f Line with 10% Lime and Flyash Admixtures Added

6.2 Permeability

6.2.1 Natural Sludges

The permeability of natural sludges H-2 and C-1 given in Figures 5.15 and 5.16 change significantly with increases in backpressure or average head. Minute air bubbles entrapped within the material during sludge dewatering or formed by decomposition greatly reduced the pore area available for fluid flow. Reduction in this air volume is approximated by Boyle's law at low backpressures. As the average head increases, Henry's law of solubility must also be considered. Bishop and Elden (1950) have derived the expression

$$\Delta u_{a_s} = u_{a_o} \frac{(1 - S_o)}{S_o H} \quad (6.2)$$

for computation of the pressure increase, Δu_{a_s} , needed to obtain full saturation. The initial degree of saturation when the sample is unconfined equals S_o , the initial pressure of the air in the voids when the sample is unconfined equals u_{a_o} , and H is Henry's coefficient of solubility (approximately 0.02 cc of air per cc of water at 20° C). The curves given in Figures 5.15 and 5.16 indicate that the effect of air bubbles on the permeability disappears in the vicinity of 60 to 120 feet of head of water (26 to 52 psi). This is predicted by Eq. 6.2 for an initial degree of saturation in the range of 92 to 98 percent. The measured degree of saturation ranged from 92 to 97.5 percent.

At low backpressures a certain hydraulic head was required to initiate flow as listed in Table 5.6. With a

total absence of backpressure, this gradient was approximately 12. This magnitude then decreased with an increase in backpressure and appeared to be related to air bubbles contained in the sludge pores. This deviation from Darcy's law has serious implications with respect to sludge drainage and consolidation in field embankments where the gradients may be close to unity. It explains why the sludge deposits studied by Mazzola (1969) showed little change in water content since placement several years earlier and why no settlement has occurred at many mills' disposal areas. The incorporation of sand drains or drainage blankets and possible surcharge loads in a fill project will contribute to better drainage and more rapid consolidation.

To verify that air bubbles in the sludge were responsible for the reduced permeability at low backpressures, certain samples were subjected to a vacuum and/or treated with a sterilant prior to testing. The vacuum essentially removed all the existing air bubbles while the sterilant (mercuric oxide) greatly reduced biological decomposition and hence, the formation of additional gas bubbles. The effectiveness of these pretreatments is shown in the top curves of Figures 5.15 and 5.16. The combination of both pretreatments almost totally reduced the dependence of the permeability on the average head. At low backpressures, however, some increase in permeability is still noted with an increase in the hydraulic gradient. De Wiest (1969) states that such behavior is typical in materials composed

partially of asymmetrical particles. Increased heads or velocities tend to reorient these particles into a parallel structure. This reorientation enlarges the cross sectional area, reduces the tortuosity of the flow path, and increases the permeability. Due to the elongated fibers, pulp and papermill sludges have such a structure. Other possible factors that could contribute to the variance from a constant value include small experimental defects in equipment and that only a 10 psi vacuum was available. With the removal of the entrapped air, the need for a certain hydraulic gradient to initiate flow was eliminated.

The permeability of soil is dependent on a number of factors which include the void ratio (Taylor, 1948). Void ratio is defined as the ratio of void volume to solid volume. For the sludges, it was convenient to determine the relationship between solids content and permeability. The relationship between permeability, solids content, and average head is shown for sludge H-2 in a three-dimensional plot in Figure 5.17. At 60 percent solids by weight the permeability approaches 10^{-8} cm/sec. This is significant since materials with values in this range are considered impermeable. As a result, it may be expected that consolidation will be a long term process and noticeable settlement will cease with the material at a relatively high water content. A similar type of influence of solids content on permeability is indicated for sludge C-1 in Figure 5.18.

6.2.2 Organic Content

The water content versus consolidation pressure curves shown in Figure 6.3 clearly illustrate the large effect that sludge organic content must have on the permeability. The results presented in Figure 5.19 show this influence of organic content on permeability at four solids contents. Permeability data from Figure 5.19, at an average head of 150 feet of water, is plotted against organic content in Figure 6.6. The four curves illustrate that no simple relationship exists between permeability and organic content and that additional variables must be considered. Taylor (1948) gives an expression for the permeability k of a soil as

$$k = D_s^2 \frac{\gamma_w}{\mu} \frac{e^3}{1+e} C \quad (6.3)$$

From the terms on the right hand side of this expression, the following outline of factors relate to the pulp and papermill sludges.

1. D_s represents the average grain size for a soil and for a given soil is constant. The preparation procedures outlined in Chapter III for changing the organic content did not maintain an average particle size as all the fines were washed through the sieve.

2. The second factor depends on the properties of the pore fluid where γ_w is the unit weight and μ is the viscosity. Increasing the organic content may increase the overall viscosity of the pore fluid in that more water is held by adsorption on the surfaces of the fibers and other organic

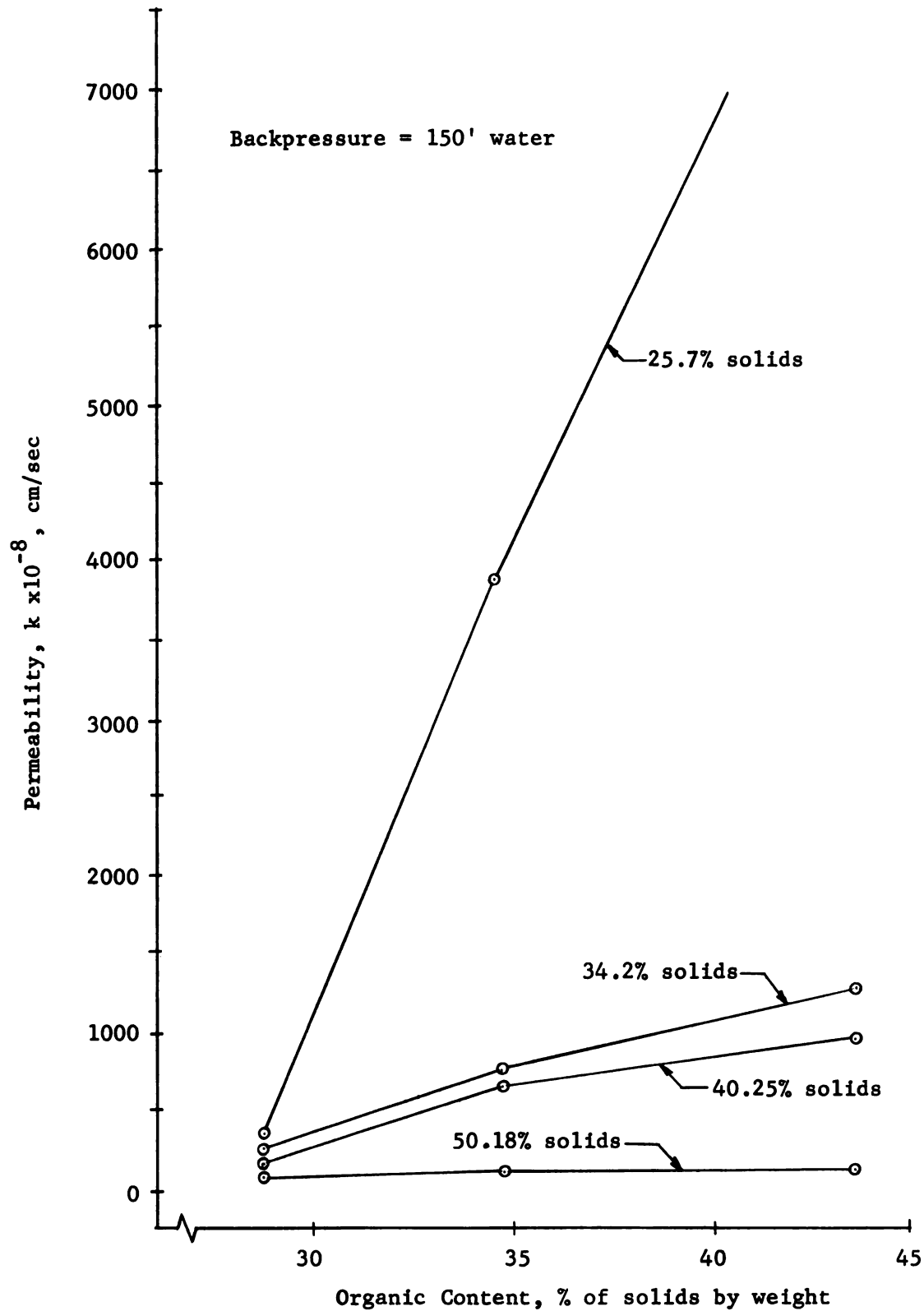


Figure 6.6 Permeability, Organic Content, and Solids Content Relationships for Sludge H-2

particles. The water retention curves shown in Figure 5.32 support this in that more water is held at a given tension for sludge samples with higher organic contents.

3. For soils, the permeability is dependent on the void ratio e . For the same solids content by weight, addition of fibrous material to sludge appears to increase the void ratio. This may result from the fibrous material being somewhat compressible. Seepage can occur, however, through only part of the pore space as part of the water is bound to the fibers and other organic particles. No method is available at present for obtaining values for a ratio between the volume of free water and that fixed.

4. Permeability also depends on the shapes and arrangements of pores, or on the sludge structure, as represented by the composite shape factor C . Shapes of the fibrous organic particles differ significantly from clay particles, hence, the shape factor will change with a change in organic content. De Wiest (1969) also indicates that there is reason to believe particles shaped as the fiber is will reorientate in passing a fluid. Hence, the more fiber, the more reorientation.

5. Permeability depends on the amount of undissolved gas within the media. This factor would appear to be constant for the backpressure of 150 feet of water considered in Figure 6.6.

The changes in permeability shown in Figure 6.6 must be due to changes in the first four factors above which, by

the nature of the material would be very difficult to consider separately.

The mechanical change of organic content used for sludge H-2 was intended to give some insight as to possible changes in engineering characteristics of the sludge during decomposition. In nature this decomposition will be accompanied by the formation of gases. Data shown in Figure 6.6 has excluded this factor by considering a backpressure of 150 feet of water. The hydraulic heads existing in most sludge embankments will normally be in the range of 0 to 60 feet of water. Hence, it can be expected that gas formation will contribute to a decrease in permeability in these embankments.

6.2.3 Lime and Flyash Admixtures

The chemical reactions which occur when lime or flyash is mixed with a soil or sludge tend to improve drainability and increase permeability. The water retention curve given in Figure 5.32 for sludge H-2 plus 10 percent lime shows a relatively large reduction in water holding ability as compared to the natural sludge. Arman and Munfakh (1970) state that when lime is added to an organic soil, some of the Ca^{++} ions are used to satisfy the exchange capacity of the organic matter. This would alter the sludge-water relationships. The permeability of sludges H-2 and C-1 does increase with the addition of lime and flyash as shown in Figures 5.20 - 5.23 and 5.25 - 5.28. Data from Figures 5.22 and 5.28 has been used in Figure 6.7 to show the relative

change in permeability of sludge H-2 with both lime and flyash. Lime is seen to be approximately twice as effective as flyash. The total change in permeability is relatively small.

The presence of entrapped gas within the material also made it necessary to treat the samples containing the lime or flyash with the sterilant and to subject them to a vacuum in order to obtain a relatively constant permeability at low backpressures. The lime admixture appeared to reduce the capacity of the sludge to retain the air bubbles within the mass. This behavior would account for the increase observed in the permeabilities with no backpressure and would be beneficial in improving the drainability and consolidation of a sludge embankment. With flyash, the significance of the entrapped air was similar to that for the natural sludges.

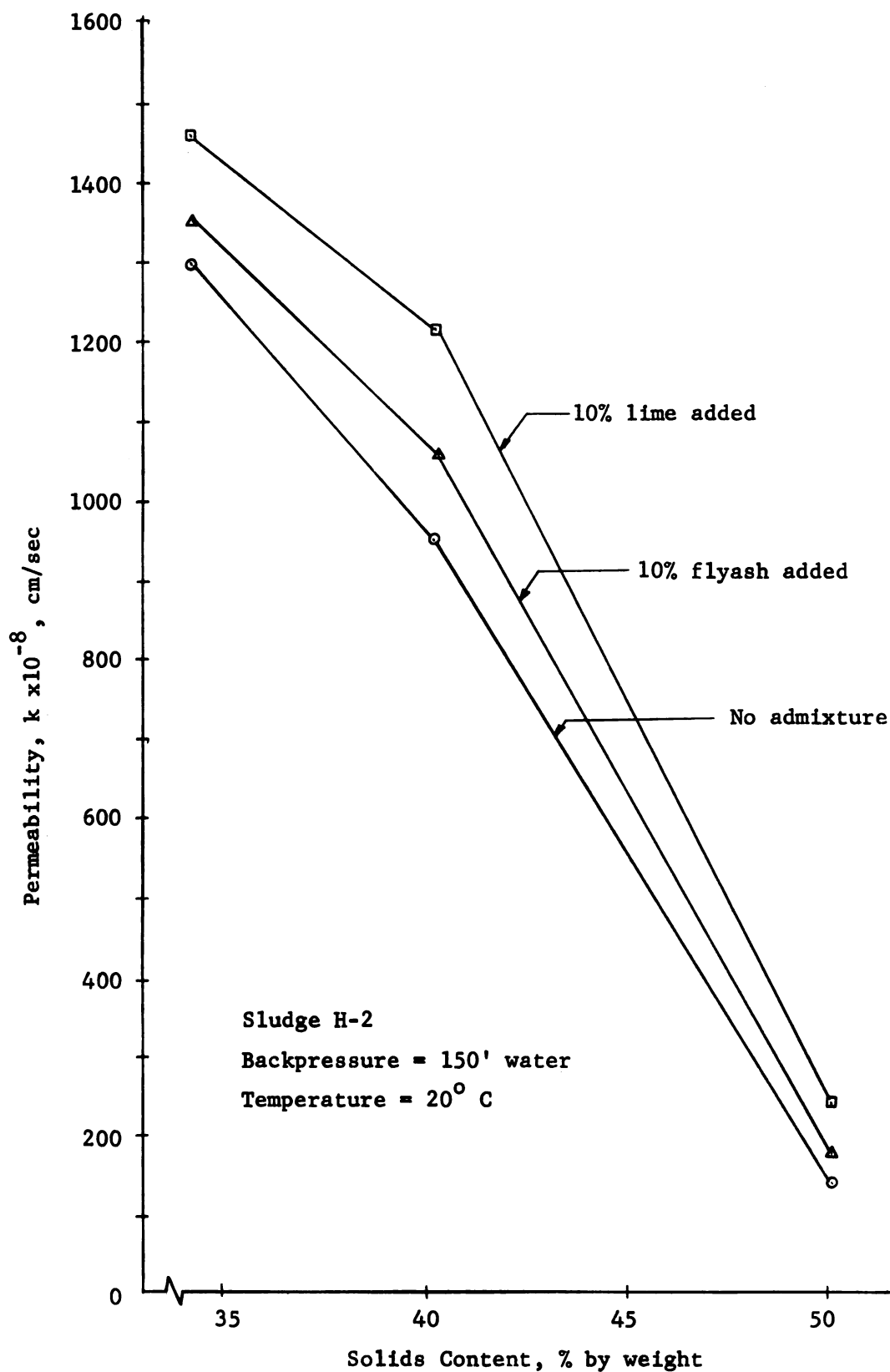


Figure 6.7 Permeability, Solids Content, and Lime or Flyash Relationships for Sludge H-2

CHAPTER VII

SUMMARY AND CONCLUSIONS

The summary and conclusions are presented under two headings: shear strength parameters and permeability of pulp and papermill sludges. Items covered under each heading are intended to reflect the findings of this study and are limited to the sludges studied, the methods of sample preparation, and the test procedures employed.

7.1 Shear Strength Parameters

Two sludges, one from an integrated pulp and papermill and the other from a secondary fiber mill, were subjected to a series of consolidated-undrained triaxial tests in three forms; (1) the natural state, (2) combined with 10 percent lime or flyash, and (3) sludge H-2 with different organic contents. Experimental data was summarized in terms of typical stress-strain curves, $\bar{p} - q$ plots which gave the angle of internal friction and cohesion on an effective stress basis, and water content and undrained strength relationships to all-around consolidation pressure. The following conclusions on shear strength are based on the above results and information available in the field of soil mechanics.

1. The engineering characteristics of dewatered pulp and papermill sludges are influenced by their solids content, the amount of organic material present, and the character of this organic material. Sludge H-2 would not maintain the required triaxial sample shape for samples containing less than about 42 percent solids by weight. Sludge C-1, with more and larger fibrous materials, required about 35 percent solids by weight to maintain its shape. This means that field embankments constructed of similar sludges must have lateral supports in the form of dikes until water drainage is sufficient to mobilize the required shear strength.

2. Triaxial test data shows that the strength of pulp and papermill sludges is essentially frictional and in accordance with the principal of effective stress. For the dewatered sludges the observed angle of internal friction $\bar{\phi}$ was close to 58 degrees and the cohesion was approximately zero. Thus, for practical purposes, the shear stress at failure, τ_f , can be represented by the equation

$$\tau_f = \bar{\sigma} \tan \bar{\phi} \quad (7.1)$$

3. The stress-strain curves show that large strains are required to fully mobilize the available shear strength. This implies that in a design situation, deformation or settlement may govern before stability. That is, an embankment may remain stable but deformations may become so large as to be unacceptable.

4. The angle of internal friction appears to be dependent

on the organic content of the sludge. For sludge H-2, the ϕ values ranged from 64 degrees at an organic content of 50.1 percent down to about 38 degrees for an organic content of 28.6 percent. If sludge decomposition means a reduction in fiber content, then the shear strength will decrease in accordance with equation 7.1. This may not be as serious as the strength data indicates. Mazzola (1969) observed no visually evident decomposition in sludge samples of the same deposit representing ages of 1 and 12 years.

5. The undrained strength of pulp and papermill sludges appears to be directly related to the consolidation pressure. This means for a uniform sludge deposit the undrained strength should increase linearly with depth.

6. The lime and flyash admixtures appear to have little effect on the angle of internal friction ϕ . A small cohesion value $\bar{c}$ was observed for each series of tests including these admixtures. Some increase in the undrained strength of sludge H-2 is apparent. These changes in $\bar{c}$ and c_u are small but would contribute to the stability of a sludge embankment.

7.2 Permeability of Pulp and Papermill Sludges

The same two sludges were tested in a variable head permeameter in the same forms as above. Experimental data was presented for a range of backpressures and at several solids contents. The presence of minute gas bubbles entrapped within the sludge mass was allowed for by pretreatment of the sludge with a biological sterilant and a vacuum

prior to testing. The following conclusions are based on the permeability test data and information available in the soil mechanics literature.

1. The permeability of pulp and papermill sludges is greatly affected by minute air bubbles entrapped within the sludge mass as shown in Figures 5.15 and 5.16. This gas will dissolve in the pore fluid or reduce to an insignificant volume when the backpressure or average head is increased to a certain value. This backpressure can be estimated by equation 6.2 (Bishop and Eldin, 1950) derived on the basis of Boyle's law and Henry's law of solubility.

2. Pretreatment of the sludge with a sterilant (mercuric oxide) and subjecting the sample to a vacuum eliminates the problem of minute air bubbles at low backpressures. The results of the mercuric oxide pretreatment indicate some biological decomposition is taking place and that mercuric oxide is effective in reducing this to a point where little additional gas is formed.

3. At low backpressures the natural sludges require a threshold hydraulic gradient to initiate flow. With sludge H-2 and no backpressure this gradient was as high as 11.77. As backpressures were sufficiently increased, this threshold gradient disappeared. This phenomena explains why the existing sludge deposits (Mazzola, 1969) have shown little decrease in water content over a period of several years.

4. Permeability of the sludge is a function of the organic content when the amount of fibrous material is changed by

washing the sludge through a U. S. Standard No. 16 sieve as described in section 3.4. This procedure served as a means to simulate decomposition. The experimental data showed a decrease in permeability with a decrease in the amount of fibrous material. At the same time the sludge would retain less water at the lower fiber contents.

5. Mixing the sludge with 10 percent lime or flyash by dry weight did increase the permeability to a small degree. Lime was approximately twice as effective as flyash. These admixtures would contribute to easier drainage of sludge deposits.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Adams, J. I., "Laboratory Compression Tests on Peat," Proceedings 7th Muskeg Research Conf., 1961.
- Adams, J. I., "The Engineering Behavior of a Canadian Muskeg," Proceedings 6th Internat. Conf. on Soil Mechanics and Found. Engr., Vol. I: pp 3-7, 1965.
- Arman, A., "A Definition of Organic Soils, An Engineering Identification," Engr. Research Bull. No. 101, Louisiana State University, Baton Rouge, Louisiana, 1969.
- Arman, A., and Munfakh, G. A., "Stabilization of Organic Soils with Lime," Engr. Research Bull. No. 103, Louisiana State University, Baton Rouge, Louisiana, 1970.
- Bishop, A. W., and Eldin, A. K. G., "Undrained Triaxial Tests on Saturated Sands and their Significance in the General Theory of Shear Strength," Geotechnique, Vol. II, pp 13-32, 1950.
- Bishop, A. W., and Henkel, D. J., The Measurement of Soil Properties in the Triaxial Test, Edward Arnold (publishers) Ltd., London, 1962.
- Baver, L. D., Soil Physics, 3rd ed., John Wiley & Sons, Inc., New York, 1956.
- De Wiest, R. J. M., Flow Through Porous Media, Academic Press, New York, 1969.
- Gehm, H. W., "Current Developments in the Dewatering of Papermill Sludges," National Council for Stream Improvement Tech. Bull. No. 113, March, 1959.
- Gehm, H. W., "Removal, Thickening, and Dewatering of Waste Solids," Pulp and Paper Magazine of Canada, March, 1960.
- Gibbs, H. J., Hilf, J. W., Holtz, W. G., and Walker, F. C., "Shear Strength of Cohesive Soils," Proceedings, Research Conf. on Shear Strength of Cohesive Soils, A.S.C.E., 1960.

- Gillespie, W. J., Gellman, I., and Janes, R. L., "Utilization of High Ash Papermill Waste Solids," National Council of the Paper Industry for Air and Stream Improvement, Inc., 1970.
- Gupta, R. P., and Swartzendruber, D., "Flow-Associated Reduction in the Hydraulic Conductivity of Quartz Sand," Proceedings, Soil Science Society of Am., pp 6-10, 1962.
- Hanrahan, E. T., "An Investigation of Some Physical Properties of Peat," Geotechnique, Vol. IV, pp 108-23, 1954.
- Hardy, R. M., "Research on Shearing Strength of Muskeg and Its Application," Proceedings, 10th Muskeg Research Conf., National Research Council, Canada, pp 25-32, May, 1964.
- Jaky, J., "The Coefficient of Earth Pressure at Rest," Journal of the Society of Hungarian Architects and Engineers, pp 335-58, 1944.
- Lambe, T. W., Soil Testing for Engineers, John Wiley & Sons, Inc., New York, 1951.
- Lambe, T. W., and Whitman, R. V., Soil Mechanics, John Wiley & Sons, Inc., New York, 1969.
- Leonards, G. A., Foundation Engineering, McGraw-Hill Book Co., Inc., New York, 1962.
- Mazzola, C. A., "Soil Index Properties of High Ash Primary Pulp and Paper Sludges," National Council of the Paper Industry for Air and Stream Improvement, Inc., October, 1969.
- Miller, R. J., and Low, P. F., "Threshold Gradient for Water Flow in Clay Systems," Proceedings, Soil Science Society of Am., Vol. 27, No. 6, pp 605-9, November-December, 1963.
- Mitchell, J. K., and Younger, J. S., "Abnormalities in Hydraulic Flow Through Fine-Grained Soils," ASTM STP 417, pp 106-139, 1967.
- National Council for Air and Stream Improvement, Inc., "Mechanical Dewatering of Papermill Sludges," Tech. Bull. No. 37, October, 1950.
- _____, "Current Developments in the Dewatering of Papermill Sludges," Tech. Bull. No. 113, March, 1969.
- _____, "Recent Developments in the Disposal of Pulp and Paper Industry Sludges," Tech. Bull. No. 136, Nov., 1960.

- _____, "Mechanical Pressing of Primary Dewatered Papermill Sludges," Tech. Bull. No. 174, June, 1964.
- _____, "Settleable Solids Removal Practices in the Pulp and Paper Industry," Tech. Bull. No. 178, Nov., 1964.
- _____, "Manual of Practice for Sludge Handling in the Pulp and Paper Industry," Tech. Bull. No. 190, June, 1966.
- Richards, B. G., "Moisture Flow and Equilibria in Unsaturated Soils for Shallow Foundations," Permeability and Capillarity of Soils, ASTM STP 417, pp 4-23, 1967.
- Scott, R. F., Principles of Soil Mechanics, Addison Wesley Publishing Co., Reading, Mass., 1963.
- Taylor, D. W., Fundamentals of Soil Mechanics, John Wiley & Sons, Inc., New York, 1948.
- Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, 1st ed., John Wiley & Sons, Inc., New York, 1948.
- _____, Soil Mechanics in Engineering Practice, 2nd ed., John Wiley & Sons, Inc., New York, 1967.
- Thompson, "Lime Reactivity of Illinois Soils," Journal of Soil Mechanics and Found. Engr., Vol. 92, SM 5, pp 67-92, September, 1966.
- Umbreit, W. W., "Soil Microbiology," Modern Microbiology, W. H. Freeman and Co., San Francisco, 1962.
- Waksman, S. A., "Cellulose and Sludge Decomposition in Soil," National Council for Air and Stream Improvement, Inc., Tech. Bull. No. 120, 1960.
- Wu, T. H., Soil Mechanics, Allyn and Bacon, Inc., Boston, 1966.

APPENDIX A
TRIAXIAL TEST DATA

Table A-1 Data, Triaxial Test A-1

Sludge H-1					
$p = 0.70 \text{ kg/cm}^2$			$w_f = 71.38\%$		
$\bar{\sigma}_{1f} = 2.34 \text{ kg/cm}^2$			$c_u = 1.05 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.24 \text{ kg/cm}^2$			$A_f = 0.33$		
$u_f = 2.57 \text{ kg/cm}^2$			$c_v = 0.0013 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	0.73	0.73
1.36	0.0472	2.14	0.68	0.84	0.67
3.17	0.0554	2.16	0.80	1.03	0.65
5.90	0.0617	2.22	0.89	1.29	0.59
7.71	0.0688	2.26	1.00	1.47	0.56
10.89	0.1074	2.36	1.55	1.73	0.45
11.79	0.1382	2.39	2.00	1.80	0.42
13.15	0.2090	2.45	3.02	1.89	0.37
14.06	0.2786	2.47	4.03	1.96	0.34
14.97	0.3665	2.50	5.30	2.01	0.32
15.42	0.4171	2.50	6.03	2.04	0.31
16.78	0.5542	2.52	8.02	2.13	0.29
18.14	0.7323	2.54	10.59	2.20	0.27
19.05	0.8402	2.56	12.15	2.25	0.25
19.96	0.9776	2.57	14.14	2.29	0.25
20.87	1.1389	2.57	16.47	2.32	0.24
21.32	1.2344	2.57	18.56	2.34	0.24
21.77	1.4132	2.57	20.05	2.34	0.24

Table A-2 Data, Triaxial Test A-2

Sludge H-1					
$p = 1.40 \text{ kg/cm}^2$			$w_f = 67.62\%$		
$\bar{\sigma}_{1f} = 4.35 \text{ kg/cm}^2$			$c_u = 2.04 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.26 \text{ kg/cm}^2$			$A_f = 0.27$		
$u_f = 3.25 \text{ kg/cm}^2$			$c_v = 0.0019 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.14	0.00	1.43	1.43
5.90	0.0064	2.21	0.10	2.02	1.31
11.34	0.0132	2.35	0.20	2.54	1.17
13.61	0.0196	2.43	0.30	2.73	1.09
14.97	0.0259	2.48	0.39	2.84	1.03
16.78	0.0381	2.57	0.58	2.98	0.95
18.14	0.0536	2.65	0.82	3.05	0.87
19.05	0.0691	2.71	1.05	3.10	0.81
21.32	0.1387	2.84	2.11	3.21	0.67
24.04	0.2670	2.98	4.06	3.34	0.54
26.31	0.4120	3.04	6.27	3.47	0.47
28.12	0.5392	3.09	8.21	3.56	0.42
30.39	0.6736	3.13	10.24	3.70	0.38
32.21	0.7920	3.16	12.06	3.79	0.35
35.83	0.9992	3.21	15.21	4.00	0.31
39.01	1.1720	3.23	17.84	4.18	0.29
41.73	1.2992	3.25	19.78	4.33	0.26
42.64	1.3404	3.26	20.40	4.38	0.26
46.27	1.4961	3.28	22.77	4.58	0.24
50.80	1.6525	3.29	25.16	4.84	0.22

Table A-3 Data, Triaxial Test A-3

Sludge H-1					
$p = 2.11 \text{ kg/cm}^2$			$w_f = 59.51\%$		
$\bar{\sigma}_{1f} = 5.07 \text{ kg/cm}^2$			$c_u = 2.34 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.38 \text{ kg/cm}^2$			$A_f = 0.35$		
$u_f = 3.83 \text{ kg/cm}^2$			$c_v = 0.0015 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	2.18	2.18
1.81	0.0305	2.15	0.47	2.29	2.06
9.07	0.0391	2.30	0.60	3.06	1.92
16.78	0.0523	2.53	0.80	3.79	1.68
21.32	0.0747	2.84	1.14	4.05	1.38
24.95	0.1389	3.10	2.12	4.21	1.12
26.76	0.1938	3.22	2.96	4.28	0.99
28.58	0.2692	3.34	4.11	4.34	0.87
29.94	0.3409	3.47	5.20	4.34	0.75
30.85	0.4105	3.51	6.26	4.37	0.71
31.75	0.4557	3.53	6.95	4.42	0.68
32.66	0.5075	3.56	7.64	4.47	0.66
33.57	0.5626	3.57	8.58	4.53	0.64
34.47	0.6299	3.61	9.61	4.55	0.60
35.38	0.6812	3.63	10.39	4.59	0.58
37.20	0.7940	3.68	12.12	4.67	0.53
39.92	0.9596	3.73	14.64	4.79	0.48
41.73	1.0757	3.77	16.41	4.87	0.45
44.45	1.2134	3.81	18.51	5.00	0.41
46.27	1.3122	3.83	20.02	5.07	0.38
48.99	1.4534	3.84	22.18	5.20	0.37
52.62	1.6205	3.87	24.73	5.36	0.35
53.52	1.6586	3.87	25.31	5.41	0.34
56.24	1.7983	3.86	27.44	5.52	0.36

Table A-4 Data, Triaxial Test A-4

Sludge H-2, 43% organic matter					
$p = 0.70 \text{ kg/cm}^2$		$w_f = 111.69\%$			
$\bar{\sigma}_{1f} = 1.74 \text{ kg/cm}^2$		$c_u = 0.83 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.08 \text{ kg/cm}^2$		$A_f = 0.37$			
$u_f = 2.73 \text{ kg/cm}^2$		$c_v = 0.0038 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	0.70	0.70
2.59	0.0066	2.14	0.10	0.99	0.67
3.70	0.0137	2.16	0.22	1.12	0.65
4.44	0.0185	2.17	0.29	1.20	0.64
4.81	0.0234	2.18	0.37	1.23	0.63
5.54	0.0356	2.21	0.56	1.30	0.60
6.28	0.0566	2.25	0.89	1.35	0.56
6.65	0.0653	2.27	1.03	1.37	0.54
7.76	0.1344	2.37	2.11	1.40	0.45
8.50	0.2073	2.43	3.25	1.42	0.39
8.87	0.2603	2.46	4.09	1.42	0.35
9.61	0.3612	2.51	5.67	1.45	0.31
9.98	0.4199	2.53	6.59	1.46	0.28
10.72	0.5403	2.57	8.48	1.48	0.24
11.46	0.6485	2.61	10.18	1.49	0.20
12.57	0.8258	2.65	12.97	1.53	0.16
13.31	0.9235	2.67	14.50	1.57	0.14
14.42	1.0559	2.69	16.58	1.63	0.12
15.52	1.1890	2.71	18.67	1.68	0.10
16.45	1.2756	2.73	20.03	1.74	0.08
17.93	1.4056	2.74	22.07	1.82	0.07
18.67	1.4704	2.75	23.09	1.86	0.06

Table A-5 Data, Triaxial Test A-5

Sludge H-2, 43% organic matter					
$p = 1.40 \text{ kg/cm}^2$			$w_f = 95.13\%$		
$\bar{\sigma}_{1f} = 2.97 \text{ kg/cm}^2$			$c_u = 1.38 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.20 \text{ kg/cm}^2$			$A_f = 0.43$		
$u_f = 3.31 \text{ kg/cm}^2$			$c_v = 0.0043 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	1.41	1.41
3.70	0.0071	2.12	0.11	1.88	1.39
5.55	0.0124	2.18	0.20	2.06	1.33
7.02	0.0190	2.25	0.31	2.18	1.27
8.13	0.0254	2.30	0.41	2.27	1.21
9.61	0.0373	2.39	0.60	2.37	1.12
10.72	0.0488	2.45	0.79	2.45	1.06
11.46	0.0630	2.51	1.02	2.49	1.01
14.05	0.1367	2.71	2.20	2.61	0.81
15.16	0.1941	2.80	3.13	2.64	0.72
15.52	0.2588	2.85	4.18	2.61	0.66
16.26	0.3302	2.92	5.33	2.61	0.59
17.01	0.3980	2.97	6.42	2.63	0.55
17.74	0.4737	3.01	7.64	2.65	0.51
18.11	0.5121	3.03	8.26	2.66	0.49
18.85	0.5918	3.07	9.55	2.68	0.45
19.22	0.6317	3.09	10.19	2.69	0.43
20.70	0.7684	3.13	12.40	2.75	0.38
21.91	0.8727	3.18	14.08	2.79	0.34
23.29	1.0099	3.23	16.29	2.84	0.29
24.77	1.1237	3.28	18.13	2.89	0.24
26.62	1.2482	3.31	20.14	2.98	0.20
28.47	1.3650	3.34	22.02	3.07	0.17
30.68	1.4895	3.38	24.03	3.18	0.14
32.16	1.5644	3.40	25.24	3.26	0.12
33.27	1.6165	3.40	26.08	3.33	0.11
36.60	1.7536	3.42	28.29	3.52	0.09

Table A-6 Data, Triaxial Test A-6

Sludge H-2, 43% organic matter					
$p = 2.11 \text{ kg/cm}^2$			$w_f = 85.87\%$		
$\bar{\sigma}_{1f} = 3.92 \text{ kg/cm}^2$			$c_u = 1.82 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.28 \text{ kg/cm}^2$			$A_f = 0.50$		
$u_f = 3.94 \text{ kg/cm}^2$			$c_v = 0.0036 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	2.11	2.11
7.02	0.0168	2.55	0.28	2.68	1.67
7.76	0.0188	2.57	0.31	2.77	1.65
9.61	0.0254	2.62	0.42	2.98	1.60
10.72	0.0310	2.66	0.51	3.10	1.56
11.46	0.0356	2.69	0.59	3.18	1.53
12.94	0.0488	2.76	0.81	3.31	1.46
14.05	0.0602	2.82	1.00	3.40	1.40
17.01	0.1227	3.05	2.03	3.57	1.17
18.48	0.1905	3.21	3.15	3.60	1.01
19.59	0.2611	3.33	4.32	3.60	0.89
20.33	0.3127	3.38	5.17	3.62	0.84
21.81	0.4305	3.49	7.12	3.65	0.73
22.55	0.5016	3.54	8.30	3.66	0.67
23.29	0.5685	3.59	9.41	3.67	0.62
24.03	0.6294	3.63	10.42	3.70	0.59
25.50	0.7686	3.72	12.72	3.72	0.50
27.36	0.9200	3.80	15.22	3.77	0.42
29.57	1.0841	3.88	17.94	3.84	0.34
31.79	1.2245	3.95	20.26	3.93	0.27
34.02	1.3564	4.00	22.45	4.02	0.22
37.71	1.5303	4.05	25.32	4.23	0.17
42.88	1.7480	4.06	28.93	4.56	0.16

Table A-7 Data, Triaxial Test A-7

Sludge H-2, 43% organic matter					
$p = 2.11 \text{ kg/cm}^2$			$w_f = 87.22\%$		
$\bar{\sigma}_{1f} = 4.45 \text{ kg/cm}^2$			$c_u = 2.05 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.36 \text{ kg/cm}^2$			$A_f = 0.43$		
$u_f = 3.86 \text{ kg/cm}^2$			$c_v = 0.0042 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	2.11	2.11
6.35	0.0122	2.20	0.21	2.88	2.02
9.07	0.0183	2.26	0.31	3.20	1.96
10.89	0.0254	2.31	0.43	3.39	1.91
11.79	0.0307	2.35	0.52	3.47	1.87
12.70	0.0373	2.39	0.63	3.55	1.82
14.06	0.0480	2.47	0.81	3.65	1.75
15.42	0.0635	2.53	1.07	3.77	1.68
18.60	0.1219	2.78	2.05	3.92	1.43
20.41	0.1847	2.98	3.11	3.94	1.24
21.77	0.2476	3.10	4.17	3.97	1.12
22.68	0.3023	3.18	5.09	3.97	1.03
23.59	0.3604	3.29	6.07	3.95	0.93
24.49	0.4209	3.35	7.09	3.98	0.87
25.40	0.4790	3.40	8.07	4.01	0.82
26.31	0.5441	3.45	9.17	4.03	0.77
27.22	0.6142	3.50	10.35	4.05	0.72
28.58	0.7173	3.58	12.08	4.07	0.64
30.39	0.8252	3.66	13.90	4.13	0.56
32.66	0.9647	3.74	16.25	4.21	0.47
35.38	1.0975	3.82	18.49	4.33	0.40
38.10	1.2169	3.87	20.50	4.48	0.35
40.82	1.3327	3.94	22.45	4.60	0.28
44.45	1.4465	3.98	24.37	4.83	0.24
47.17	1.5235	3.99	25.66	5.02	0.23

Table A-8 Data, Triaxial Test A-8

Sludge H-2, 43% organic matter					
$p = 2.81 \text{ kg/cm}^2$			$w_f = 80.40\%$		
$\bar{\sigma}_{1f} = 5.62 \text{ kg/cm}^2$			$c_u = 2.60 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.42 \text{ kg/cm}^2$			$A_f = 0.46$		
$u_f = 4.50 \text{ kg/cm}^2$			$c_v = 0.0050 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.08	0.00	2.84	2.84
3.17	0.0071	2.08	0.12	3.29	2.84
4.99	0.0119	2.09	0.20	3.54	2.83
9.53	0.0183	2.12	0.31	4.15	2.80
11.79	0.0234	2.16	0.40	4.43	2.76
13.61	0.0297	2.19	0.50	4.65	2.73
15.42	0.0381	2.25	0.65	4.85	2.67
17.24	0.0495	2.32	0.84	5.03	2.60
19.05	0.0665	2.43	1.13	5.17	2.50
22.68	0.1278	2.80	2.17	5.27	2.12
24.49	0.1704	3.04	2.89	5.26	1.88
26.31	0.2304	3.27	3.91	5.23	1.65
28.12	0.3081	3.49	5.22	5.21	1.42
29.94	0.3998	3.72	6.78	5.16	1.20
31.75	0.4953	3.89	8.40	5.15	1.03
32.66	0.5364	3.94	9.10	5.19	0.97
33.57	0.5893	4.02	9.99	5.19	0.90
36.28	0.7506	4.17	12.73	5.24	0.75
38.10	0.8341	4.26	14.14	5.30	0.66
40.82	0.9779	4.37	16.58	5.38	0.55
43.54	1.0937	4.44	18.54	5.51	0.49
47.17	1.2299	4.53	20.85	5.69	0.39
48.99	1.2982	4.57	22.01	5.78	0.36
52.16	1.3985	4.62	23.71	5.95	0.31

Table A-9 Data, Triaxial Test A-9

Sludge H-2, 43% organic matter					
$p = 3.51 \text{ kg/cm}^2$			$w_f = 78.57\%$		
$\bar{\sigma}_{1f} = 6.53 \text{ kg/cm}^2$			$c_u = 3.07 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.40 \text{ kg/cm}^2$			$A_f = 0.39$		
$u_f = 5.23 \text{ kg/cm}^2$			$c_v = 0.0053 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	2.81	2.81
5.55	0.0058	2.90	0.10	3.53	2.72
10.72	0.0119	3.14	0.20	4.04	2.49
14.05	0.0175	3.30	0.30	4.36	2.33
16.27	0.0234	3.41	0.40	4.57	2.22
18.12	0.0302	3.49	0.51	4.74	2.13
19.22	0.0356	3.55	0.60	4.84	2.08
21.44	0.0475	3.67	0.80	5.04	1.95
22.92	0.0561	3.72	0.95	5.19	1.90
26.62	0.1191	4.00	2.02	5.40	1.62
28.83	0.1811	4.20	3.06	5.50	1.44
31.05	0.2593	4.35	4.39	5.58	1.27
34.01	0.3792	4.55	6.42	5.69	1.08
36.23	0.4892	4.67	8.28	5.77	0.95
38.44	0.5969	4.78	10.10	5.85	0.85
41.41	0.7336	4.89	12.41	5.99	0.73
44.36	0.8572	5.00	14.50	6.12	0.63
46.58	0.9505	5.07	16.08	6.22	0.56
48.80	1.0371	5.13	17.55	6.33	0.50
51.76	1.1430	5.21	19.34	6.47	0.42
54.71	1.2459	5.27	21.08	6.61	0.35
58.41	1.3640	5.34	23.08	6.79	0.28
62.81	1.4823	5.41	25.08	7.04	0.21

Table A-10 Data, Triaxial Test A-10

Sludge H-2, 43% organic matter					
$p = 4.92 \text{ kg/cm}^2$			$w_f = 67.88\%$		
$\bar{\sigma}_{1f} = 11.19 \text{ kg/cm}^2$			$c_u = 5.14 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.90 \text{ kg/cm}^2$			$A_f = 0.39$		
$u_f = 6.13 \text{ kg/cm}^2$			$c_v = 0.0030 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	4.92	4.92
15.89	0.0056	2.12	0.10	7.36	4.91
19.96	0.0112	2.14	0.20	7.96	4.89
23.66	0.0173	2.18	0.30	8.49	4.85
25.88	0.0244	2.21	0.43	8.79	4.82
27.36	0.0300	2.23	0.52	8.99	4.80
28.84	0.0371	2.26	0.65	9.18	4.77
30.31	0.0447	2.31	0.78	9.36	4.72
32.53	0.0599	2.39	1.05	9.60	4.64
38.45	0.1237	2.73	2.17	10.09	4.30
42.14	0.1781	3.03	3.12	10.29	4.00
45.84	0.2357	3.34	4.13	10.47	3.69
48.80	0.2985	3.66	5.23	10.50	3.37
51.02	0.3597	3.98	6.30	10.41	3.05
56.19	0.4724	4.51	8.27	10.46	2.52
59.89	0.5735	4.89	10.04	10.44	2.14
63.59	0.6858	5.23	12.01	10.42	1.80
70.24	0.8070	5.54	14.13	10.78	1.50
75.79	0.9317	5.79	16.31	11.01	1.24
79.48	1.0389	5.96	18.19	11.08	1.06
85.03	1.1796	6.18	20.65	11.24	0.85
88.72	1.2601	6.29	22.06	11.39	0.74

Table A-11 Data, Triaxial Test A-11

Sludge C-1					
$p = 1.50 \text{ kg/cm}^2$			$w_f = 104.59\%$		
$\bar{\sigma}_{1f} = 3.54 \text{ kg/cm}^2$			$c_u = 1.71 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.12 \text{ kg/cm}^2$			$A_f = 0.30$		
$u_f = 3.60 \text{ kg/cm}^2$			$c_v = 0.0086 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	1.14	1.14
7.71	0.0076	2.69	0.12	2.00	1.03
8.42	0.0112	2.70	0.18	2.08	1.02
9.83	0.0203	2.78	0.32	2.17	0.94
10.54	0.0269	2.81	0.43	2.23	0.91
11.25	0.0351	2.83	0.56	2.30	0.89
11.95	0.0452	2.88	0.72	2.33	0.84
12.66	0.0574	2.90	0.92	2.40	0.82
13.37	0.0732	2.97	1.17	2.41	0.75
15.21	0.1372	3.10	2.19	2.49	0.62
16.34	0.1925	3.19	3.08	2.52	0.53
17.47	0.2540	3.21	4.06	2.62	0.51
18.60	0.3233	3.29	5.17	2.65	0.43
19.45	0.3820	3.31	6.11	2.71	0.41
20.30	0.4475	3.34	7.15	2.75	0.38
21.29	0.5144	3.38	8.22	2.80	0.34
22.28	0.5789	3.42	9.25	2.84	0.30
23.13	0.6350	3.43	10.15	2.91	0.29
25.41	0.7668	3.49	12.26	3.00	0.23
27.09	0.8819	3.52	14.10	3.13	0.20
29.36	1.0081	3.53	16.11	3.29	0.19
31.62	1.1308	3.58	18.07	3.40	0.14
34.17	1.2649	3.60	20.22	3.55	0.12
36.71	1.3819	3.62	22.09	3.70	0.10
40.68	1.5337	3.63	25.51	3.96	0.09

Table A-12 Data, Triaxial Test A-12

Sludge C-1					
$p =$	2.50	kg/cm^2	$w_f =$	99.44%	
$\bar{\sigma}_{1f} =$	4.53	kg/cm^2	$c_u =$	2.31	kg/cm^2
$\bar{\sigma}_{3f} =$	-0.10	kg/cm^2	$A_f =$	0.26	
$u_f =$	4.80	kg/cm^2	$c_v =$	0.0111	cm^2/min
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	1.08	1.08
6.16	0.0127	3.65	0.21	1.88	1.05
6.16	0.0254	3.65	0.43	1.88	1.05
6.16	0.0381	3.65	0.64	1.88	1.05
6.35	0.0508	3.65	0.85	1.91	1.05
7.20	0.0622	3.72	1.05	1.95	0.98
13.17	0.0919	3.95	1.55	2.51	0.75
16.15	0.1293	4.04	2.17	2.81	0.66
18.69	0.1801	4.22	3.03	2.94	0.48
20.78	0.2410	4.27	4.05	3.14	0.43
22.57	0.3023	4.35	5.08	3.26	0.35
24.06	0.3632	4.37	6.11	3.40	0.33
25.25	0.4194	4.42	7.05	3.47	0.28
26.44	0.4750	4.47	7.98	3.54	0.23
27.64	0.5344	4.51	8.98	3.61	0.19
28.98	0.5939	4.57	9.98	3.68	0.13
31.22	0.7142	4.63	12.01	3.80	0.07
33.90	0.8435	4.65	14.18	4.00	0.05
36.58	0.9629	4.71	16.19	4.16	-0.01
39.27	1.0714	4.74	18.01	4.34	-0.04
42.55	1.1900	4.80	20.00	4.53	-0.10
46.10	1.3129	4.83	22.07	4.75	-0.13
49.94	1.4275	4.86	24.00	5.00	-0.16
53.44	1.5260	4.90	25.65	5.20	-0.20

Table A-13 Data, Triaxial Test A-13

Sludge C-1					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 97.71\%$		
$\bar{\sigma}_{1f} = 6.66 \text{ kg/cm}^2$			$c_u = 3.18 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.30 \text{ kg/cm}^2$			$A_f = 0.34$		
$u_f = 4.92 \text{ kg/cm}^2$			$c_v = 0.0079 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.18	0.00	3.04	3.04
10.89	0.0053	2.40	0.09	4.29	2.82
15.36	0.0150	2.65	0.25	4.65	2.57
18.34	0.0249	2.87	0.42	4.83	2.35
19.84	0.0310	2.97	0.53	4.92	2.24
22.82	0.0488	3.22	0.83	5.07	2.00
24.31	0.0610	3.32	1.04	5.16	1.90
28.78	0.1171	3.82	1.99	5.22	1.40
31.77	0.1857	4.02	3.16	5.37	1.20
34.00	0.2563	4.25	4.36	5.38	0.97
36.99	0.3663	4.32	6.23	5.60	0.90
39.97	0.4935	4.48	8.40	5.70	0.74
42.21	0.5900	4.59	10.04	5.76	0.63
47.39	0.7854	4.70	13.36	6.08	0.52
52.63	0.9822	4.82	16.71	6.34	0.40
57.88	1.1483	4.92	19.54	6.61	0.30
60.32	1.2278	4.92	20.89	6.77	0.30
64.87	1.3553	5.00	23.06	6.98	0.22
71.85	1.5362	5.10	26.14	7.31	0.12

Table A-14 Data, Triaxial Test A-14

Sludge C-1					
$p = 3.50 \text{ kg/cm}^2$			$w_f = 95.13\%$		
$\bar{\sigma}_{1f} = 8.43 \text{ kg/cm}^2$			$c_u = 4.01 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.41 \text{ kg/cm}^2$			$A_f = 0.34$		
$u_f = 5.31 \text{ kg/cm}^2$			$c_v = 0.0086 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	3.17	3.17
7.20	0.0071	2.55	0.12	4.14	3.17
9.65	0.0127	2.59	0.21	4.42	3.13
13.97	0.0178	2.69	0.30	4.90	3.03
17.57	0.0246	2.80	0.42	5.27	2.92
20.45	0.0310	2.90	0.52	5.55	2.82
21.89	0.0363	2.99	0.61	5.65	2.73
23.33	0.0409	3.08	0.69	5.75	2.64
24.77	0.0488	3.17	0.82	5.85	2.55
25.49	0.0528	3.19	0.89	5.92	2.53
26.93	0.0615	3.32	1.04	5.98	2.40
30.53	0.0917	3.58	1.55	6.18	2.14
32.69	0.1209	3.77	2.04	6.25	1.95
35.57	0.1753	4.06	2.95	6.30	1.82
37.73	0.2433	4.24	4.10	6.34	1.48
38.45	0.3040	4.43	5.12	6.19	1.29
41.18	0.3635	4.47	6.13	6.44	1.25
44.93	0.4171	4.63	7.03	6.70	1.09
46.37	0.4801	4.68	8.09	6.76	1.04
46.80	0.5357	4.75	9.03	6.69	0.97
47.09	0.5954	4.80	10.03	6.61	0.92
57.62	0.7219	4.92	12.17	7.60	0.80
60.71	0.8367	5.03	14.10	7.69	0.69
68.46	0.9682	5.15	16.32	8.26	0.57
72.17	1.0742	5.23	18.10	8.43	0.49
74.65	1.1915	5.31	20.08	8.42	0.41
80.23	1.3109	5.40	22.09	8.72	0.32
83.95	1.4254	5.43	24.02	8.86	0.29
86.42	1.5255	5.50	25.71	8.84	0.22

Table A-15 Data, Triaxial Test A-15

Sludge C-1					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 89.47\%$		
$\bar{\sigma}_{1f} = 6.74 \text{ kg/cm}^2$			$c_u = 3.23 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.28 \text{ kg/cm}^2$			$A_f = 0.56$		
$u_f = 5.80 \text{ kg/cm}^2$			$c_v = 0.0058 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.19	0.00	3.89	3.89
9.48	0.0061	2.21	0.11	5.23	3.87
10.19	0.0655	2.21	1.14	5.31	3.87
17.26	0.0886	2.57	1.54	5.95	3.51
25.75	0.1191	3.20	2.07	6.49	2.88
29.99	0.1494	3.54	2.59	6.73	2.54
32.82	0.1775	3.90	3.08	6.74	2.18
37.07	0.2372	4.28	4.12	6.89	1.80
39.90	0.2901	4.42	5.04	7.03	1.60
42.73	0.3653	4.74	6.34	7.08	1.34
46.26	0.4707	5.40	8.17	7.17	1.08
49.09	0.5932	5.22	10.29	7.17	0.86
50.51	0.7066	5.22	12.27	7.21	0.86
51.92	0.8232	5.49	14.29	6.97	0.59
54.04	0.9909	5.61	17.21	6.88	0.47
56.17	1.1384	5.80	19.77	6.74	0.28
56.87	1.1872	5.80	20.61	6.75	0.28
58.29	1.2700	5.85	22.05	6.74	0.22
60.41	1.3957	5.92	24.24	6.72	0.16
63.95	1.5524	6.00	26.96	6.78	0.08

Table A-16 Data, Triaxial Test A-16

Sludge C-1					
$p = 4.92 \text{ kg/cm}^2$			$w_f = 94.39\%$		
$\bar{\sigma}_{1f} = 7.82 \text{ kg/cm}^2$			$c_u = 3.85 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.13 \text{ kg/cm}^2$			$A_f = 0.62$		
$u_f = 6.90 \text{ kg/cm}^2$			$c_v = 0.0089 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	4.92	4.92
6.35	0.0061	2.64	0.10	5.24	4.39
7.71	0.0124	2.69	0.21	5.38	4.34
12.25	0.0175	2.84	0.30	5.83	4.19
16.33	0.0234	3.04	0.40	6.18	3.99
19.51	0.0290	3.17	0.50	6.47	3.86
22.23	0.0353	3.29	0.61	6.72	3.74
24.49	0.0411	3.44	0.71	6.87	3.59
26.76	0.0475	3.54	0.82	7.07	3.49
28.12	0.0536	3.66	0.92	7.12	3.37
29.93	0.0607	3.75	1.04	7.27	3.28
35.38	0.0927	4.11	1.59	7.61	2.92
38.10	0.1201	4.35	2.07	7.71	2.68
43.55	0.1834	4.79	3.15	7.92	2.24
47.17	0.2438	5.08	4.19	8.04	1.95
50.80	0.3282	5.38	5.64	8.10	1.64
54.43	0.3960	5.57	6.81	8.30	1.46
58.06	0.4890	5.80	8.41	8.40	1.23
59.88	0.5283	5.87	9.08	8.49	1.16
63.50	0.6205	6.10	10.67	8.57	0.93
65.32	0.7026	6.21	12.08	8.57	0.82
64.41	0.8039	6.85	13.82	7.66	0.18
63.50	0.9525	6.87	16.37	7.30	0.14
67.13	1.0584	6.90	18.20	7.53	0.13
71.67	1.1709	6.90	20.13	7.84	0.13
78.02	1.3061	6.90	22.45	8.28	0.13
81.65	1.3716	6.90	23.58	8.53	0.13
88.45	1.5570	6.91	26.77	8.85	0.12

Table A-17 Data, Triaxial Test A-17

Sludge H-2, 28% organic matter					
$p = 1.00 \text{ kg/cm}^2$			$w_f = 66.96\%$		
$\bar{\sigma}_{1f} = 3.36 \text{ kg/cm}^2$			$c_u = 1.52 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.32 \text{ kg/cm}^2$			$A_f = 0.22$		
$u_f = 2.76 \text{ kg/cm}^2$			$c_v = 0.0022 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	0.99	0.99
8.78	0.0069	2.11	0.10	2.01	0.97
10.94	0.0160	2.18	0.24	2.20	0.90
11.66	0.0208	2.21	0.32	2.25	0.87
12.38	0.0279	2.24	0.42	2.31	0.84
13.10	0.0358	2.29	0.54	2.34	0.79
13.82	0.0488	2.37	0.74	2.34	0.71
14.54	0.0635	2.40	0.96	2.40	0.68
16.42	0.1478	2.52	2.24	2.47	0.56
17.57	0.2316	2.61	3.51	2.49	0.47
18.72	0.2964	2.62	4.49	2.59	0.46
19.87	0.3937	2.67	5.96	2.64	0.41
21.02	0.4750	2.69	7.19	2.71	0.39
21.60	0.5283	2.69	8.00	2.76	0.39
22.75	0.6076	2.70	9.20	2.84	0.38
23.90	0.6886	2.70	10.42	2.93	0.38
25.63	0.8435	2.71	12.77	3.03	0.37
27.36	0.9505	2.74	14.39	3.13	0.34
28.51	1.0571	2.74	16.00	3.19	0.34
30.53	1.2009	2.76	18.18	3.29	0.32
32.25	1.3663	2.76	20.68	3.37	0.32
33.41	1.4862	2.76	22.49	3.40	0.32
34.42	1.5240	2.76	23.07	3.47	0.32

Table A-18 Data, Triaxial Test A-18

Sludge H-2, 28% organic matter					
$p = 2.00 \text{ kg/cm}^2$			$w_f = 63.60\%$		
$\bar{\sigma}_{1f} = 4.69 \text{ kg/cm}^2$			$c_u = 2.08 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.52 \text{ kg/cm}^2$			$A_f = 0.29$		
$u_f = 3.60 \text{ kg/cm}^2$			$c_v = 0.0031 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	1.74	1.74
12.37	0.0071	2.51	0.11	3.14	1.61
17.53	0.0191	2.84	0.30	3.44	1.28
20.96	0.0361	3.04	0.56	3.66	1.08
22.68	0.0635	3.10	0.99	3.80	1.02
24.40	0.1074	3.29	1.67	3.80	0.83
26.12	0.1826	3.32	2.84	3.94	0.80
27.83	0.2631	3.40	4.09	4.03	0.72
29.21	0.3665	3.47	5.69	4.06	0.65
30.58	0.4425	3.49	6.87	4.16	0.63
31.96	0.5392	3.50	8.37	4.25	0.62
32.99	0.5961	3.52	9.26	4.31	0.60
34.02	0.6698	3.52	10.40	4.38	0.60
36.02	0.8100	3.58	12.58	4.45	0.54
38.14	0.9454	3.58	14.68	4.57	0.54
39.52	1.0701	3.60	16.62	4.60	0.52
41.58	1.2172	3.60	18.90	4.70	0.52
42.61	1.3774	3.60	21.39	4.67	0.52
43.64	1.4448	3.60	22.44	4.71	0.52
45.71	1.5629	3.63	24.27	4.78	0.49

Table A-19 Data, Triaxial Test A-19

Sludge H-2, 28% organic matter					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 62.51\%$		
$\bar{\sigma}_{1f} = 6.04 \text{ kg/cm}^2$			$c_u = 2.72 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.61 \text{ kg/cm}^2$			$A_f = 0.42$		
$u_f = 4.48 \text{ kg/cm}^2$			$c_v = 0.0017 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.17	0.00	2.92	2.92
7.76	0.0071	2.19	0.11	3.88	2.90
13.72	0.0130	2.21	0.20	4.63	2.88
18.94	0.0201	2.30	0.32	5.20	2.79
21.92	0.0259	2.33	0.41	5.54	2.76
24.16	0.0323	2.42	0.51	5.73	2.67
25.65	0.0386	2.50	0.61	5.84	2.59
27.14	0.0462	2.60	0.73	5.92	2.49
27.89	0.0523	2.63	0.82	5.99	2.46
28.64	0.0582	2.70	0.92	6.01	2.39
29.38	0.0663	2.78	1.04	6.02	2.31
33.11	0.1267	3.20	2.00	6.03	1.89
35.35	0.1951	3.62	3.07	5.84	1.47
37.58	0.2723	3.88	4.29	5.80	1.21
38.33	0.3119	3.93	4.92	5.81	1.16
39.82	0.3830	4.13	6.04	5.73	0.96
41.31	0.4526	4.20	7.13	5.78	0.89
42.80	0.5202	4.29	8.20	5.81	0.80
45.30	0.6916	4.37	10.90	5.86	0.72
48.09	0.8545	4.42	13.47	5.98	0.67
49.14	0.9632	4.42	15.18	5.98	0.67
51.24	1.1166	4.46	17.60	6.01	0.63
52.29	1.1831	4.46	18.65	6.05	0.63
53.33	1.2748	4.48	20.09	6.05	0.61
55.43	1.4379	4.48	22.66	6.08	0.61
56.41	1.5618	4.49	24.61	6.02	0.60

Table A-20 Data, Triaxial Test A-20

Sludge H-2, 28% organic matter					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 58.25\%$		
$\bar{\sigma}_{1f} = 6.91 \text{ kg/cm}^2$			$c_u = 2.92 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 1.06 \text{ kg/cm}^2$			$A_f = 0.49$		
$u_f = 5.03 \text{ kg/cm}^2$			$c_v = 0.0029 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.12	0.00	3.97	3.97
12.17	0.0061	2.13	0.10	5.47	3.96
18.53	0.0127	2.20	0.20	6.19	3.89
22.78	0.0183	2.30	0.29	6.61	3.79
27.02	0.0262	2.41	0.41	7.02	3.68
28.44	0.0310	2.50	0.49	7.10	3.59
30.56	0.0376	2.60	0.60	7.26	3.49
32.68	0.0462	2.72	0.73	7.40	3.37
34.10	0.0538	2.82	0.85	7.47	3.27
35.51	0.0620	2.97	0.98	7.49	3.12
40.46	0.1257	3.60	1.99	7.41	2.49
43.29	0.1859	4.03	2.95	7.28	2.06
45.41	0.2540	4.33	4.03	7.17	1.76
47.54	0.3231	4.50	5.12	7.19	1.59
49.66	0.4224	4.70	6.70	7.14	1.39
50.37	0.4872	4.82	7.73	7.04	1.27
51.07	0.5469	4.82	8.67	7.06	1.27
52.49	0.6914	4.96	10.97	6.93	1.13
53.90	0.8090	5.00	12.83	6.92	1.09
55.32	0.9454	5.00	15.00	6.93	1.09
56.73	1.0825	5.00	17.17	6.93	1.09
57.44	1.1857	5.00	18.81	6.88	1.09
58.85	1.2619	5.03	20.02	6.91	1.06
60.27	1.4041	5.09	22.27	6.82	0.99
61.68	1.5448	5.09	24.50	6.78	0.99

Table A-21 Data, Triaxial Test A-21

Sludge H-2, 28% organic matter					
$p =$	4.92	kg/cm^2	$w_f =$	55.94%	
$\bar{\sigma}_{1f} =$	10.24	kg/cm^2	$c_u =$	4.03	kg/cm^2
$\bar{\sigma}_{3f} =$	2.19	kg/cm^2	$A_f =$	0.34	
$u_f =$	4.84	kg/cm^2	$c_v =$	0.0027	cm^2/min
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	4.92	4.92
8.16	0.0063	2.12	0.10	5.83	4.91
17.24	0.0130	2.13	0.21	6.86	4.90
25.40	0.0191	2.14	0.30	7.77	4.89
30.84	0.0264	2.15	0.42	8.37	4.88
34.47	0.0351	2.16	0.56	8.77	4.87
36.29	0.0424	2.17	0.67	8.96	4.86
38.10	0.0490	2.18	0.78	9.15	4.85
39.01	0.0538	2.19	0.85	9.23	4.84
40.82	0.0643	2.25	1.02	9.37	4.78
46.27	0.1283	2.33	2.03	9.85	4.70
49.90	0.1839	2.40	2.91	10.13	4.63
53.52	0.2560	2.58	4.06	10.28	4.45
57.15	0.3312	2.77	5.25	10.41	4.26
60.78	0.4094	2.91	6.49	10.58	4.12
64.41	0.5062	3.14	8.02	10.62	3.89
66.23	0.5618	3.27	8.90	10.62	3.76
69.85	0.6434	3.48	10.19	10.68	3.55
75.30	0.7813	3.81	12.38	10.71	3.22
78.93	0.8941	4.09	14.16	10.64	2.94
83.92	1.0381	4.42	16.45	10.57	2.61
86.18	1.1410	4.62	18.08	10.43	2.41
88.45	1.2540	4.83	19.87	10.25	2.20
90.72	1.3492	4.99	21.38	10.14	2.04
92.99	1.4348	5.11	22.73	10.08	1.92
95.26	1.5258	5.23	24.17	10.01	1.80

Table A-22 Data, Triaxial Test A-22

Sludge H-2, 35% organic matter					
$p = 1.00 \text{ kg/cm}^2$			$w_f = 81.81\%$		
$\bar{\sigma}_{1f} = 3.01 \text{ kg/cm}^2$			$c_u = 1.46 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.09 \text{ kg/cm}^2$			$A_f = 0.28$		
$u_f = 2.99 \text{ kg/cm}^2$			$c_v = 0.0024 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.18	0.00	0.90	0.90
9.07	0.0061	2.32	0.09	1.85	0.76
10.51	0.0175	2.32	0.27	2.02	0.76
11.23	0.0315	2.49	0.48	1.94	0.59
11.95	0.0394	2.50	0.60	2.01	0.58
12.67	0.0457	2.50	0.70	2.10	0.58
13.39	0.0533	2.51	0.82	2.17	0.57
14.11	0.0640	2.52	0.98	2.25	0.56
16.27	0.1300	2.67	2.00	2.33	0.41
17.71	0.2040	2.72	3.13	2.43	0.36
18.43	0.2799	2.76	4.30	2.45	0.32
19.15	0.3465	2.79	5.32	2.48	0.29
19.87	0.4171	2.79	6.40	2.53	0.29
20.59	0.4854	2.82	7.45	2.56	0.26
21.31	0.5687	2.85	8.73	2.58	0.23
22.03	0.6327	2.85	9.71	2.63	0.23
22.75	0.6924	2.88	10.63	2.65	0.20
23.47	0.7709	2.89	11.84	2.69	0.19
25.20	0.9398	2.91	14.43	2.77	0.17
27.07	1.0701	2.92	16.43	2.89	0.16
28.51	1.2085	2.96	18.55	2.92	0.12
29.95	1.2852	2.98	19.73	3.00	0.10
30.82	1.3388	3.00	20.56	3.03	0.08
32.83	1.4554	3.00	22.35	3.16	0.08
34.27	1.5301	3.00	23.49	3.24	0.08

Table A-23 Data, Triaxial Test A-23

Sludge H-2, 35% organic matter					
$p = 2.00 \text{ kg/cm}^2$			$w_f = 72.65\%$		
$\bar{\sigma}_{1f} = 4.30 \text{ kg/cm}^2$			$c_u = 3.81 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.29 \text{ kg/cm}^2$			$A_f = 0.42$		
$u_f = 3.81 \text{ kg/cm}^2$			$c_v = 0.0026 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.10	0.00	2.00	2.00
7.22	0.0056	2.10	0.09	2.90	2.00
12.37	0.0142	2.17	0.22	3.48	1.93
14.09	0.0185	2.20	0.29	3.66	1.90
15.81	0.0259	2.27	0.41	3.81	1.83
17.53	0.0376	2.38	0.59	3.91	1.72
19.24	0.0551	2.47	0.87	4.03	1.63
20.96	0.0836	2.64	1.32	4.06	1.46
23.02	0.1496	2.98	2.36	3.94	1.12
24.05	0.1935	3.07	3.06	3.96	1.03
25.09	0.2596	3.21	4.10	3.92	0.89
26.12	0.3231	3.32	5.10	3.89	0.78
27.15	0.3815	3.39	6.03	3.92	0.71
28.52	0.4747	3.48	7.50	3.94	0.62
29.21	0.5380	3.50	8.50	3.96	0.60
30.58	0.6447	3.56	10.18	3.99	0.54
32.65	0.8001	3.61	12.64	4.07	0.49
34.02	0.8961	3.65	14.16	4.12	0.45
36.77	1.0203	3.70	16.12	4.28	0.40
38.15	1.1171	3.76	17.65	4.29	0.34
39.52	1.2370	3.79	19.54	4.31	0.31
40.21	1.2893	3.82	20.37	4.31	0.28
42.96	1.4168	3.85	22.38	4.44	0.25
45.02	1.5260	3.88	24.11	4.51	0.22

Table A-24 Data, Triaxial Test A-24

Sludge H-2, 35% organic matter					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 68.25\%$		
$\bar{\sigma}_{1f} = 5.86 \text{ kg/cm}^2$			$c_u = 2.73 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.41 \text{ kg/cm}^2$			$A_f = 0.46$		
$u_f = 4.71 \text{ kg/cm}^2$			$c_v = 0.0022 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.19	0.00	2.93	2.93
7.61	0.0081	2.21	0.13	3.89	2.91
8.35	0.0188	2.22	0.30	3.98	2.90
9.84	0.0251	2.25	0.40	4.14	2.87
14.32	0.0310	2.32	0.50	4.64	2.80
18.05	0.0386	2.40	0.62	5.04	2.72
21.03	0.0467	2.50	0.75	5.32	2.62
22.52	0.0528	2.58	0.85	5.43	2.54
24.01	0.0607	2.67	0.98	5.53	2.45
29.23	0.1214	3.20	1.96	5.63	1.92
32.22	0.1890	3.65	3.04	5.51	1.47
34.45	0.2687	3.91	4.33	5.48	1.21
35.94	0.3302	4.03	5.32	5.50	1.09
37.44	0.4196	4.20	6.76	5.44	0.92
38.93	0.4895	4.28	7.88	5.48	0.84
39.67	0.5428	4.30	8.74	5.51	0.82
41.16	0.6256	4.37	10.07	5.54	0.75
43.40	0.7701	4.46	12.40	5.58	0.66
46.69	0.9446	4.50	15.21	5.74	0.62
50.19	1.1311	4.65	18.21	5.78	0.47
53.68	1.2807	4.73	20.62	5.91	0.39
57.18	1.4354	4.80	23.11	6.01	0.32
60.67	1.5524	4.90	25.00	6.11	0.22

Table A-25 Data, Triaxial Test A-25

Sludge H-2, 35% organic matter					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 65.62\%$		
$\bar{\sigma}_{1f} = 6.71 \text{ kg/cm}^2$			$c_u = 3.01 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.69 \text{ kg/cm}^2$			$A_f = 0.50$		
$u_f = 5.39 \text{ kg/cm}^2$			$c_v = 0.0023 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.36	0.00	3.72	3.72
10.19	0.0081	2.38	0.13	5.09	3.70
11.60	0.0208	2.38	0.34	5.28	3.70
12.31	0.0284	2.40	0.46	5.35	3.68
14.43	0.0335	2.40	0.55	5.66	3.68
17.26	0.0376	2.46	0.61	5.96	3.62
21.51	0.0432	2.52	0.70	6.47	3.56
24.33	0.0488	2.58	0.79	6.79	3.50
27.16	0.0559	2.67	0.91	7.08	3.41
29.99	0.0678	2.79	1.10	7.33	3.29
36.36	0.1278	3.30	2.08	7.63	2.78
39.19	0.1849	3.63	3.01	7.63	2.45
41.31	0.2497	4.00	4.06	7.48	2.08
43.43	0.3320	4.28	5.40	7.40	1.80
44.85	0.3929	4.46	6.39	7.34	1.62
46.26	0.4539	4.60	7.39	7.32	1.48
47.68	0.5126	4.70	8.34	7.34	1.38
49.09	0.6193	4.82	10.08	7.28	1.26
50.51	0.7645	5.01	12.44	7.10	1.07
51.92	0.9098	5.15	14.80	6.96	0.93
52.63	0.9888	5.20	16.09	6.90	0.88
54.04	1.1222	5.31	18.26	6.79	0.77
55.46	1.2543	5.42	20.41	6.68	0.66
56.87	1.3589	5.50	22.11	6.62	0.58
59.00	1.5248	5.58	24.81	6.55	0.50

Table A-26 Data, Triaxial Test A-26

Sludge H-2, 35% organic matter					
$p = 4.92 \text{ kg/cm}^2$		$w_f = 61.32\%$			
$\bar{\sigma}_{1f} = 9.48 \text{ kg/cm}^2$		$c_u = 4.28 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.91 \text{ kg/cm}^2$		$A_f = 0.46$			
$u_f = 6.12 \text{ kg/cm}^2$		$c_v = 0.0022 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	4.92	4.92
6.35	0.0071	2.22	0.11	5.67	4.81
13.61	0.0124	2.24	0.20	6.63	4.79
19.96	0.0183	2.28	0.30	7.44	4.75
24.49	0.0246	2.33	0.40	8.00	4.70
27.22	0.0307	2.38	0.50	8.31	4.65
29.94	0.0386	2.44	0.62	8.62	4.59
31.75	0.0452	2.50	0.73	8.80	4.53
32.66	0.0495	2.53	0.80	8.89	4.50
34.47	0.0589	2.59	0.95	9.06	4.44
35.38	0.0635	2.64	1.02	9.13	4.39
41.73	0.1205	3.14	2.02	9.43	3.89
45.36	0.1849	3.58	2.98	9.41	3.45
48.99	0.2586	4.05	4.17	9.33	2.97
51.71	0.3223	4.41	5.20	9.26	2.62
53.52	0.3790	4.66	6.11	9.17	2.37
56.25	0.4610	4.98	7.44	9.10	2.05
58.06	0.5204	5.16	8.40	9.07	1.87
61.69	0.6299	5.41	10.16	9.12	1.62
65.32	0.7442	5.62	12.01	9.20	1.41
68.95	0.8755	5.79	14.13	9.25	1.24
72.58	1.0099	5.94	16.29	9.32	1.09
76.20	1.1549	6.05	18.63	9.37	0.98
78.93	1.2344	6.12	19.92	9.47	0.91
79.83	1.2626	6.14	20.37	9.51	0.89
86.18	1.4127	6.23	22.79	9.81	0.80
90.72	1.5260	6.30	24.62	9.99	0.73

Table A-27 Data, Triaxial Test A-27

Sludge H-2, 50% organic matter					
$p = 1.00 \text{ kg/cm}^2$			$w_f = 109.35\%$		
$\bar{\sigma}_{1f} = 2.18 \text{ kg/cm}^2$			$c_u = 1.08 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.01 \text{ kg/cm}^2$			$A_f = 0.46$		
$u_f = 3.04 \text{ kg/cm}^2$			$c_v = 0.0034 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.05	0.00	1.00	1.00
5.33	0.0046	2.13	0.08	1.64	0.92
6.77	0.0107	2.20	0.18	1.77	0.85
8.21	0.0236	2.28	0.39	1.88	0.77
8.93	0.0325	2.32	0.54	1.94	0.73
9.65	0.0480	2.40	0.80	1.95	0.65
10.37	0.0660	2.43	1.09	2.02	0.62
11.81	0.1316	2.57	2.18	2.05	0.48
12.53	0.1925	2.68	3.19	2.02	0.37
13.25	0.2748	2.70	4.55	2.07	0.35
13.68	0.3424	2.75	5.67	2.06	0.30
14.40	0.4125	2.80	6.83	2.08	0.25
14.69	0.4780	2.82	7.92	2.07	0.23
15.26	0.5796	2.88	9.60	2.05	0.17
15.84	0.6881	2.92	11.40	2.04	0.13
16.99	0.8778	2.96	14.54	2.07	0.09
18.14	1.0216	3.00	16.92	2.10	0.05
19.30	1.1420	3.02	18.92	2.16	0.03
20.45	1.2664	3.05	20.98	2.19	0.00
21.74	1.3533	3.06	22.42	2.29	-0.01
23.24	1.4803	3.09	24.52	2.36	-0.04
24.19	1.5489	3.09	25.66	2.41	-0.04

Table A-28 Data, Triaxial Test A-28

Sludge H-2, 50% organic matter					
$p = 2.00 \text{ kg/cm}^2$			$w_f = 101.12\%$		
$\bar{\sigma}_{1f} = 3.97 \text{ kg/cm}^2$			$c_u = 1.92 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.13 \text{ kg/cm}^2$			$A_f = 0.44$		
$u_f = 4.00 \text{ kg/cm}^2$			$c_v = 0.0036 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	1.93	1.93
12.37	0.0079	2.45	0.14	3.45	1.67
14.09	0.0175	2.56	0.31	3.58	1.56
15.81	0.0358	2.72	0.64	3.66	1.40
17.53	0.0645	2.92	1.14	3.69	1.20
19.24	0.1214	3.08	2.15	3.75	1.04
20.28	0.1745	3.20	3.09	3.75	0.92
21.31	0.2405	3.43	4.27	3.63	0.69
22.34	0.3294	3.43	5.84	3.72	0.69
23.37	0.4171	3.50	7.40	3.73	0.62
24.40	0.5105	3.60	9.05	3.71	0.52
25.77	0.6205	3.62	11.01	3.80	0.50
27.84	0.7607	3.72	13.49	3.87	0.40
29.90	0.9014	3.89	15.99	3.85	0.23
31.62	1.0058	3.94	17.84	3.92	0.18
32.65	1.0866	3.98	19.27	3.93	0.14
33.68	1.1417	4.00	20.25	3.99	0.12
36.08	1.2797	4.08	22.69	4.05	0.04
37.11	1.3444	4.08	23.84	4.10	0.04
39.18	1.4514	4.08	25.74	4.23	0.04

Table A-29 Data, Triaxial Test A-29

Sludge H-2, 50% organic matter					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 90.09\%$		
$\bar{\sigma}_{1f} = 6.07 \text{ kg/cm}^2$			$c_u = 2.91 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.24 \text{ kg/cm}^2$			$A_f = 0.48$		
$u_f = 4.98 \text{ kg/cm}^2$			$c_v = 0.0051 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.14	0.00	3.08	3.08
13.87	0.0058	2.25	0.10	5.07	2.97
16.85	0.0130	2.39	0.23	5.38	2.83
18.34	0.0183	2.48	0.33	5.51	2.74
19.84	0.0251	2.54	0.45	5.67	2.68
21.33	0.0335	2.70	0.60	5.73	2.52
22.82	0.0437	2.78	0.78	5.87	2.44
24.31	0.0579	2.92	1.03	5.94	2.30
26.55	0.0831	3.13	1.48	6.05	2.09
28.79	0.1255	3.50	2.24	5.98	1.72
31.02	0.1925	3.80	3.43	5.96	1.42
32.51	0.2637	3.98	4.70	5.93	1.24
34.01	0.3330	4.10	5.93	5.96	1.12
35.50	0.4196	4.20	7.48	5.99	1.02
36.24	0.4592	4.31	8.18	5.95	0.91
37.73	0.5438	4.45	9.69	5.93	0.77
38.48	0.6060	4.50	10.80	5.92	0.72
39.97	0.6881	4.60	12.26	5.93	0.62
41.46	0.7780	4.69	13.86	5.94	0.53
43.90	0.9251	4.80	16.48	5.97	0.42
45.65	1.0097	4.84	17.99	6.05	0.38
47.39	1.0902	4.96	19.42	6.04	0.26
49.14	1.1699	5.00	20.84	6.11	0.22
52.63	1.3007	5.10	23.17	6.24	0.12
56.13	1.4097	5.15	25.11	6.43	0.07
61.37	1.5486	5.20	27.59	6.75	0.02

Table A-30 Data, Triaxial Test A-30

Sludge H-2, 50% organic matter					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 79.90\%$		
$\bar{\sigma}_{1f} = 7.05 \text{ kg/cm}^2$			$c_u = 3.30 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.46 \text{ kg/cm}^2$			$A_f = 0.54$		
$u_f = 5.63 \text{ kg/cm}^2$			$c_v = 0.0033 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.05	0.00	4.04	4.04
10.75	0.0147	2.10	0.27	5.68	3.99
15.70	0.0226	2.12	0.41	6.44	3.97
18.53	0.0277	2.15	0.50	6.86	3.94
21.36	0.0330	2.20	0.60	7.25	3.89
23.49	0.0396	2.24	0.72	7.54	3.85
24.90	0.0452	2.29	0.82	7.70	3.80
26.31	0.0513	2.33	0.93	7.88	3.76
27.02	0.0554	2.37	1.00	7.95	3.72
32.68	0.1123	2.82	2.03	8.33	3.27
35.51	0.1648	3.17	2.98	8.37	2.92
37.63	0.2189	3.50	3.96	8.31	2.59
39.79	0.2824	3.88	5.11	8.17	2.09
41.17	0.3495	4.10	6.32	8.09	1.99
43.29	0.4465	4.43	8.08	7.95	1.66
45.44	0.5575	4.72	10.08	7.83	1.37
47.54	0.6533	4.97	11.81	7.75	1.12
48.95	0.7628	5.15	13.79	7.61	0.94
49.66	0.8514	5.18	15.40	7.56	0.91
51.07	0.9964	5.53	18.02	7.18	0.56
52.49	1.1488	5.70	20.78	6.96	0.38
53.20	1.2187	5.75	22.04	6.90	0.34
54.61	1.3205	5.82	23.88	6.84	0.27
55.60	1.3842	5.88	25.03	6.80	0.21
58.15	1.5270	6.00	27.61	6.74	0.09

Table A-31 Data, Triaxial Test A-31

Sludge H-2, 50% organic matter					
$p = 4.92 \text{ kg/cm}^2$			$w_f = 74.90\%$		
$\bar{\sigma}_{1f} = 9.52 \text{ kg/cm}^2$			$c_u = 4.57 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.38 \text{ kg/cm}^2$			$A_f = 0.49$		
$u_f = 6.65 \text{ kg/cm}^2$			$c_v = 0.0032 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	4.92	4.92
5.44	0.0069	2.11	0.13	5.78	4.92
9.07	0.0107	2.13	0.20	6.33	4.90
13.61	0.0160	2.19	0.30	6.99	4.84
19.05	0.0226	2.33	0.42	7.71	4.70
20.87	0.0274	2.41	0.51	7.91	4.62
22.68	0.0330	2.47	0.61	8.14	4.56
24.49	0.0401	2.49	0.74	8.40	4.54
26.31	0.0505	2.61	0.94	8.55	4.42
28.12	0.0615	2.76	1.14	8.69	4.27
33.57	0.1166	3.35	2.16	8.89	3.68
37.20	0.1745	3.90	3.23	8.84	3.13
40.82	0.2603	4.57	4.82	8.63	2.46
44.45	0.3604	5.07	6.67	8.54	1.96
46.27	0.4181	5.28	7.73	8.52	1.75
48.08	0.4768	5.48	8.82	8.50	1.55
49.90	0.5329	5.62	9.86	8.54	1.41
51.71	0.5931	5.79	10.97	8.54	1.24
55.34	0.6942	6.02	12.84	8.66	1.01
58.97	0.7920	6.23	14.65	8.79	0.80
62.60	0.8872	6.36	16.41	8.97	0.67
68.04	1.0023	6.55	18.54	9.27	0.48
71.67	1.0754	6.65	19.90	9.49	0.38
73.48	1.1085	6.66	20.51	9.63	0.37
78.93	1.2070	6.74	22.33	10.01	0.29
88.45	1.3188	6.82	24.40	10.82	0.21
95.26	1.4031	6.87	25.97	11.35	0.16
102.06	1.4788	6.89	27.36	11.90	0.13

Table A-32 Data, Triaxial Test A-32

Sludge H-2 + 10% Lime, 43% organic matter					
$p = 0.70 \text{ kg/cm}^2$			$w_f = 111.80\%$		
$\bar{\sigma}_{1f} = 2.35 \text{ kg/cm}^2$			$c_u = 1.16 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.03 \text{ kg/cm}^2$			$A_f = 0.26$		
$u_f = 2.62 \text{ kg/cm}^2$			$c_v = 0.0123 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.02	0.00	0.63	0.63
9.48	0.0074	2.10	0.11	1.61	0.55
10.89	0.0124	2.11	0.19	1.76	0.54
12.31	0.0224	2.19	0.34	1.83	0.46
13.02	0.0335	2.25	0.50	1.85	0.40
13.72	0.0485	2.29	0.73	1.88	0.36
14.43	0.0843	2.32	1.27	1.92	0.33
15.00	0.1397	2.39	2.10	1.92	0.26
15.56	0.1986	2.44	2.99	1.90	0.21
16.41	0.2891	2.49	4.35	1.91	0.16
16.98	0.3465	2.50	5.21	1.94	0.15
17.54	0.4399	2.51	6.62	1.97	0.14
18.39	0.5519	2.52	8.30	2.01	0.13
19.52	0.6683	2.53	10.05	2.08	0.12
20.66	0.8118	2.58	12.21	2.10	0.07
22.07	0.9505	2.60	14.30	2.16	0.05
23.20	1.0919	2.61	16.43	2.20	0.04
24.62	1.2146	2.61	18.27	2.29	0.04
26.03	1.3477	2.62	20.27	2.35	0.03
27.45	1.4557	2.63	21.90	2.42	0.03
28.58	1.5311	2.63	23.03	2.48	0.03

Table A-33 Data, Triaxial Test A-33

Sludge H-2 + 10% Lime, 43% organic matter					
$p = 1.50 \text{ kg/cm}^2$			$w_f = 102.04\%$		
$\bar{\sigma}_{1f} = 3.30 \text{ kg/cm}^2$			$c_u = 1.61 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.08 \text{ kg/cm}^2$			$A_f = 0.27$		
$u_f = 2.96 \text{ kg/cm}^2$			$c_v = 0.0249 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.10	0.00	0.94	0.94
9.99	0.0074	2.25	0.11	1.97	0.79
12.23	0.0127	2.32	0.20	2.17	0.72
14.47	0.0203	2.42	0.31	2.33	0.62
15.96	0.0284	2.49	0.44	2.43	0.55
16.70	0.0356	2.53	0.55	2.48	0.51
17.45	0.0442	2.56	0.68	2.53	0.48
18.20	0.0584	2.58	0.90	2.60	0.46
18.94	0.0815	2.62	1.26	2.64	0.42
19.98	0.1397	2.69	2.15	2.67	0.35
20.88	0.2045	2.70	3.15	2.74	0.34
21.78	0.2703	2.74	4.17	2.77	0.30
22.67	0.3518	2.77	5.42	2.81	0.27
23.86	0.4575	2.80	7.05	2.87	0.24
25.35	0.5933	2.82	9.15	2.95	0.22
26.25	0.6723	2.85	10.36	2.98	0.19
27.74	0.8052	2.88	12.41	3.04	0.16
28.93	0.9144	2.89	14.10	3.09	0.15
30.57	1.0422	2.92	16.06	3.16	0.12
32.33	1.1758	2.94	18.12	3.22	0.10
34.00	1.3035	2.96	20.09	3.30	0.08
35.79	1.4374	2.98	22.16	3.36	0.06
37.29	1.5415	2.99	23.76	3.42	0.05

Table A-34 Data, Triaxial Test A-34

Sludge H-2 + 10% Lime, 43% organic matter					
$p = 2.00 \text{ kg/cm}^2$			$w_f = 92.51\%$		
$\bar{\sigma}_{1f} = 4.57 \text{ kg/cm}^2$			$c_u = 2.22 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.12 \text{ kg/cm}^2$			$A_f = 0.41$		
$u_f = 3.91 \text{ kg/cm}^2$			$c_v = 0.0153 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.08	0.00	1.95	1.95
9.10	0.0071	2.12	0.11	2.99	1.91
12.08	0.0130	2.22	0.20	3.25	1.81
15.06	0.0208	2.41	0.33	3.41	1.62
16.55	0.0254	2.46	0.40	3.53	1.57
18.05	0.0333	2.57	0.53	3.60	1.46
18.79	0.0378	2.61	0.60	3.65	1.42
21.02	0.0513	2.78	0.81	3.74	1.25
22.52	0.0655	2.88	1.03	3.81	1.15
25.50	0.1346	3.20	2.12	3.81	0.83
26.70	0.1981	3.36	3.13	3.75	0.67
27.74	0.2611	3.44	4.12	3.76	0.59
28.78	0.3332	3.50	5.26	3.78	0.53
29.68	0.3879	3.52	6.12	3.83	0.51
30.57	0.4475	3.55	7.06	3.87	0.48
31.47	0.5065	3.60	7.99	3.88	0.43
33.86	0.6541	3.68	10.32	3.97	0.35
36.24	0.7767	3.74	12.26	4.08	0.29
38.63	0.9047	3.77	14.28	4.21	0.26
41.32	1.0317	3.81	16.28	4.34	0.22
43.41	1.1303	3.90	17.84	4.38	0.13
46.69	1.2692	3.91	20.03	4.57	0.12
50.19	1.3993	3.94	22.08	4.75	0.09
54.38	1.5362	3.98	24.24	4.96	0.05

Table A-35 Data, Triaxial Test A-35

Sludge H-2 + 10% Lime, 43% organic matter					
$p = 2.90 \text{ kg/cm}^2$			$w_f = 89.21\%$		
$\bar{\sigma}_{1f} = 7.96 \text{ kg/cm}^2$			$c_u = 3.79 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.38 \text{ kg/cm}^2$			$A_f = 0.31$		
$u_f = 4.52 \text{ kg/cm}^2$			$c_v = 0.0132 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.19	0.00	2.71	2.71
8.78	0.0089	2.24	0.14	3.75	2.66
9.50	0.0157	2.24	0.25	3.84	2.66
10.94	0.0249	2.29	0.40	3.97	2.61
15.26	0.0307	2.35	0.50	4.44	2.55
18.14	0.0368	2.41	0.59	4.74	2.49
20.30	0.0434	2.48	0.70	4.93	2.42
22.46	0.0508	2.52	0.82	5.16	2.38
26.06	0.0716	2.68	1.16	5.43	2.22
33.26	0.1245	3.15	2.01	5.82	1.75
36.14	0.1796	3.49	2.90	5.79	1.41
37.58	0.2464	3.68	3.98	5.72	1.22
41.18	0.3071	3.83	4.96	5.95	1.07
42.62	0.3797	3.92	6.13	5.97	0.98
43.78	0.4318	3.99	6.97	5.99	0.91
44.06	0.5034	4.05	8.13	5.90	0.85
45.50	0.5659	4.11	9.13	5.95	0.79
48.96	0.6330	4.19	10.22	6.19	0.71
51.55	0.7475	4.27	12.07	6.28	0.63
55.76	0.8793	4.37	14.19	6.50	0.53
66.60	0.9964	4.42	16.08	7.45	0.48
70.32	1.1283	4.49	18.21	7.58	0.41
77.13	1.2776	4.53	20.62	8.00	0.37
81.47	1.3873	4.59	22.39	8.20	0.31
85.18	1.5240	4.62	24.60	8.29	0.28

Table A-36 Data, Triaxial Test A-36

Sludge H-2 + 10% Lime, 43% organic matter					
$p = 3.50 \text{ kg/cm}^2$		$w_f = 77.45\%$			
$\bar{\sigma}_{1f} = 9.14 \text{ kg/cm}^2$		$c_u = 4.27 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.61 \text{ kg/cm}^2$		$A_f = 0.45$			
$u_f = 4.79 \text{ kg/cm}^2$		$c_v = 0.0132 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principle Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	0.91	0.00	4.49	4.49
11.68	0.0069	0.88	0.11	5.99	4.52
15.12	0.0513	0.88	0.85	6.41	4.52
16.84	0.0630	0.93	1.04	6.57	4.47
32.30	0.0904	1.62	1.49	7.79	3.78
51.20	0.1214	2.60	2.00	9.12	2.80
59.79	0.1979	3.58	3.27	9.11	1.82
61.86	0.2586	3.68	4.27	9.18	1.72
63.23	0.3327	3.92	5.49	9.00	1.48
64.61	0.4026	4.05	6.65	8.95	1.35
66.67	0.4999	4.17	8.25	8.93	1.23
69.42	0.6167	4.20	10.18	9.05	1.20
71.48	0.7366	4.35	12.16	8.96	1.05
74.92	0.8595	4.58	14.19	8.92	0.82
77.66	0.9779	4.60	16.15	9.00	0.80
81.44	1.1138	4.75	18.39	9.02	0.65
85.22	1.2243	4.79	20.22	9.17	0.61
88.66	1.3381	4.95	22.10	9.15	0.45
94.16	1.4630	4.99	24.16	9.41	0.41

Table A-37 Data, Triaxial Test A-37

Sludge H-2 + 10% Lime, 43% organic matter					
$p =$	4.92	kg/cm^2	$w_f =$	79.67%	
$\bar{\sigma}_{1f} =$	10.24	kg/cm^2	$c_u =$	4.74	kg/cm^2
$\bar{\sigma}_{3f} =$	0.75	kg/cm^2	$A_f =$	0.44	
$u_f =$	6.28	kg/cm^2	$c_v =$	0.0153	cm^2/min
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	4.92	4.92
5.44	0.0061	2.12	0.10	5.65	4.91
15.42	0.0124	2.20	0.20	6.94	4.83
23.51	0.0178	2.31	0.29	7.95	4.72
30.48	0.0254	2.47	0.42	8.77	4.56
34.47	0.0315	2.60	0.52	9.14	4.43
36.28	0.0376	2.71	0.61	9.26	4.32
39.92	0.0442	2.98	0.72	9.49	4.05
41.73	0.0505	3.11	0.83	9.59	3.92
44.45	0.0617	3.40	1.01	9.66	3.63
51.71	0.1290	4.47	2.11	9.51	2.56
54.43	0.1880	5.05	3.07	9.22	1.98
56.25	0.2517	5.19	4.12	9.24	1.85
58.06	0.3066	5.34	5.01	9.26	1.69
59.87	0.3744	5.43	6.12	9.31	1.60
61.69	0.4247	5.52	6.95	9.38	1.51
65.32	0.5705	5.72	9.33	9.43	1.31
67.13	0.6292	5.78	10.29	9.51	1.25
70.76	0.7468	5.88	12.21	9.67	1.15
76.21	0.8865	5.04	14.50	9.93	0.99
79.83	1.0865	6.12	16.14	10.09	0.91
83.92	1.1704	6.25	19.14	10.09	0.78
88.45	1.2761	6.31	20.87	10.32	0.72
92.99	1.3721	6.42	22.44	10.50	0.61
97.52	1.4529	6.47	23.76	10.76	0.56
102.06	1.5324	6.50	25.06	11.02	0.53

Table A-38 Data, Triaxial Test A-38

Sludge H-2 + 10% Lime, 28% organic matter					
$p = 1.00 \text{ kg/cm}^2$			$w_f = 97.23\%$		
$\bar{\sigma}_{1f} = 2.98 \text{ kg/cm}^2$			$c_u = 1.35 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.27 \text{ kg/cm}^2$			$A_f = 0.21$		
$u_f = 2.82 \text{ kg/cm}^2$			$c_v = 0.0147 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principle Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	0.85	0.85
9.07	0.0061	2.34	0.09	1.87	0.75
11.95	0.0168	2.44	0.25	2.13	0.65
12.67	0.0226	2.50	0.34	2.15	0.59
13.39	0.0307	2.58	0.47	2.16	0.51
14.11	0.0427	2.62	0.65	2.20	0.47
14.83	0.0612	2.68	0.93	2.23	0.41
15.55	0.0919	2.72	1.39	2.27	0.37
16.27	0.1529	2.78	2.32	2.28	0.31
17.71	0.2068	2.80	3.13	2.41	0.29
19.15	0.3363	2.80	5.09	2.54	0.29
19.87	0.4496	2.82	6.81	2.56	0.27
21.60	0.5364	2.83	8.13	2.71	0.26
22.75	0.7056	2.83	10.69	2.77	0.26
24.19	0.8197	2.83	12.42	2.88	0.26
25.34	0.9959	2.83	15.09	2.92	0.26
26.64	1.1270	2.83	17.07	2.99	0.26
27.50	1.2764	2.83	19.33	3.00	0.26
27.22	1.3746	2.81	20.82	2.94	0.28
28.51	1.4732	2.83	22.32	3.00	0.26
28.94	1.6159	2.82	24.48	2.97	0.27
28.22	1.6998	2.83	25.75	2.85	0.26
29.32	1.7988	2.82	27.25	2.90	0.26

Table A-39 Data, Triaxial Test A-39

Sludge H-2 + 10% Lime, 28% organic matter					
$p = 2.00 \text{ kg/cm}^2$		$w_f = 87.23\%$			
$\bar{\sigma}_{1f} = 4.24 \text{ kg/cm}^2$		$c_u = 1.89 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.46 \text{ kg/cm}^2$		$A_f = 0.41$			
$u_f = 3.64 \text{ kg/cm}^2$		$c_v = 0.0142 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.08	0.00	2.02	2.02
17.87	0.0056	2.22	0.09	4.02	1.88
21.31	0.0130	2.60	0.21	4.05	1.50
23.02	0.0299	3.00	0.37	3.85	1.10
24.74	0.0434	3.18	0.69	3.87	0.92
25.77	0.0462	3.31	0.74	3.86	0.79
26.80	0.1107	3.42	1.77	3.84	0.68
27.84	0.1699	3.51	2.71	3.84	0.59
28.87	0.2395	3.57	3.83	3.86	0.53
29.90	0.3081	3.60	4.92	3.91	0.50
30.93	0.3632	3.60	5.80	4.00	0.50
31.96	0.4425	3.62	7.07	4.04	0.48
32.99	0.5418	3.62	8.65	4.10	0.48
34.02	0.6337	3.62	10.12	4.15	0.48
36.08	0.8026	3.64	12.82	4.23	0.46
37.11	0.9131	3.64	14.58	4.26	0.46
38.14	0.9987	3.64	15.95	4.31	0.46
39.18	1.1882	3.64	18.98	4.27	0.46
39.86	1.4458	3.64	23.09	4.14	0.46
39.86	1.5519	3.62	24.79	4.08	0.48

Table A-40 Data, Triaxial Test A-40

Sludge H-2 + 10% Lime, 28% organic matter					
$p = 3.00 \text{ kg/cm}^2$		$w_f = 81.07\%$			
$\bar{\sigma}_{1f} = 5.70 \text{ kg/cm}^2$		$c_u = 2.59 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.52 \text{ kg/cm}^2$		$A_f = 0.48$			
$u_f = 4.60 \text{ kg/cm}^2$		$c_v = 0.0123 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.08	0.00	3.04	3.04
8.80	0.0056	2.10	0.09	4.13	3.02
15.51	0.0124	2.25	0.20	4.82	2.87
19.98	0.0183	2.40	0.29	5.23	2.72
22.97	0.0239	2.58	0.38	5.42	2.54
25.21	0.0297	2.78	0.48	5.49	2.34
27.44	0.0361	2.88	0.58	5.67	2.24
28.93	0.0427	3.09	0.69	5.64	2.03
30.43	0.0495	3.18	0.80	5.74	1.94
31.92	0.0589	3.37	0.95	5.73	1.75
32.66	0.0660	3.40	1.06	5.78	1.72
36.39	0.1250	3.90	2.01	5.71	1.22
37.88	0.1859	4.16	2.99	5.58	0.96
39.37	0.2621	4.35	4.21	5.51	0.77
40.87	0.3454	4.42	5.55	5.56	0.70
42.36	0.4374	4.48	7.03	5.59	0.64
44.25	0.5530	4.48	8.89	5.71	0.64
46.00	0.6505	4.48	10.45	5.82	0.64
47.74	0.7620	4.52	12.24	5.87	0.60
49.14	0.9428	4.52	15.15	5.84	0.60
50.19	1.0615	4.60	17.06	5.75	0.52
51.24	1.2268	4.60	19.71	5.69	0.52
52.98	1.3495	4.63	21.68	5.71	0.49
54.73	1.5735	4.65	25.28	5.61	0.47

Table A-41 Data, Triaxial Test A-41

Sludge H-2 + 10% Lime, 28% organic matter					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 77.75\%$		
$\bar{\sigma}_{1f} = 6.78 \text{ kg/cm}^2$			$c_u = 2.95 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.87 \text{ kg/cm}^2$			$A_f = 0.54$		
$u_f = 5.21 \text{ kg/cm}^2$			$c_v = 0.0159 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principle Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.03	0.00	4.05	4.05
10.19	0.0071	2.07	0.12	5.33	4.01
14.43	0.0137	2.12	0.22	5.83	3.96
20.09	0.0196	2.28	0.32	6.41	3.80
25.75	0.0246	2.46	0.40	6.96	3.62
29.99	0.0300	2.65	0.49	7.31	3.43
34.24	0.0378	2.95	0.61	7.56	3.13
37.07	0.0439	3.20	0.71	7.67	2.88
39.19	0.0505	3.35	0.82	7.79	2.73
40.60	0.0556	3.50	0.90	7.82	2.58
42.02	0.0635	3.68	1.03	7.82	2.40
46.26	0.1224	4.47	1.98	7.51	1.61
48.39	0.2090	4.80	3.38	7.36	1.28
49.80	0.2809	5.00	4.56	7.26	1.08
50.51	0.3660	5.10	5.92	7.16	0.98
51.21	0.4552	5.10	7.37	7.15	0.98
51.92	0.5466	5.15	8.85	7.08	0.93
52.63	0.6312	5.15	10.22	7.08	0.93
53.34	0.7569	5.21	12.25	6.96	0.87
54.04	0.8425	5.21	13.64	6.94	0.87
54.75	0.9406	5.21	15.22	6.91	0.87
55.46	1.0541	5.21	17.06	6.86	0.87
56.17	1.1679	5.21	18.90	6.80	0.87
56.87	1.2543	5.21	20.30	6.77	0.87
57.16	1.3589	5.22	22.00	6.66	0.86
57.58	1.4331	5.25	23.20	6.59	0.83
57.86	1.5062	5.25	24.38	6.52	0.83
58.26	1.6180	5.25	26.19	6.43	0.83

Table A-42 Data, Triaxial Test A-42

Sludge C-1 + 10% Lime					
$p = 1.00 \text{ kg/cm}^2$		$w_f = 113.79\%$			
$\bar{\sigma}_{1f} = 3.57 \text{ kg/cm}^2$		$c_u = 1.78 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.00 \text{ kg/cm}^2$		$A_f = 0.16$			
$u_f = 3.09 \text{ kg/cm}^2$		$c_v = 0.0291 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	0.57	0.57
12.10	0.0058	2.62	0.09	1.77	0.47
13.54	0.0127	2.67	0.19	1.87	0.42
14.26	0.0175	2.69	0.27	1.93	0.40
15.70	0.0302	2.71	0.46	2.06	0.38
16.42	0.0404	2.72	0.62	2.13	0.37
17.14	0.0536	2.78	0.82	2.14	0.31
17.86	0.0716	2.79	1.10	2.20	0.30
19.29	0.1407	2.84	2.16	2.28	0.25
21.46	0.2169	2.88	3.33	2.44	0.21
22.18	0.2563	2.90	3.93	2.48	0.19
23.62	0.3426	2.96	5.25	2.54	0.13
24.34	0.4397	2.98	6.74	2.55	0.11
26.50	0.5126	3.00	7.86	2.72	0.09
28.22	0.5923	3.01	9.08	2.84	0.08
29.38	0.6505	3.02	9.97	2.92	0.07
30.82	0.7894	3.05	12.10	2.96	0.04
34.42	0.9317	3.09	14.28	3.17	0.00
35.86	1.0681	3.09	16.37	3.23	0.00
40.18	1.2019	3.09	18.43	3.53	0.00
40.90	1.2469	3.09	19.12	3.56	0.00
41.62	1.3228	3.09	20.28	3.57	0.00
45.94	1.4641	3.09	22.44	3.84	0.00
48.38	1.5479	3.09	23.73	3.97	0.00

Table A-43 Data, Triaxial Test A-43

Sludge C-1 + 10% Lime					
$p = 2.00 \text{ kg/cm}^2$			$w_f = 102.12\%$		
$\bar{\sigma}_{1f} = 5.45 \text{ kg/cm}^2$			$c_u = 2.59 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.27 \text{ kg/cm}^2$			$A_f = 0.35$		
$u_f = 3.84 \text{ kg/cm}^2$			$c_v = 0.0366 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.04	0.00	2.07	2.07
17.86	0.0053	2.28	0.08	3.91	1.83
19.59	0.0124	2.38	0.20	4.00	1.73
21.31	0.0208	2.95	0.33	3.63	1.16
23.02	0.0335	3.03	0.53	3.74	1.08
24.74	0.0554	3.19	0.87	3.77	0.92
26.46	0.0897	3.30	1.41	3.84	0.81
28.18	0.1443	3.45	2.27	3.86	0.66
29.90	0.2088	3.52	3.29	3.95	0.59
31.62	0.2723	3.59	4.29	4.04	0.52
33.33	0.3576	3.63	5.63	4.14	0.48
35.05	0.4425	3.65	6.97	4.25	0.46
38.49	0.5908	3.75	9.31	4.42	0.36
40.21	0.6558	3.78	10.33	4.52	0.33
43.99	0.8075	3.82	12.72	4.76	0.29
46.74	0.8666	3.83	13.65	4.97	0.28
49.49	1.0226	3.84	16.11	5.10	0.27
52.23	1.1247	3.84	17.71	5.27	0.27
53.61	1.2106	3.84	19.07	5.32	0.27
55.67	1.2700	3.84	20.00	5.45	0.27
58.76	1.4013	3.90	22.07	5.54	0.21
62.54	1.5316	3.90	24.12	5.73	0.21

Table A-44 Data, Triaxial Test A-44

Sludge C-1 + 10% Lime					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 94.46\%$		
$\bar{\sigma}_{1f} = 7.94 \text{ kg/cm}^2$			$c_u = 3.89 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.16 \text{ kg/cm}^2$			$A_f = 0.40$		
$u_f = 5.05 \text{ kg/cm}^2$			$c_v = 0.0325 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	1.91	0.00	3.30	3.30
13.27	0.0061	2.10	0.10	4.72	3.11
18.49	0.0127	2.30	0.21	5.15	2.91
21.48	0.0185	2.47	0.30	5.34	2.74
22.97	0.0231	2.62	0.45	5.51	2.55
25.95	0.0328	2.86	0.53	5.49	2.35
28.93	0.0457	3.10	0.74	5.60	2.11
30.45	0.0554	3.14	0.90	5.74	2.07
33.41	0.0808	3.60	1.31	5.62	1.61
37.14	0.1351	3.95	2.20	5.70	1.26
40.12	0.2004	4.18	3.26	5.75	1.03
42.36	0.2570	4.35	4.18	5.79	0.86
44.25	0.3205	4.47	5.21	5.84	0.74
46.00	0.3749	4.49	6.10	5.97	0.72
47.74	0.4374	4.52	7.11	6.08	0.69
49.49	0.4933	4.62	8.02	6.12	0.59
51.24	0.5438	4.70	8.84	6.19	0.51
54.73	0.6368	4.70	10.35	6.48	0.51
58.92	0.7523	4.80	12.23	6.70	0.41
64.17	0.8910	4.90	14.49	6.98	0.31
68.71	0.9952	5.00	16.18	7.21	0.21
73.95	1.1077	5.00	18.01	7.58	0.21
80.94	1.2512	5.06	20.35	7.99	0.15
86.18	1.3528	5.09	22.00	8.29	0.12
93.52	1.4790	5.13	24.05	8.72	0.08
96.67	1.5395	5.17	25.03	8.85	0.04

Table A-45 Data, Triaxial Test A-45

Sludge C-1 + 10% Lime					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 89.78\%$		
$\bar{\sigma}_{1f} = 6.77 \text{ kg/cm}^2$			$c_u = 3.13 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.51 \text{ kg/cm}^2$			$A_f = 0.57$		
$u_f = 5.57 \text{ kg/cm}^2$			$c_v = 0.0325 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.02	0.00	4.06	4.06
12.73	0.0046	2.03	0.08	5.62	4.05
13.44	0.0124	2.03	0.21	5.70	4.05
14.86	0.0231	2.06	0.38	5.84	4.02
15.56	0.0284	2.09	0.47	5.90	3.99
18.39	0.0381	2.19	0.63	6.14	3.89
26.88	0.0488	2.52	0.81	6.84	3.56
33.95	0.0635	2.98	1.06	7.23	3.10
36.78	0.0714	3.18	1.19	7.37	2.90
41.03	0.0892	3.52	1.48	7.53	2.56
45.27	0.1242	4.02	2.06	7.52	2.06
48.81	0.1875	4.40	3.12	7.50	1.68
50.22	0.2568	4.65	4.27	7.35	1.43
51.64	0.3609	4.81	6.00	7.24	1.27
53.76	0.4905	5.27	8.15	6.99	0.91
55.18	0.6375	5.34	10.60	6.81	0.74
57.30	0.7777	5.42	12.93	6.80	0.66
60.13	0.9652	5.56	16.05	6.73	0.52
62.96	1.1694	5.60	19.44	6.73	0.48
63.66	1.2090	5.56	20.10	6.78	0.52
68.59	1.3487	5.56	22.42	7.07	0.52
73.94	1.5240	5.54	25.34	7.33	0.54

Table A-46 Data, Triaxial Test A-46

Sludge C-1 + 10% Lime					
$p = 5.00 \text{ kg/cm}^2$			$w_f = 81.09\%$		
$\bar{\sigma}_{1f} = 7.22 \text{ kg/cm}^2$			$c_u = 3.37 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.47 \text{ kg/cm}^2$			$A_f = 0.65$		
$u_f = 6.62 \text{ kg/cm}^2$			$c_v = 0.080 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.19	0.00	4.90	4.90
12.87	0.0071	2.60	0.12	6.11	4.49
18.97	0.0142	3.11	0.24	6.38	3.98
23.09	0.0216	3.47	0.36	6.54	3.62
25.16	0.0277	4.00	0.46	6.26	3.09
30.31	0.0582	4.19	0.96	6.70	2.90
33.40	0.0884	4.65	1.46	6.61	2.44
35.46	0.1250	5.11	2.07	6.38	1.98
37.53	0.1814	5.36	3.00	6.34	1.73
39.59	0.2512	5.60	4.16	6.30	1.49
42.68	0.3663	5.80	6.06	6.37	1.29
45.77	0.4948	6.02	8.19	6.40	1.07
48.87	0.6137	6.11	10.15	6.55	0.98
51.96	0.7267	6.18	12.02	6.71	0.91
55.05	0.8463	6.32	14.00	6.77	0.77
59.18	0.9779	6.43	16.18	6.95	0.66
63.30	1.1120	6.55	18.40	7.09	0.54
66.39	1.2040	6.61	19.92	7.22	0.48
67.42	1.2273	6.65	20.31	7.26	0.44
71.55	1.3299	6.75	22.00	7.41	0.34
76.70	1.4432	6.78	23.88	7.71	0.31
81.86	1.5444	6.82	25.55	8.00	0.27

Table A-47 Data, Triaxial Test A-47

Sludge H-2 + 10% Flyash, 43% organic matter					
$p = 1.00 \text{ kg/cm}^2$		$w_f = 90.21\%$			
$\bar{\sigma}_{1f} = 2.48 \text{ kg/cm}^2$		$c_u = 1.21 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.06 \text{ kg/cm}^2$		$A_f = 0.36$			
$u_f = 3.02 \text{ kg/cm}^2$		$c_v = 0.0041 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.11	0.00	0.92	0.92
4.61	0.0099	2.17	0.16	1.47	0.91
6.05	0.0178	2.19	0.28	1.63	0.89
7.49	0.0251	2.32	0.40	1.67	0.76
8.93	0.0356	2.37	0.56	1.80	0.71
9.65	0.0432	2.47	0.68	1.78	0.61
10.37	0.0528	2.47	0.83	1.87	0.61
11.09	0.0688	2.49	1.09	1.93	0.59
13.25	0.1623	2.67	2.56	1.99	0.41
13.97	0.2263	2.70	3.57	2.03	0.38
14.69	0.3101	2.74	4.90	2.05	0.34
16.13	0.4244	2.80	6.70	2.12	0.28
16.85	0.5225	2.83	8.25	2.14	0.25
17.57	0.6297	2.88	9.94	2.14	0.20
19.01	0.7351	2.89	11.61	2.25	0.19
20.45	0.9014	2.95	14.23	2.28	0.13
21.89	1.0163	2.98	16.05	2.35	0.10
23.33	1.1593	3.02	18.31	2.39	0.06
24.05	1.2029	3.02	19.00	2.44	0.06
24.77	1.2700	3.02	20.05	2.48	0.06
26.93	1.3891	3.03	21.93	2.62	0.05
29.23	1.5250	3.06	24.08	2.73	0.02

Table A-48 Data, Triaxial Test A-48

Sludge H-2 + 10% Flyash, 43% organic matter					
$p = 2.00 \text{ kg/cm}^2$		$w_f = 78.20\%$			
$\bar{\sigma}_{1f} = 4.48 \text{ kg/cm}^2$		$c_u = 2.16 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.17 \text{ kg/cm}^2$		$A_f = 0.42$			
$u_f = 3.92 \text{ kg/cm}^2$		$c_v = 0.0035 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.13	0.00	1.96	1.96
14.09	0.0107	2.48	0.18	3.45	1.61
15.81	0.0224	2.53	0.37	3.62	1.56
17.53	0.0389	2.72	0.64	3.65	1.37
19.24	0.0671	2.85	1.11	3.73	1.24
20.96	0.1163	3.08	1.92	3.70	1.01
22.34	0.1697	3.20	2.80	3.73	0.89
23.71	0.2367	3.30	3.91	3.77	0.79
25.09	0.3216	3.38	5.31	3.81	0.71
26.46	0.4072	3.49	6.72	3.83	0.60
27.84	0.4912	3.52	8.11	3.91	0.57
29.90	0.6193	3.60	10.22	4.00	0.49
31.96	0.7513	3.68	12.40	4.07	0.41
33.33	0.8418	3.70	13.89	4.14	0.39
35.40	0.9451	3.82	15.59	4.17	0.27
36.77	1.0155	3.82	16.76	4.27	0.27
38.83	1.1092	3.89	18.30	4.35	0.20
40.89	1.2009	3.92	19.81	4.46	0.17
41.92	1.2349	3.92	20.38	4.53	0.17
45.02	1.3449	3.97	22.19	4.70	0.12
48.45	1.4549	4.00	24.01	4.90	0.09
51.55	1.5438	4.05	25.47	5.06	0.04

Table A-49 Data, Triaxial Test A-49

Sludge H-2 + 10% Flyash, 43% organic matter					
$p = 3.00 \text{ kg/cm}^2$			$w_f = 72.13\%$		
$\bar{\sigma}_{1f} = 6.25 \text{ kg/cm}^2$			$c_u = 2.93 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.39 \text{ kg/cm}^2$			$A_f = 0.46$		
$u_f = 4.86 \text{ kg/cm}^2$			$c_v = 0.0034 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	3.07	3.07
7.01	0.0046	2.18	0.08	4.02	3.07
8.50	0.0196	2.18	0.33	4.22	3.07
9.25	0.0328	2.20	0.55	4.30	3.05
13.72	0.0414	2.32	0.69	4.79	2.93
16.70	0.0478	2.40	0.80	5.11	2.85
21.18	0.0638	2.69	1.07	5.42	2.56
27.89	0.1217	3.25	2.03	5.72	2.00
30.87	0.1847	3.68	3.09	5.65	1.57
33.11	0.2497	3.81	4.17	5.77	1.44
34.60	0.3129	3.97	5.23	5.75	1.28
36.09	0.3871	4.10	6.47	5.75	1.15
38.33	0.5022	4.29	8.39	5.75	0.96
39.07	0.5364	4.34	8.97	5.76	0.91
40.57	0.6091	4.39	10.18	5.83	0.86
42.80	0.7320	4.48	12.24	5.89	0.77
45.30	0.8575	4.65	14.33	5.89	0.60
48.79	1.0160	4.72	16.98	6.05	0.53
50.54	1.0866	4.80	18.16	6.09	0.45
52.29	1.1532	4.85	19.28	6.15	0.40
54.03	1.2060	4.86	20.16	6.27	0.39
57.53	1.3279	4.96	22.20	6.39	0.29
62.77	1.4610	5.02	24.42	6.70	0.23
66.26	1.5491	5.09	25.90	6.86	0.16

Table A-50 Data, Triaxial Test A-50

Sludge H-2 + 10% Flyash, 43% organic matter					
$p = 4.00 \text{ kg/cm}^2$			$w_f = 67.62\%$		
$\bar{\sigma}_{1f} = 6.74 \text{ kg/cm}^2$			$c_u = 3.14 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.47 \text{ kg/cm}^2$			$A_f = 0.54$		
$u_f = 5.59 \text{ kg/cm}^2$			$c_v = 0.0041 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.18	0.00	3.88	3.88
10.04	0.0015	2.20	0.03	5.34	3.84
10.75	0.0239	2.22	0.40	5.34	3.84
12.87	0.0493	2.29	0.83	5.56	3.77
14.29	0.0521	2.30	0.88	5.74	3.76
17.83	0.0594	2.39	1.01	6.14	3.67
26.31	0.0874	2.72	1.48	6.97	3.34
30.56	0.1204	3.00	2.04	7.25	3.06
35.51	0.1867	3.51	3.16	7.37	2.55
38.34	0.2489	3.90	4.21	7.31	2.16
40.46	0.3053	4.16	5.17	7.28	1.90
41.88	0.3973	4.31	6.72	7.22	1.66
44.71	0.4470	4.58	7.57	7.27	1.48
46.12	0.4989	4.72	8.44	7.26	1.34
47.54	0.5563	4.87	9.41	7.22	1.19
48.95	0.6109	4.97	10.34	7.24	1.09
50.37	0.7198	5.02	12.18	7.24	1.04
51.78	0.8385	5.32	14.19	6.96	0.74
53.20	0.9685	5.48	16.39	6.81	0.58
55.03	1.1085	5.50	18.76	6.82	0.56
56.03	1.1872	5.60	20.09	6.73	0.46
58.14	1.3284	5.67	22.48	6.71	0.39
59.56	1.4158	5.71	23.96	6.69	0.35
61.68	1.5288	5.80	25.88	6.67	0.26

Table A-51 Data, Triaxial Test A-51

Sludge H-2 + 10% Flyash, 43% organic matter					
$p = 4.92 \text{ kg/cm}^2$		$w_f = 62.81\%$			
$\bar{\sigma}_{1f} = 8.64 \text{ kg/cm}^2$		$c_u = 3.96 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.71 \text{ kg/cm}^2$		$A_f = 0.53$			
$u_f = 6.32 \text{ kg/cm}^2$		$c_v = 0.0033 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.11	0.00	4.92	4.92
4.54	0.0066	2.73	0.11	4.95	4.29
9.98	0.0124	2.78	0.23	5.82	4.24
13.61	0.0178	2.83	0.30	6.17	4.20
17.24	0.0251	2.89	0.42	6.74	4.12
19.96	0.0305	2.94	0.51	6.97	4.09
21.77	0.0358	2.99	0.60	7.17	4.04
23.59	0.0434	3.06	0.73	7.36	3.97
25.40	0.0521	3.14	0.87	7.53	3.89
27.22	0.0622	3.23	1.04	7.70	3.80
30.84	0.0937	3.49	1.57	7.93	3.54
33.57	0.1257	3.74	2.11	8.05	3.29
37.20	0.1915	4.18	3.21	8.06	2.85
39.92	0.2637	4.56	4.42	7.99	2.47
41.73	0.3208	4.81	5.38	7.93	2.22
43.55	0.3759	5.00	6.31	7.93	2.03
45.36	0.4326	5.17	7.26	7.95	1.86
47.17	0.4912	5.31	8.24	7.98	1.62
48.99	0.5588	5.46	9.38	7.99	1.57
49.90	0.5984	5.53	10.04	8.00	1.50
53.52	0.7231	5.75	12.13	8.09	1.28
57.15	0.8443	5.83	14.17	8.30	1.20
60.78	0.9703	6.02	16.28	8.37	1.01
64.41	1.0729	6.19	18.00	8.48	0.84
68.04	1.1783	6.30	19.77	8.63	0.73
68.95	1.2068	6.33	20.25	8.66	0.70
73.48	1.3226	6.43	22.19	8.88	0.60
78.92	1.4460	6.53	24.26	9.15	0.50
79.83	1.4930	6.56	25.05	9.14	0.47

Table A-52 Data, Triaxial Test A-52

Sludge C-1 + 10% Flyash					
$p = 1.00 \text{ kg/cm}^2$			$w_f = 105.38\%$		
$\bar{\sigma}_{1f} = 2.80 \text{ kg/cm}^2$			$c_u = 1.36 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.08 \text{ kg/cm}^2$			$A_f = 0.31$		
$u_f = 3.00 \text{ kg/cm}^2$			$c_v = 0.0094 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.14	0.00	0.94	0.94
7.63	0.0097	2.22	0.15	1.77	0.86
8.35	0.0157	2.28	0.25	1.79	0.80
9.79	0.0328	2.40	0.51	1.84	0.68
11.23	0.0538	2.47	0.84	1.93	0.61
11.95	0.0711	2.50	1.11	1.99	0.58
12.67	0.0970	2.57	1.52	1.99	0.51
14.11	0.1628	2.67	2.55	2.05	0.41
15.12	0.2969	2.74	4.64	2.05	0.34
16.99	0.4097	2.80	6.41	2.17	0.28
18.43	0.4953	2.85	7.75	2.25	0.23
19.15	0.6431	2.89	10.06	2.24	0.19
22.32	0.8123	2.92	12.70	2.48	0.16
22.75	0.9352	2.92	14.63	2.48	0.16
27.79	1.2492	3.00	19.54	2.74	0.08
28.80	1.2855	3.00	20.11	2.82	0.08
45.79	1.4077	3.00	22.02	4.33	0.08
48.67	1.5321	3.01	23.96	4.47	0.07

Table A-53 Data, Triaxial Test A-53

Sludge C-1 + 10% Flyash					
$p = 2.00 \text{ kg/cm}^2$		$w_f = 92.40\%$			
$\bar{\sigma}_{1f} = 8.03 \text{ kg/cm}^2$		$c_u = 3.92 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.19 \text{ kg/cm}^2$		$A_f = 0.22$			
$u_f = 3.93 \text{ kg/cm}^2$		$c_v = 0.0094 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.18	0.00	1.94	1.94
11.34	0.0048	2.42	0.08	3.12	1.70
13.06	0.0127	2.58	0.21	3.17	1.54
14.78	0.0231	2.67	0.38	3.30	1.45
16.50	0.0411	2.92	0.68	3.25	1.20
18.21	0.0716	3.00	1.18	3.38	1.12
21.65	0.1707	3.25	2.80	3.51	0.87
42.27	0.2494	3.12	4.10	6.08	1.00
57.73	0.3630	3.41	5.96	7.52	0.71
61.17	0.4887	3.57	8.03	7.60	0.55
64.61	0.6622	3.67	10.87	7.67	0.45
66.32	0.7374	3.72	12.11	7.71	0.40
69.76	0.8895	3.78	14.61	7.81	0.34
71.48	0.9660	3.82	15.86	7.84	0.30
74.92	1.1077	3.90	18.19	7.90	0.22
76.63	1.1661	3.91	19.15	7.98	0.21
78.35	1.2248	3.93	20.11	8.04	0.19
81.79	1.3505	3.97	22.18	8.13	0.15
87.97	1.5464	4.00	25.39	8.35	0.12

Table A-54 Data, Triaxial Test A-54

Sludge C-1 + 10% Flyash					
$p = 2.50 \text{ kg/cm}^2$			$w_f = 86.57\%$		
$\bar{\sigma}_{1f} = 7.46 \text{ kg/cm}^2$			$c_u = 3.44 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.58 \text{ kg/cm}^2$			$A_f = 0.29$		
$u_f = 4.13 \text{ kg/cm}^2$			$c_v = 0.0081 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	2.61	2.61
11.48	0.0155	2.10	0.27	4.38	2.59
12.23	0.0384	2.10	0.66	4.48	2.60
13.72	0.0505	2.10	0.88	4.71	2.60
14.47	0.0587	2.10	1.02	4.82	2.60
25.65	0.0889	2.50	1.54	6.12	2.19
31.62	0.1224	2.72	2.12	6.78	1.98
36.09	0.1857	2.93	3.22	7.19	1.77
38.33	0.2510	3.10	4.35	7.29	1.60
40.57	0.3485	3.34	6.04	7.27	1.36
42.80	0.4755	3.56	8.24	7.23	1.14
45.30	0.6294	3.78	10.91	7.18	0.92
47.04	0.7257	3.88	12.58	7.20	0.82
48.79	0.8207	4.00	14.23	7.19	0.65
50.54	0.9215	4.00	15.97	7.29	0.70
54.03	1.0813	4.10	18.74	7.41	0.60
55.78	1.1679	4.13	20.25	7.47	0.57
59.27	1.3056	4.20	22.63	7.62	0.50
61.02	1.3846	4.21	24.00	7.69	0.49
64.52	1.5344	4.32	26.60	7.73	0.38

Table A-55 Data, Triaxial Test A-55

Sludge C-1 + 10% Flyash					
$p = 3.00 \text{ kg/cm}^2$		$w_f = 81.84\%$			
$\bar{\sigma}_{1f} = 6.98 \text{ kg/cm}^2$		$c_u = 3.34 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.31 \text{ kg/cm}^2$		$A_f = 0.41$			
$u_f = 4.81 \text{ kg/cm}^2$		$c_v = 0.0094 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	3.03	3.03
12.53	0.0074	2.18	0.12	4.59	2.94
15.51	0.0155	2.32	0.26	4.84	2.80
17.75	0.0234	2.47	0.39	4.98	2.65
19.24	0.0307	2.57	0.51	5.07	2.55
20.73	0.0394	2.79	0.66	5.13	2.42
22.22	0.0500	2.90	0.84	5.12	2.22
23.71	0.0630	2.98	1.05	5.23	2.14
26.70	0.0963	3.27	1.60	5.31	1.85
28.19	0.1199	3.46	2.00	5.30	1.66
31.17	0.1808	3.71	3.01	5.39	1.41
33.41	0.2393	3.84	3.98	5.51	1.28
37.14	0.3589	4.12	5.98	5.60	1.00
40.87	0.4856	4.31	8.09	5.76	0.81
44.25	0.5977	4.43	9.95	5.94	0.69
47.74	0.7221	4.60	12.02	6.06	0.52
51.24	0.8428	4.66	14.03	6.27	0.46
54.73	0.9573	4.72	15.94	6.46	0.40
58.23	1.0627	4.79	17.69	6.65	0.33
61.72	1.1572	4.81	19.27	6.88	0.31
63.47	1.2060	4.81	20.08	6.99	0.31
69.06	1.3543	4.90	22.55	7.27	0.22
73.96	1.4702	5.00	24.48	7.48	0.12
77.45	1.5621	5.00	26.01	7.67	0.12

Table A-56 Data, Triaxial Test A-56

Sludge C-1 + 10% Flyash					
$p =$	3.50	kg/cm^2	$w_f =$	75.70%	
$\bar{\sigma}_{1f} =$	6.33	kg/cm^2	$c_u =$	3.28	kg/cm^2
$\bar{\sigma}_{3f} =$	-0.24	kg/cm^2	$A_f =$	0.57	
$u_f =$	5.83	kg/cm^2	$c_v =$	0.0081	cm^2/min
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm^2	%	kg/cm^2	kg/cm^2
0.00	0.0000	2.09	0.00	3.50	3.50
13.72	0.0030	2.11	0.05	5.62	3.48
14.43	0.0183	2.11	0.31	5.72	3.48
15.84	0.0307	2.12	0.53	5.92	3.47
20.09	0.0361	2.15	0.62	6.55	3.44
21.50	0.0514	2.15	0.86	6.76	3.44
21.50	0.0605	2.19	1.04	6.71	3.40
29.99	0.0851	2.39	1.46	7.80	3.20
34.23	0.1138	2.55	1.96	8.27	3.04
37.07	0.1725	2.90	2.96	8.29	2.69
39.19	0.2637	3.30	4.53	8.12	2.29
40.60	0.3475	3.62	5.97	7.91	1.97
42.02	0.4635	3.98	7.96	7.64	1.61
44.14	0.5880	4.28	10.10	7.49	1.31
46.97	0.7165	4.62	12.31	7.38	0.97
49.09	0.8580	5.08	14.14	7.03	0.51
50.51	0.9807	5.34	16.85	6.79	0.25
52.63	1.1499	5.80	19.16	6.37	-0.21
53.34	1.2065	5.92	20.73	6.25	-0.33
54.75	1.2954	6.10	22.26	6.12	-0.51
56.87	1.4265	6.48	24.51	5.80	-0.89
58.99	1.5591	6.78	26.79	5.54	-1.19

Table A-57 Data, Triaxial Test A-57

Sludge C-1 + 10% Flyash					
$p = 4.00 \text{ kg/cm}^2$		$w_f = 70.14\%$			
$\bar{\sigma}_{1f} = 6.76 \text{ kg/cm}^2$		$c_u = 3.17 \text{ kg/cm}^2$			
$\bar{\sigma}_{3f} = 0.41 \text{ kg/cm}^2$		$A_f = 0.55$			
$u_f = 5.69 \text{ kg/cm}^2$		$c_v = 0.0071 \text{ cm}^2/\text{min}$			
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.16	0.00	3.94	3.94
16.98	0.0074	2.31	0.12	6.05	3.79
19.81	0.0132	2.42	0.22	6.31	3.68
24.05	0.0257	2.70	0.43	6.59	3.40
25.47	0.0302	2.83	0.54	6.64	3.27
26.88	0.0386	2.96	0.65	6.68	3.14
29.00	0.0511	3.15	0.86	6.78	2.95
30.42	0.0627	3.30	1.05	6.81	2.80
33.25	0.0884	3.60	1.48	6.86	2.50
36.08	0.1242	3.89	2.08	6.92	2.21
39.61	0.1872	4.24	3.14	7.00	1.89
42.44	0.2494	4.50	4.18	7.02	1.60
44.57	0.3068	4.62	5.14	7.11	1.48
46.69	0.3688	4.79	6.18	7.15	1.31
48.81	0.5011	5.00	8.40	7.06	1.10
50.22	0.6025	5.11	10.10	7.01	0.99
52.35	0.7572	5.27	12.69	6.92	0.83
54.47	0.8971	5.44	15.04	6.83	0.66
56.59	1.0264	5.60	17.20	6.74	0.50
59.42	1.1829	5.68	19.83	6.77	0.42
60.13	1.2210	5.72	20.47	6.75	0.38
62.25	1.3180	5.81	22.09	6.75	0.29
72.16	1.5319	5.94	25.68	7.31	0.16

Table A-58 Data, Triaxial Test A-58

Sludge C-1 + 10% Flyash					
$p = 5.00 \text{ kg/cm}^2$			$w_f = 62.25\%$		
$\bar{\sigma}_{1f} = 6.70 \text{ kg/cm}^2$			$c_u = 3.13 \text{ kg/cm}^2$		
$\bar{\sigma}_{3f} = 0.44 \text{ kg/cm}^2$			$A_f = 0.71$		
$u_f = 6.58 \text{ kg/cm}^2$			$c_v = 0.0081 \text{ cm}^2/\text{min}$		
Load	Displ.	Pore Pressure	Strain	Effective Principal Stress	Effective Minor Stress
kg	cm	kg/cm ²	%	kg/cm ²	kg/cm ²
0.00	0.0000	2.09	0.00	4.93	4.93
16.91	0.0058	2.94	0.11	6.72	4.08
17.94	0.0102	3.00	0.19	6.82	4.02
18.97	0.0150	3.18	0.27	6.80	3.84
20.00	0.0206	3.32	0.38	6.82	3.70
21.03	0.0269	3.42	0.49	6.88	3.60
22.06	0.0358	3.63	0.66	6.82	3.39
23.09	0.0447	3.68	0.82	6.92	3.34
24.12	0.0582	4.03	1.07	6.73	2.99
28.25	0.1143	4.47	2.09	6.88	2.55
30.31	0.1654	4.99	3.03	6.63	2.03
32.37	0.2416	5.30	4.43	6.56	1.72
34.43	0.3348	5.49	6.13	6.59	1.53
36.50	0.4252	5.89	7.79	6.40	1.13
38.56	0.5380	5.94	9.86	6.52	1.08
41.65	0.7013	6.20	12.85	6.50	0.82
44.74	0.8641	6.42	15.83	6.49	0.60
46.80	0.9596	6.50	17.58	6.56	0.52
49.90	1.0848	6.58	19.87	6.70	0.44
50.93	1.1384	6.58	20.86	6.75	0.44
52.99	1.2126	6.60	22.21	6.87	0.42
58.15	1.3825	6.79	25.33	7.03	0.23
63.30	1.5489	6.80	28.37	7.32	0.22

APPENDIX B
PERMEABILITY TEST DATA

Table B-1 Permeability Test Data for Natural Sludge H-2, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	12.45	0.0	2.62	5.28	512.
164.5	154.5	2.93	5.0	14.15	22.86	2217.
164.5	154.5	1.68	10.0	25.69	40.41	3920.
164.5	154.5	1.18	15.0	37.23	57.82	5609.
164.5	154.5	0.92	20.0	48.77	74.40	7217.
164.5	154.5	0.86	22.5	54.54	79.81	7741.
164.5	154.5	0.81	25.0	60.31	84.95	8240.
164.5	154.5	0.79	27.5	66.08	87.25	8463.
164.5	154.5	0.79	30.0	71.85	87.33	8471.
164.5	154.5	0.79	35.0	83.39	87.60	8498.
164.5	154.5	0.79	40.0	94.92	87.68	8505.
164.5	154.5	0.79	45.0	106.46	87.92	8528.
164.5	154.5	0.79	50.0	118.00	88.04	8540.
164.5	154.5	0.79	60.0	141.08	88.19	8553.
164.5	154.5	0.79	80.0	187.23	88.35	8570.
164.5	154.5	0.79	100.0	233.39	88.45	8580.

Table B-2 Permeability Test Data for Natural Sludge C-1, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	1.00	0.0	2.62	65.68	6371.
164.5	154.5	1.00	5.0	14.15	66.98	6497.
164.5	154.5	0.99	10.0	25.69	68.57	6651.
164.5	154.5	0.97	15.0	37.23	70.34	6823.
164.5	154.5	0.95	20.0	48.77	72.06	6989.
164.5	154.5	0.95	22.5	54.54	72.25	7008.
164.5	154.5	0.95	25.0	60.31	72.43	7025.
164.5	154.5	0.95	27.5	66.08	72.56	7038.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.95	35.0	83.39	72.85	7066.
164.5	154.5	0.95	40.0	94.92	72.91	7072.
164.5	154.5	0.95	45.0	106.46	73.11	7092.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-3 Permeability Test Data for Sludge H-2, 43 percent organic matter, vacuum and sterilant pretreated, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.78	0.0	2.62	84.21	8169.
164.5	154.5	0.79	5.0	14.15	84.79	8224.
164.5	154.5	0.80	10.0	25.69	84.86	8231.
164.5	154.5	0.79	15.0	37.23	86.37	8378.
164.5	154.5	0.79	20.0	48.77	86.65	8405.
164.5	154.5	0.79	22.5	54.54	86.88	8427.
164.5	154.5	0.79	25.0	60.31	87.10	8448.
164.5	154.5	0.79	27.5	66.08	87.25	8463.
164.5	154.5	0.78	30.0	71.85	88.45	8579.
164.5	154.5	0.78	35.0	83.39	88.73	8607.
164.5	154.5	0.78	40.0	94.92	88.80	8614.
164.5	154.5	0.78	45.0	106.46	89.05	8638.
164.5	154.5	0.78	50.0	118.00	89.17	8649.
164.5	154.5	0.78	60.0	141.08	89.31	8663.
164.5	154.5	0.78	80.0	187.23	89.48	8680.
164.5	154.5	0.78	100.0	233.39	89.58	8690.

Table B-4 Permeability Test Data for Sludge C-1, vacuum and sterilant pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressures	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.90	0.0	2.62	72.98	7079.
164.5	154.5	0.91	5.0	14.15	73.60	7140.
164.5	154.5	0.93	10.0	25.69	72.99	7080.
164.5	154.5	0.93	15.0	37.23	73.37	7117.
164.5	154.5	0.93	20.0	48.77	73.60	7140.
164.5	154.5	0.94	22.5	54.54	73.02	7082.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.95	45.0	106.46	73.11	7092.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-5 Permeability Test Data for Sludge H-2, 43 percent organic matter, sterilant pretreated, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	1.81	0.0	2.62	36.29	3520.
164.5	154.5	1.43	5.0	14.15	46.84	4543.
164.5	154.5	1.18	10.0	25.69	57.53	5580.
164.5	154.5	1.01	15.0	37.23	67.56	6553.
164.5	154.5	0.88	20.0	48.77	77.79	7545.
164.5	154.5	0.83	22.5	54.54	82.69	8021.
164.5	154.5	0.80	25.0	60.31	86.01	8343.
164.5	154.5	0.79	27.5	66.08	87.25	8463.
164.5	154.5	0.79	30.0	71.85	87.33	8471.
164.5	154.5	0.79	35.0	83.39	87.60	8498.
164.5	154.5	0.79	40.0	94.92	87.68	8505.
164.5	154.5	0.79	45.0	106.46	87.92	8528.
164.5	154.5	0.79	50.0	118.00	88.04	8540.
164.5	154.5	0.79	60.0	141.08	88.18	8553.
164.5	154.5	0.79	80.0	187.23	88.35	8570.
164.5	154.5	0.80	100.0	233.39	87.35	8472.

Table B-6 Permeability Test Data for Sludge H-2, 43 percent organic matter, vacuum pretreated, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.95	0.0	2.62	69.14	6707.
164.5	154.5	0.92	5.0	14.15	72.80	7062.
164.5	154.5	0.89	10.0	25.69	76.28	7399.
164.5	154.5	0.85	15.0	37.23	80.27	7787.
164.5	154.5	0.82	20.0	48.77	83.48	8097.
164.5	154.5	0.81	22.5	54.54	84.73	8219.
164.5	154.5	0.80	25.0	60.31	86.01	8343.
164.5	154.5	0.79	27.5	66.08	87.25	8463.
164.5	154.5	0.78	30.0	71.85	88.45	8579.
164.5	154.5	0.79	35.0	83.39	87.60	8498.
164.5	154.5	0.79	40.0	94.92	87.68	8505.
164.5	154.5	0.79	45.0	106.46	87.92	8528.
164.5	154.5	0.79	50.0	118.00	88.04	8540.
164.5	154.5	0.79	60.0	141.08	88.19	8553.
164.5	154.5	0.79	80.0	187.23	88.35	8570.
164.5	154.5	0.79	100.0	233.39	88.45	8580.

Table B-7 Permeability Test Data for Sludge C-1, sterilant pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.96	0.0	2.62	68.42	6637.
164.5	154.5	0.96	5.0	14.15	69.77	6768.
164.5	154.5	0.96	10.0	25.69	70.71	6859.
164.5	154.5	0.96	15.0	37.23	71.08	6894.
164.5	154.5	0.95	20.0	48.77	72.06	6989.
164.5	154.5	0.95	22.5	54.54	72.25	7008.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.95	40.0	94.92	72.91	7072.
164.5	154.5	0.95	45.0	106.46	73.11	7092.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-8 Permeability Test Data for Sludge C-1, vacuum pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.92	0.0	2.62	71.40	6925.
164.5	154.5	0.93	5.0	14.15	72.02	6986.
164.5	154.5	0.94	10.0	25.69	72.22	7005.
164.5	154.5	0.94	15.0	37.23	72.59	7041.
164.5	154.5	0.94	20.0	48.77	72.82	7064.
164.5	154.5	0.94	22.5	54.54	73.02	7082.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.95	45.0	106.46	73.11	7092.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-9 Permeability Test Data for Natural Sludge H-2, 34.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	14.56	0.0	2.62	4.51	438.
164.5	154.5	11.05	5.0	14.15	6.06	588.
164.5	154.5	8.93	10.0	25.69	7.60	737.
164.5	154.5	7.43	15.0	37.23	9.18	891.
164.5	154.5	6.39	20.0	48.77	10.71	1039.
164.5	154.5	5.98	22.5	54.54	11.48	1113.
164.5	154.5	5.68	25.0	60.31	12.11	1175.
164.5	154.5	5.53	27.5	66.08	12.46	1209.
164.5	154.5	5.42	30.0	71.85	12.73	1235.
164.5	154.5	5.30	35.0	83.39	13.06	1267.
164.5	154.5	5.24	40.0	94.92	13.22	1282.
164.5	154.5	5.22	45.0	106.46	13.31	1291.
164.5	154.5	5.21	50.0	118.00	13.35	1295.
164.5	154.5	5.21	60.0	141.08	13.37	1297.
164.5	154.5	5.21	80.0	187.23	13.40	1299.
164.5	154.5	5.21	100.0	233.39	13.41	1301.

Table B-10 Permeability Test Data for Natural Sludge H-2, 40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	18.95	0.0	2.62	3.25	315.
164.5	154.5	14.95	5.0	14.15	4.48	435.
164.5	154.5	12.38	10.0	25.69	5.48	532.
164.5	154.5	10.48	15.0	37.23	6.51	632.
164.5	154.5	9.08	20.0	48.77	7.54	731.
164.5	154.5	8.56	22.5	54.54	8.02	778.
164.5	154.5	8.04	25.0	60.31	8.56	830.
164.5	154.5	7.71	27.5	66.08	8.94	867.
164.5	154.5	7.48	30.0	71.85	9.22	895.
164.5	154.5	7.26	35.0	83.39	9.53	925.
164.5	154.5	7.14	40.0	94.92	9.70	941.
164.5	154.5	7.12	45.0	106.46	9.70	946.
164.5	154.5	7.11	50.0	118.00	9.78	949.
164.5	154.5	7.11	60.0	141.08	9.80	950.
164.5	154.5	7.11	80.0	187.23	9.82	952.
164.5	154.5	7.11	100.0	233.39	9.83	953.

Table B-11 Permeability Test Data for Natural Sludge H-2, 50.18 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	150.44	0.0	2.62	0.44	4235.
164.5	154.5	111.42	5.0	14.15	0.60	5831.
164.5	154.5	89.39	10.0	25.69	0.76	7366.
164.5	154.5	73.44	15.0	37.23	0.93	9012.
164.5	154.5	62.77	20.0	48.77	1.09	1058.
164.5	154.5	58.76	22.5	54.54	1.17	1133.
164.5	154.5	54.96	25.0	60.31	1.25	1214.
164.5	154.5	52.71	27.5	66.08	1.31	1268.
164.5	154.5	51.57	30.0	71.85	1.34	1298.
164.5	154.5	50.14	35.0	83.39	1.38	1339.
164.5	154.5	49.33	40.0	94.92	1.40	1362.
164.5	154.5	48.97	45.0	106.46	1.42	1376.
164.5	154.5	48.64	50.0	118.00	1.43	1387.
164.5	154.5	48.65	60.0	141.08	1.43	1389.
164.5	154.5	48.71	80.0	187.23	1.43	1390.
164.5	154.5	48.73	100.0	233.39	1.43	1391.

Table B-12 Permeability Test Data for Natural Sludge C-1, 38.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	4.45	0.0	2.62	14.76	1432.
164.5	154.5	4.39	5.0	14.15	15.26	1480.
164.5	154.5	4.32	10.0	25.69	15.71	1524.
164.5	154.5	4.21	15.0	37.23	16.21	1572.
164.5	154.5	4.12	20.0	48.77	16.61	1612.
164.5	154.5	4.11	22.5	54.54	16.70	1620.
164.5	154.5	4.11	25.0	60.31	16.74	1624.
164.5	154.5	4.11	27.5	66.08	16.77	1627.
164.5	154.5	4.11	30.0	71.85	16.70	1628.
164.5	154.5	4.12	35.0	83.39	16.80	1629.
164.5	154.5	4.12	40.0	94.92	16.81	1631.
164.5	154.5	4.13	45.0	106.46	16.82	1631.
164.5	154.5	4.14	50.0	118.00	16.80	1630.
164.5	154.5	4.14	60.0	141.08	16.83	1632.
164.5	154.5	4.15	80.0	187.23	16.82	1631.
164.5	154.5	4.15	100.0	233.39	16.84	1633.

Table B-13 Permeability Test Data for Natural Sludge C-1, 46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	8.46	0.0	2.62	7.76	753.
164.5	154.5	8.40	5.0	14.15	7.97	774.
164.5	154.5	8.27	10.0	25.69	8.21	796.
164.5	154.5	8.07	15.0	37.23	8.46	820.
164.5	154.5	7.90	20.0	48.77	8.66	840.
164.5	154.5	7.81	22.5	54.54	8.79	852.
164.5	154.5	7.76	25.0	60.31	8.87	860.
164.5	154.5	7.75	27.5	66.08	8.89	863.
164.5	154.5	7.74	30.0	71.85	8.91	865.
164.5	154.5	7.75	35.0	83.39	8.93	866.
164.5	154.5	7.75	40.0	94.92	8.94	867.
164.5	154.5	7.76	45.0	106.46	8.95	868.
164.5	154.5	7.75	50.0	118.00	8.97	870.
164.5	154.5	7.77	60.0	141.08	8.97	870.
164.5	154.5	7.77	80.0	187.23	8.98	871.
164.5	154.5	7.78	100.0	233.39	8.98	871.

Table B-14 Permeability Test Data for Natural Sludge C-1, 52.5 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	16.32	0.0	2.62	4.02	390.
164.5	154.5	16.31	5.0	14.15	4.11	398.
164.5	154.5	16.24	10.0	25.69	4.18	406.
164.5	154.5	16.01	15.0	37.23	4.26	413.
164.5	154.5	15.75	20.0	48.77	4.35	422.
164.5	154.5	15.72	22.5	54.54	4.37	424.
164.5	154.5	15.76	25.0	60.31	4.37	424.
164.5	154.5	15.79	27.5	66.08	4.37	423.
164.5	154.5	15.80	30.0	71.85	4.37	424.
164.5	154.5	15.81	35.0	83.39	4.38	425.
164.5	154.5	15.83	40.0	94.92	4.38	424.
164.5	154.5	15.87	45.0	106.46	4.38	424.
164.5	154.5	15.89	50.0	118.00	4.38	425.
164.5	154.5	15.92	60.0	141.08	4.38	424.
164.5	154.5	15.95	80.0	187.23	4.38	424.
164.5	154.5	15.97	100.0	233.39	4.38	424.

Table B-15 Permeability Test Data for Sludge H-2, 28 percent organic matter, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	60.46	0.0	2.62	1.09	105.
164.5	154.5	45.27	5.0	14.15	1.48	144.
164.5	154.5	36.45	10.0	25.69	1.86	181.
164.5	154.5	30.25	15.0	37.23	2.26	219.
164.5	154.5	26.05	20.0	48.77	2.63	255.
164.5	154.5	24.94	22.5	54.54	2.75	267.
164.5	154.5	24.10	25.0	60.31	2.86	277.
164.5	154.5	23.46	27.5	66.08	2.94	285.
164.5	154.5	23.15	30.0	71.85	2.98	289.
164.5	154.5	22.67	35.0	83.39	3.05	296.
164.5	154.5	22.46	40.0	94.92	3.08	299.
164.5	154.5	22.38	45.0	106.46	3.10	301.
164.5	154.5	22.33	50.0	118.00	3.11	302.
164.5	154.5	22.30	60.0	141.08	3.12	303.
164.5	154.5	22.34	80.0	187.23	3.12	303.
164.5	154.5	22.36	100.0	233.39	3.13	303.

Table B-16 Permeability Test Data for Sludge H-2, 35 percent organic matter, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	7.65	0.0	2.62	8.59	833.
164.5	154.5	4.53	5.0	14.15	14.79	1434.
164.5	154.5	3.23	10.0	25.69	21.02	2039.
164.5	154.5	2.51	15.0	37.23	27.18	2637.
164.5	154.5	2.08	20.0	48.77	32.91	3192.
164.5	154.5	1.98	22.5	54.54	34.66	3362.
164.5	154.5	1.91	25.0	60.31	36.02	3494.
164.5	154.5	1.87	27.5	66.08	36.86	3575.
164.5	154.5	1.83	30.0	71.85	37.70	3657.
164.5	154.5	1.79	35.0	83.39	38.66	3750.
164.5	154.5	1.77	40.0	94.92	39.13	3796.
164.5	154.5	1.74	45.0	106.46	39.92	3872.
164.5	154.5	1.74	50.0	118.00	39.97	3877.
164.5	154.5	1.74	60.0	141.08	40.04	3883.
164.5	154.5	1.74	80.0	187.23	40.11	3891.
164.5	154.5	1.74	100.0	233.39	40.16	3895.

Table B-17 Permeability Test Data for Sludge H-2, 28 percent organic matter, 34.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	69.76	0.0	2.62	0.94	913.
164.5	154.5	59.94	5.0	14.15	1.12	1084.
164.5	154.5	52.07	10.0	25.69	1.30	1265.
164.5	154.5	45.80	15.0	37.23	1.49	1445.
164.5	154.5	40.84	20.0	48.77	1.68	1626.
164.5	154.5	39.02	22.5	54.54	1.76	1706.
164.5	154.5	36.94	25.0	60.31	1.86	1807.
164.5	154.5	35.82	27.5	66.08	1.92	1867.
164.5	154.5	34.73	30.0	71.85	1.99	1927.
164.5	154.5	33.78	35.0	83.39	2.05	1987.
164.5	154.5	33.47	40.0	94.92	2.07	2007.
164.5	154.5	33.23	45.0	106.46	2.09	2028.
164.5	154.5	33.28	50.0	118.00	2.09	2027.
164.5	154.5	33.00	60.0	141.08	2.11	2048.
164.5	154.5	33.07	80.0	187.23	2.11	2047.
164.5	154.5	32.94	100.0	233.39	2.12	2058.

Table B-18 Permeability Test Data for Sludge H-2, 28 percent organic matter, 40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	82.45	0.0	2.62	0.80	773.
164.5	154.5	74.41	5.0	14.15	0.90	873.
164.5	154.5	67.64	10.0	25.69	1.00	974.
164.5	154.5	61.63	15.0	37.23	1.11	1074.
164.5	154.5	56.55	20.0	48.77	1.21	1174.
164.5	154.5	54.37	22.5	54.54	1.26	1224.
164.5	154.5	51.95	25.0	60.31	1.32	1285.
164.5	154.5	50.86	27.5	66.08	1.36	1315.
164.5	154.5	50.13	30.0	71.85	1.38	1335.
164.5	154.5	49.55	35.0	83.39	1.40	1355.
164.5	154.5	49.59	40.0	94.92	1.40	1355.
164.5	154.5	49.35	45.0	106.46	1.41	1365.
164.5	154.5	49.43	50.0	118.00	1.41	1365.
164.5	154.5	49.15	60.0	141.08	1.42	1375.
164.5	154.5	49.24	80.0	187.23	1.42	1375.
164.5	154.5	49.30	100.0	233.39	1.42	1375.

Table B-19 Permeability Test Data for Sludge H-2, 28 percent organic matter, 50.18 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	114.60	0.0	2.62	0.57	556.
164.5	154.5	114.18	5.0	14.15	0.59	569.
164.5	154.5	112.93	10.0	25.69	0.60	583.
164.5	154.5	111.02	15.0	37.23	0.61	596.
164.5	154.5	109.00	20.0	48.77	0.63	609.
164.5	154.5	108.04	22.5	54.54	0.64	616.
164.5	154.5	107.61	25.0	60.31	0.64	620.
164.5	154.5	107.28	27.5	66.08	0.64	623.
164.5	154.5	106.86	30.0	71.85	0.65	626.
164.5	154.5	107.02	35.0	83.39	0.65	627.
164.5	154.5	106.94	40.0	94.92	0.65	628.
164.5	154.5	107.24	45.0	106.46	0.65	628.
164.5	154.5	107.21	50.0	118.00	0.65	629.
164.5	154.5	107.21	60.0	141.08	0.65	630.
164.5	154.5	107.25	80.0	187.23	0.65	631.
164.5	154.5	107.37	100.0	233.39	0.65	631.

Table B-20 Permeability Test Data for Sludge H-2, 35 percent organic matter, 34.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	16.75	0.0	2.62	3.92	3804.
164.5	154.5	14.01	5.0	14.15	4.78	4637.
164.5	154.5	12.06	10.0	25.69	5.63	5460.
164.5	154.5	10.52	15.0	37.23	6.49	6291.
164.5	154.5	9.46	20.0	48.77	7.24	7019.
164.5	154.5	9.24	22.5	54.54	7.43	7205.
164.5	154.5	9.07	25.0	60.31	7.59	7358.
164.5	154.5	8.98	27.5	66.08	7.68	7446.
164.5	154.5	8.94	30.0	71.85	7.72	7485.
164.5	154.5	8.92	35.0	83.39	7.76	7526.
164.5	154.5	8.88	40.0	94.92	7.80	7566.
164.5	154.5	8.86	45.0	106.46	7.84	7604.
164.5	154.5	8.80	50.0	118.00	7.90	7666.
164.5	154.5	8.79	60.0	141.08	7.93	7687.
164.5	154.5	8.78	80.0	187.23	7.95	7711.
164.5	154.5	8.79	100.0	233.39	7.95	7711.

Table B-21 Permeability Test Data for Sludge H-2, 35 percent organic matter, 40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	20.28	0.0	2.62	3.24	3142.
164.5	154.5	16.95	5.0	14.15	3.95	3833.
164.5	154.5	14.58	10.0	25.69	4.66	4516.
164.5	154.5	12.75	15.0	37.23	5.35	5191.
164.5	154.5	11.31	20.0	48.77	6.05	5871.
164.5	154.5	10.80	22.5	54.54	6.36	6164.
164.5	154.5	10.49	25.0	60.31	6.56	6362.
164.5	154.5	10.28	27.5	66.08	6.71	6504.
164.5	154.5	10.15	30.0	71.85	6.80	6593.
164.5	154.5	10.06	35.0	83.39	6.88	6673.
164.5	154.5	10.04	40.0	94.92	6.90	6692.
164.5	154.5	10.05	45.0	106.46	6.91	6704.
164.5	154.5	10.05	50.0	118.00	6.92	6713.
164.5	154.5	10.06	60.0	141.08	6.92	6717.
164.5	154.5	10.08	80.0	187.23	6.92	6716.
164.5	154.5	10.08	100.0	233.39	6.93	6724.

Table B-22 Permeability Test Data for Sludge H-2, 35 percent organic matter, 50.18 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	99.51	0.0	2.62	0.66	640.
164.5	154.5	90.67	5.0	14.15	0.74	717.
164.5	154.5	82.84	10.0	25.69	0.82	795.
164.5	154.5	75.98	15.0	37.23	0.90	871.
164.5	154.5	70.01	20.0	48.77	0.98	948.
164.5	154.5	68.39	22.5	54.54	1.00	974.
164.5	154.5	67.31	25.0	60.31	1.02	992.
164.5	154.5	66.69	27.5	66.08	1.03	1003.
164.5	154.5	66.28	30.0	71.85	1.04	1010.
164.5	154.5	66.10	35.0	83.39	1.05	1016.
164.5	154.5	65.89	40.0	94.92	1.05	1020.
164.5	154.5	65.69	45.0	106.46	1.06	1026.
164.5	154.5	65.71	50.0	118.00	1.06	1027.
164.5	154.5	65.56	60.0	141.08	1.06	1031.
164.5	154.5	65.30	80.0	187.23	1.07	1037.
164.5	154.5	65.19	100.0	233.39	1.07	1040.

Table B-23 Permeability Test Data for Natural Sludge H-2 + 10 percent lime, 25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	2.11	0.0	2.62	31.13	3020.
164.5	154.5	1.59	5.0	14.15	42.13	4086.
164.5	154.5	1.28	10.0	25.69	53.04	5144.
164.5	154.5	1.07	15.0	37.23	63.77	6186.
164.5	154.5	0.92	20.0	48.77	74.40	7217.
164.5	154.5	0.86	22.5	54.54	79.81	7741.
164.5	154.5	0.83	25.0	60.31	82.90	8041.
164.5	154.5	0.80	27.5	66.08	86.16	8358.
164.5	154.5	0.79	30.0	71.85	87.33	8471.
164.5	154.5	0.77	35.0	83.39	89.88	8718.
164.5	154.5	0.77	40.0	94.92	89.96	8726.
164.5	154.5	0.77	45.0	106.46	90.21	8750.
164.5	154.5	0.77	50.0	118.00	90.32	8761.
164.5	154.5	0.77	60.0	141.08	90.47	8776.
164.5	154.5	0.77	80.0	187.23	90.64	8792.
164.5	154.5	0.77	100.0	233.39	90.75	8803.

Table B-24 Permeability Test Data for Sludge C-1 + 10 percent lime, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.98	0.0	2.62	67.03	6501.
164.5	154.5	0.96	5.0	14.15	69.77	6768.
164.5	154.5	0.96	10.0	25.69	70.71	6859.
164.5	154.5	0.95	15.0	37.23	71.82	6967.
164.5	154.5	0.94	20.0	48.77	72.82	7064.
164.5	154.5	0.94	22.5	54.54	73.02	7082.
164.5	154.5	0.93	25.0	60.31	73.98	7177.
164.5	154.5	0.93	27.5	66.08	74.12	7189.
164.5	154.5	0.93	30.0	71.85	74.18	7195.
164.5	154.5	0.93	35.0	83.39	74.42	7218.
164.5	154.5	0.93	40.0	94.92	74.48	7225.
164.5	154.5	0.93	45.0	106.46	74.69	7245.
164.5	154.5	0.93	50.0	118.00	74.78	7254.
164.5	154.5	0.93	60.0	141.08	74.91	7266.
164.5	154.5	0.94	80.0	187.23	74.25	7202.
164.5	154.5	0.94	100.0	233.39	74.34	7211.

Table B-25 Permeability Test Data for Natural Sludge H-2 + 10 percent lime, 34.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.78	0.0	2.62	9.69	940.
164.5	154.5	6.24	5.0	14.15	10.73	1041.
164.5	154.5	5.76	10.0	25.69	11.79	1143.
164.5	154.5	5.29	15.0	37.23	12.90	1251.
164.5	154.5	4.91	20.0	48.77	13.94	1352.
164.5	154.5	4.81	22.5	54.54	14.27	1384.
164.5	154.5	4.74	25.0	60.31	14.52	1408.
164.5	154.5	4.70	27.5	66.08	14.67	1423.
164.5	154.5	4.68	30.0	71.85	14.74	1430.
164.5	154.5	4.66	35.0	83.39	14.85	1441.
164.5	154.5	4.65	40.0	94.92	14.90	1445.
164.5	154.5	4.66	45.0	106.46	14.91	1446.
164.5	154.5	4.65	50.0	118.00	14.96	1451.
164.5	154.5	4.64	60.0	141.08	15.01	1456.
164.5	154.5	4.64	80.0	187.23	15.04	1459.
164.5	154.5	4.64	100.0	233.39	15.06	1461.

Table B-26 Permeability Test Data for Natural Sludge H-2 + 10 percent lime, 40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	7.16	0.0	2.62	9.17	890.
164.5	154.5	6.92	5.0	14.15	9.68	939.
164.5	154.5	6.65	10.0	25.69	10.21	990.
164.5	154.5	6.37	15.0	37.23	10.71	1039.
164.5	154.5	6.10	20.0	48.77	11.22	1089.
164.5	154.5	5.98	22.5	54.54	11.48	1113.
164.5	154.5	5.86	25.0	60.31	11.74	1139.
164.5	154.5	5.78	27.5	66.08	11.93	1157.
164.5	154.5	5.72	30.0	71.85	12.06	1170.
164.5	154.5	5.64	35.0	83.39	12.27	1190.
164.5	154.5	5.63	40.0	94.92	12.30	1193.
164.5	154.5	5.61	45.0	106.46	12.38	1201.
164.5	154.5	5.59	50.0	118.00	12.44	1207.
164.5	154.5	5.57	60.0	141.08	12.51	1213.
164.5	154.5	5.57	80.0	187.23	12.53	1215.
164.5	154.5	5.56	100.0	233.39	12.57	1219.

Table B-27 Permeability Test Data for Natural Sludge H-2 + 10 percent lime, 50.18 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	33.59	0.0	2.62	1.96	1897.
164.5	154.5	32.65	5.0	14.15	2.05	1990.
164.5	154.5	31.54	10.0	25.69	2.15	2088.
164.5	154.5	30.35	15.0	37.23	2.25	2181.
164.5	154.5	29.36	20.0	48.77	2.33	2262.
164.5	154.5	29.15	22.5	54.54	2.35	2284.
164.5	154.5	29.02	25.0	60.31	2.37	2300.
164.5	154.5	28.89	27.5	66.08	2.39	2314.
164.5	154.5	28.82	30.0	71.85	2.39	2322.
164.5	154.5	28.80	35.0	83.39	2.40	2331.
164.5	154.5	28.79	40.0	94.92	2.41	2334.
164.5	154.5	28.85	45.0	106.46	2.41	2335.
164.5	154.5	28.86	50.0	118.00	2.41	2338.
164.5	154.5	28.88	60.0	141.08	2.41	2340.
164.5	154.5	28.93	80.0	187.23	2.41	2340.
164.5	154.5	28.95	100.0	233.39	2.41	2341.

Table B-28 Permeability Test Data for Sludge C-1 + 10 percent lime, 38.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	2.81	0.0	2.62	23.38	2267.
164.5	154.5	2.84	5.0	14.15	23.58	2288.
164.5	154.5	2.84	10.0	25.69	23.90	2319.
164.5	154.5	2.83	15.0	37.23	24.11	2339.
164.5	154.5	2.80	20.0	48.77	24.45	2371.
164.5	154.5	2.80	22.5	54.54	24.51	2378.
164.5	154.5	2.80	25.0	60.31	24.57	2384.
164.5	154.5	2.80	27.5	66.08	24.63	2388.
164.5	154.5	2.80	30.0	71.85	24.64	2390.
164.5	154.5	2.81	35.0	83.39	24.63	2389.
164.5	154.5	2.81	40.0	94.92	24.65	2391.
164.5	154.5	2.82	45.0	106.46	24.63	2389.
164.5	154.5	2.82	50.0	118.00	24.66	2392.
164.5	154.5	2.82	60.0	141.08	24.70	2396.
164.5	154.5	2.83	80.0	187.23	24.66	2392.
164.5	154.5	2.83	100.0	233.39	24.69	2395.

Table B-29 Permeability Test Data for Sludge C-1 + 10 percent lime,
46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	5.10	0.0	2.62	12.88	1249.
164.5	154.5	5.12	5.0	14.15	13.08	1269.
164.5	154.5	5.12	10.0	25.69	13.26	1286.
164.5	154.5	5.07	15.0	37.23	13.46	1305.
164.5	154.5	5.02	20.0	48.77	13.64	1323.
164.5	154.5	5.00	22.5	54.54	13.73	1332.
164.5	154.5	5.00	25.0	60.31	13.76	1335.
164.5	154.5	5.00	27.5	66.08	13.79	1337.
164.5	154.5	5.00	30.0	71.85	13.80	1338.
164.5	154.5	5.01	35.0	83.39	13.81	1340.
164.5	154.5	5.02	40.0	94.92	13.80	1338.
164.5	154.5	5.03	45.0	106.46	13.81	1339.
164.5	154.5	5.03	50.0	118.00	13.83	1341.
164.5	154.5	5.04	60.0	141.08	13.82	1341.
164.5	154.5	5.05	80.0	187.23	13.82	1341.
164.5	154.5	5.06	100.0	233.39	13.81	1340.

Table B-30 Permeability Test Data for Sludge C-1 + 10 percent lime,
52.5 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	9.33	0.0	2.62	7.04	6829.
164.5	154.5	9.49	5.0	14.15	7.06	6856.
164.5	154.5	9.60	10.0	25.69	7.07	6859.
164.5	154.5	9.62	15.0	37.23	7.09	6880.
164.5	154.5	9.63	20.0	48.77	7.11	6895.
164.5	154.5	9.65	22.5	54.54	7.11	6899.
164.5	154.5	9.66	25.0	60.31	7.12	6909.
164.5	154.5	9.68	27.5	66.08	7.12	6907.
164.5	154.5	9.68	30.0	71.85	7.13	6913.
164.5	154.5	9.71	35.0	83.39	7.13	6914.
164.5	154.5	9.72	40.0	94.92	7.13	6912.
164.5	154.5	9.75	45.0	106.46	7.12	6910.
164.5	154.5	9.76	50.0	118.00	7.13	6912.
164.5	154.5	9.77	60.0	141.08	7.13	6916.
164.5	154.5	9.79	80.0	187.23	7.13	6915.
164.5	154.5	9.80	100.0	233.39	7.13	6916.

Table B-31 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, vacuum and sterilant pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability ft/yr	Permeability cm/sec
cm	cm	min	psi	ft water		$\times 10^{-8}$
164.5	154.5	0.75	0.0	2.62	87.58	8495.
164.5	154.5	0.76	5.0	14.15	88.13	8549.
164.5	154.5	0.76	10.0	25.69	89.32	8664.
164.5	154.5	0.76	15.0	37.23	89.78	8709.
164.5	154.5	0.76	20.0	48.77	90.07	8737.
164.5	154.5	0.76	22.5	54.54	90.31	8760.
164.5	154.5	0.76	25.0	60.31	90.53	8782.
164.5	154.5	0.76	27.5	66.08	90.70	8797.
164.5	154.5	0.76	30.0	71.85	90.77	8805.
164.5	154.5	0.76	35.0	83.39	91.06	8833.
164.5	154.5	0.76	40.0	94.92	91.14	8841.
164.5	154.5	0.76	45.0	106.46	91.39	8865.
164.5	154.5	0.76	50.0	118.00	91.51	8877.
164.5	154.5	0.76	60.0	141.08	91.66	8891.
164.5	154.5	0.77	80.0	187.23	90.64	8792.
164.5	154.5	0.77	100.0	233.39	90.75	8803.

Table B-32 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, sterilant pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability ft/yr	Permeability cm/sec
cm	cm	min	psi	ft water		$\times 10^{-8}$
164.5	154.5	0.88	0.0	2.62	74.64	7240.
164.5	154.5	0.87	5.0	14.15	76.99	7468.
164.5	154.5	0.85	10.0	25.69	79.86	7747.
164.5	154.5	0.83	15.0	37.23	82.21	7974.
164.5	154.5	0.80	20.0	48.77	85.57	8300.
164.5	154.5	0.77	22.5	54.54	89.14	8646.
164.5	154.5	0.78	25.0	60.31	88.21	8557.
164.5	154.5	0.77	27.5	66.08	89.52	8683.
164.5	154.5	0.77	30.0	71.85	89.59	8691.
164.5	154.5	0.76	35.0	83.39	91.06	8833.
164.5	154.5	0.76	40.0	94.92	91.14	8841.
164.5	154.5	0.77	45.0	106.46	90.21	8750.
164.5	154.5	0.77	50.0	118.0	90.32	8761.
164.5	154.5	0.77	60.0	141.08	90.47	8776.
164.5	154.5	0.77	80.0	187.23	90.64	8792.
164.5	154.5	0.77	100.0	233.39	90.75	8803.

Table B-33 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, vacuum pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	1.44	0.0	2.62	45.61	4425.
164.5	154.5	1.25	5.0	14.15	53.58	5198.
164.5	154.5	1.09	10.0	25.69	62.28	6041.
164.5	154.5	0.97	15.0	37.23	70.34	6823.
164.5	154.5	0.87	20.0	48.77	78.68	7632.
164.5	154.5	0.83	22.5	54.54	82.69	8021.
164.5	154.5	0.80	25.0	60.31	86.01	8343.
164.5	154.5	0.78	27.5	66.08	88.37	8572.
164.5	154.5	0.77	30.0	71.85	89.59	8691.
164.5	154.5	0.77	35.0	83.39	89.88	8718.
164.5	154.5	0.77	40.0	94.92	89.96	8726.
164.5	154.5	0.77	45.0	106.46	90.21	8750.
164.5	154.5	0.77	50.0	118.00	90.32	8761.
164.5	154.5	0.77	60.0	141.08	90.47	8776.
164.5	154.5	0.77	80.0	187.23	90.64	8792.
164.5	154.5	0.77	100.0	233.39	90.75	8803.

Table B-34 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, sterilant and vacuum pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	5.27	0.0	2.62	12.46	1209.
164.5	154.5	5.36	5.0	14.15	12.50	1212.
164.5	154.5	5.43	10.0	25.69	12.50	1213.
164.5	154.5	5.43	15.0	37.23	12.57	1219.
164.5	154.5	5.46	20.0	48.77	12.54	1216.
164.5	154.5	5.46	22.5	54.54	12.57	1219.
164.5	154.5	5.47	25.0	60.31	12.58	1220.
164.5	154.5	5.48	27.5	66.08	12.58	1220.
164.5	154.5	5.49	30.0	71.85	12.57	1219.
164.5	154.5	5.50	35.0	83.39	12.58	1221.
164.5	154.5	5.51	40.0	94.92	12.57	1219.
164.5	154.5	5.52	45.0	106.46	12.58	1221.
164.5	154.5	5.53	50.0	118.00	12.58	1220.
164.5	154.5	5.54	60.0	141.08	12.57	1220.
164.5	154.5	5.55	80.0	187.23	12.58	1220.
164.5	154.5	5.56	100.0	233.39	12.57	1219.

Table B-35 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, sterilant pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	5.64	0.0	2.62	11.65	1130.
164.5	154.5	5.68	5.0	14.15	11.79	1144.
164.5	154.5	5.69	10.0	25.69	11.93	1157.
164.5	154.5	5.65	15.0	37.23	12.08	1171.
164.5	154.5	5.60	20.0	48.77	12.22	1186.
164.5	154.5	5.59	22.5	54.54	12.28	1191.
164.5	154.5	5.56	25.0	60.31	12.38	1200.
164.5	154.5	5.55	27.5	66.08	12.42	1205.
164.5	154.5	5.53	30.0	71.85	12.48	1210.
164.5	154.5	5.53	35.0	83.39	12.51	1214.
164.5	154.5	5.53	40.0	94.92	12.53	1215.
164.5	154.5	5.55	45.0	106.46	12.52	1214.
164.5	154.5	5.56	50.0	118.00	12.51	1213.
164.5	154.5	5.55	60.0	141.08	12.55	1218.
164.5	154.5	5.56	80.0	187.23	12.55	1218.
164.5	154.5	5.57	100.0	233.39	12.55	1217.

Table B-36 Permeability Test Data for Sludge H-2 + 10 percent lime,
43 percent organic matter, vacuum pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.58	0.0	2.62	9.98	968.
164.5	154.5	6.45	5.0	14.15	10.38	1007.
164.5	154.5	6.31	10.0	25.69	10.76	1044.
164.5	154.5	6.12	15.0	37.23	11.15	1081.
164.5	154.5	5.93	20.0	48.77	11.54	1120.
164.5	154.5	5.85	22.5	54.54	11.73	1138.
164.5	154.5	5.76	25.0	60.31	11.95	1159.
164.5	154.5	5.69	27.5	66.08	12.11	1175.
164.5	154.5	5.65	30.0	71.85	12.21	1184.
164.5	154.5	5.58	35.0	83.39	12.40	1203.
164.5	154.5	5.58	40.0	94.92	12.41	1204.
164.5	154.5	5.59	45.0	106.46	12.43	1205.
164.5	154.5	5.59	50.0	118.00	12.44	1207.
164.5	154.5	5.60	60.0	141.08	12.44	1207.
164.5	154.5	5.61	80.0	187.23	12.44	1207.
164.5	154.5	5.61	100.0	233.39	12.46	1208.

Table B-37 Permeability Test Data for Sludge C-1 + 10 percent lime, sterilant and vacuum pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.88	0.0	2.62	74.64	7240.
164.5	154.5	0.90	5.0	14.15	74.42	7219.
164.5	154.5	0.91	10.0	25.69	74.60	7236.
164.5	154.5	0.92	15.0	37.23	74.17	7194.
164.5	154.5	0.92	20.0	48.77	74.40	7217.
164.5	154.5	0.92	22.5	54.54	74.60	7236.
164.5	154.5	0.92	25.0	60.31	74.79	7255.
164.5	154.5	0.92	27.5	66.08	74.92	7267.
164.5	154.5	0.92	30.0	71.85	74.99	7274.
164.5	154.5	0.93	35.0	83.39	74.42	7218.
164.5	154.5	0.93	40.0	94.92	74.48	7225.
164.5	154.5	0.93	45.0	106.46	74.69	7245.
164.5	154.5	0.93	50.0	118.00	74.78	7254.
164.5	154.5	0.93	60.0	141.08	74.91	7266.
164.5	154.5	0.93	80.0	187.23	75.05	7280.
164.5	154.5	0.94	100.0	233.39	74.34	7211.

Table B-38 Permeability Test Data for Sludge C-1 + 10 percent lime, sterilant pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.90	0.0	2.62	72.98	7079.
164.5	154.5	0.91	5.0	14.15	73.60	7140.
164.5	154.5	0.92	10.0	25.69	73.79	7157.
164.5	154.5	0.92	15.0	37.23	74.17	7194.
164.5	154.5	0.92	20.0	48.77	74.40	7217.
164.5	154.5	0.92	22.5	54.54	74.60	7236.
164.5	154.5	0.92	25.0	60.31	74.79	7255.
164.5	154.5	0.92	27.5	66.08	74.92	7267.
164.5	154.5	0.92	30.0	71.85	74.99	7274.
164.5	154.5	0.93	35.0	83.39	74.42	7218.
164.5	154.5	0.93	40.0	94.92	74.48	7225.
164.5	154.5	0.93	45.0	106.46	74.69	7245.
164.5	154.5	0.93	50.0	118.00	74.78	7254.
164.5	154.5	0.93	60.0	141.08	74.91	7266.
164.5	154.5	0.94	80.0	187.23	74.25	7202.
164.5	154.5	0.94	100.0	233.39	74.34	7211.

Table B-39 Permeability Test Data for Sludge C-1 + 10 percent lime,
vacuum pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.94	0.0	2.62	69.88	6778.
164.5	154.5	0.95	5.0	14.15	70.51	6839.
164.5	154.5	0.95	10.0	25.69	71.46	6931.
164.5	154.5	0.94	15.0	37.23	72.59	7041.
164.5	154.5	0.93	20.0	48.77	73.60	7140.
164.5	154.5	0.93	22.5	54.54	73.80	7159.
164.5	154.5	0.93	25.0	60.31	73.98	7177.
164.5	154.5	0.93	27.5	66.08	74.12	7189.
164.5	154.5	0.93	30.0	71.85	74.18	7195.
164.5	154.5	0.93	35.0	83.39	74.42	7218.
164.5	154.5	0.93	40.0	94.92	74.48	7225.
164.5	154.5	0.93	45.0	106.46	74.69	7245.
164.5	154.5	0.93	50.0	118.00	74.78	7254.
164.5	154.5	0.93	60.0	141.08	74.91	7266.
164.5	154.5	0.94	80.0	187.23	74.25	7202.
164.5	154.5	0.94	100.0	233.39	74.34	7211.

Table B-40 Permeability Test Data for Sludge C-1 + 10 percent lime,
sterilant and vacuum pretreated, 46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	4.78	0.0	2.62	13.74	1333.
164.5	154.5	4.87	5.0	14.15	13.75	1334.
164.5	154.5	4.93	10.0	25.69	13.77	1336.
164.5	154.5	4.94	15.0	37.23	13.81	1340.
164.5	154.5	4.96	20.0	48.77	13.80	1339.
164.5	154.5	4.96	22.5	54.54	13.84	1342.
164.5	154.5	4.97	25.0	60.31	13.84	1343.
164.5	154.5	4.98	27.5	66.08	13.84	1343.
164.5	154.5	4.99	30.0	71.85	13.83	1341.
164.5	154.5	5.00	35.0	83.39	13.84	1343.
164.5	154.5	5.01	40.0	94.92	13.83	1341.
164.5	154.5	5.02	45.0	106.46	13.84	1342.
164.5	154.5	5.03	50.0	118.00	13.83	1341.
164.5	154.5	5.04	60.0	141.08	13.82	1341.
164.5	154.5	5.05	80.0	187.23	13.82	1341.
164.5	154.5	5.05	100.0	233.39	13.84	1342.

Table B-41 Permeability Test Data for Sludge C-1 + 10 percent lime,
sterilant pretreated, 46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	4.87	0.0	2.62	13.49	1308.
164.5	154.5	4.93	5.0	14.15	13.59	1318.
164.5	154.5	4.98	10.0	25.69	13.63	1322.
164.5	154.5	4.98	15.0	37.23	13.70	1329.
164.5	154.5	4.97	20.0	48.77	13.77	1336.
164.5	154.5	4.98	22.5	54.54	13.78	1337.
164.5	154.5	4.98	25.0	60.31	13.82	1340.
164.5	154.5	4.99	27.5	66.08	13.81	1340.
164.5	154.5	4.99	30.0	71.85	13.83	1341.
164.5	154.5	5.00	35.0	83.39	13.84	1343.
164.5	154.5	5.01	40.0	94.92	13.83	1341.
164.5	154.5	5.02	45.0	106.46	13.84	1342.
164.5	154.5	5.03	50.0	118.00	13.83	1341.
164.5	154.5	5.04	60.0	141.08	13.82	1341.
164.5	154.5	5.05	80.0	187.23	13.82	1341.
164.5	154.5	5.05	100.0	233.39	13.84	1342.

Table B-42 Permeability Test Data for Sludge C-1 + 10 percent lime,
vacuum pretreated, 46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	4.99	0.0	2.62	13.16	1277.
164.5	154.5	5.04	5.0	14.15	13.29	1289.
164.5	154.5	5.06	10.0	25.69	13.42	1301.
164.5	154.5	5.03	15.0	37.23	13.57	1316.
164.5	154.5	5.00	20.0	48.77	13.69	1328.
164.5	154.5	4.99	22.5	54.54	13.75	1334.
164.5	154.5	4.99	25.0	60.31	13.79	1338.
164.5	154.5	4.99	27.5	66.08	13.81	1340.
164.5	154.5	5.00	30.0	71.85	13.80	1338.
164.5	154.5	5.01	35.0	83.39	13.81	1340.
164.5	154.5	5.02	40.0	94.92	13.80	1338.
164.5	154.5	5.03	45.0	106.46	13.81	1339.
164.5	154.5	5.04	50.0	118.00	13.80	1339.
164.5	154.5	5.04	60.0	141.08	13.82	1341.
164.5	154.5	5.05	80.0	187.23	13.82	1341.
164.5	154.5	5.06	100.0	233.39	13.81	1340.

Table B-43 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, 25.7 percent solids

Initial Head cm	Final Head cm	Time min	Back Pressure psi	Average Head ft water	Permeability ft/yr	Permeability cm/sec $\times 10^{-8}$
164.5	154.5	4.70	0.0	2.62	13.98	1356.
164.5	154.5	2.43	5.0	14.15	27.56	2674.
164.5	154.5	1.64	10.0	25.69	41.39	4015.
164.5	154.5	1.24	15.0	37.23	55.03	5338.
164.5	154.5	0.99	20.0	48.77	69.14	6707.
164.5	154.5	0.92	22.5	54.54	74.60	7236.
164.5	154.5	0.86	25.0	60.31	80.01	7761.
164.5	154.5	0.84	27.5	66.08	82.06	7960.
164.5	154.5	0.82	30.0	71.85	84.13	8161.
164.5	154.5	0.80	35.0	83.39	86.51	8391.
164.5	154.5	0.79	40.0	94.92	87.68	8505.
164.5	154.5	0.80	45.0	106.46	86.82	8422.
164.5	154.5	0.78	50.0	118.00	89.17	8649.
164.5	154.5	0.78	60.0	141.08	89.31	8663.
164.5	154.5	0.78	80.0	187.23	89.48	8680.
164.5	154.5	0.78	100.0	233.39	89.58	8690.

Table B-44 Permeability Test Data for Sludge C-1 + 10 percent flyash,
30.7 percent solids

Initial Head cm	Final Head cm	Time min	Back Pressure psi	Average Head ft water	Permeability ft/yr	Permeability cm/sec $\times 10^{-8}$
164.5	154.5	0.98	0.0	2.62	67.03	6501.
164.5	154.5	0.98	5.0	14.15	68.35	6630.
164.5	154.5	0.98	10.0	25.69	69.27	6719.
164.5	154.5	0.97	15.0	37.23	70.34	6823.
164.5	154.5	0.95	20.0	48.77	72.06	6989.
164.5	154.5	0.95	22.5	54.54	72.25	7008.
164.5	154.5	0.95	25.0	60.31	72.43	7025.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.94	45.0	106.46	73.89	7168.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-45 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, 34.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	9.59	0.0	2.62	6.85	664.
164.5	154.5	8.28	5.0	14.15	8.09	785.
164.5	154.5	7.27	10.0	25.69	9.34	906.
164.5	154.5	6.43	15.0	37.23	10.61	1029.
164.5	154.5	5.78	20.0	48.77	11.84	1149.
164.5	154.5	5.52	22.5	54.54	12.43	1206.
164.5	154.5	5.34	25.0	60.31	12.88	1250.
164.5	154.5	5.23	27.5	66.08	13.18	1278.
164.5	154.5	5.16	30.0	71.85	13.37	1297.
164.5	154.5	5.08	35.0	83.39	13.62	1321.
164.5	154.5	5.05	40.0	94.92	13.72	1330.
164.5	154.5	5.02	45.0	106.46	13.84	1342.
164.5	154.5	5.01	50.0	118.00	13.88	1347.
164.5	154.5	5.00	60.0	141.08	13.93	1351.
164.5	154.5	4.99	80.0	187.23	13.99	1357.
164.5	154.5	4.99	100.0	233.39	14.00	1358.

Table B-46 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, 40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	10.37	0.0	2.62	6.33	614.
164.5	154.5	9.32	5.0	14.15	7.19	697.
164.5	154.5	8.43	10.0	25.69	8.05	781.
164.5	154.5	7.65	15.0	37.23	8.92	865.
164.5	154.5	7.00	20.0	48.77	9.78	949.
164.5	154.5	6.77	22.5	54.54	10.14	983.
164.5	154.5	6.62	25.0	60.31	10.39	1008.
164.5	154.5	6.51	27.5	66.08	10.59	1027.
164.5	154.5	6.45	30.0	71.85	10.70	1037.
164.5	154.5	6.40	35.0	83.39	10.81	1049.
164.5	154.5	6.39	40.0	94.92	10.84	1051.
164.5	154.5	6.41	45.0	106.46	10.84	1051.
164.5	154.5	6.40	50.0	118.00	10.87	1054.
164.5	154.5	6.39	60.0	141.08	10.90	1057.
164.5	154.5	6.39	80.0	187.23	10.92	1060.
164.5	154.5	6.39	100.0	233.39	10.94	1061.

Table B-47 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, 50.18 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability ft/yr	Permeability cm/sec
cm	cm	min	psi	ft water		$\times 10^{-9}$
164.5	154.5	59.39	0.0	2.62	1.11	1073.
164.5	154.5	55.00	5.0	14.15	1.22	1181.
164.5	154.5	51.06	10.0	25.69	1.33	1290.
164.5	154.5	47.28	15.0	37.23	1.44	1400.
164.5	154.5	43.99	20.0	48.77	1.56	1509.
164.5	154.5	42.69	22.5	54.54	1.61	1560.
164.5	154.5	41.18	25.0	60.31	1.67	1621.
164.5	154.5	40.21	27.5	66.08	1.71	1663.
164.5	154.5	39.55	30.0	71.85	1.74	1692.
164.5	154.5	38.89	35.0	83.39	1.78	1726.
164.5	154.5	38.54	40.0	94.92	1.80	1743.
164.5	154.5	38.56	45.0	106.46	1.80	1747.
164.5	154.5	38.56	50.0	118.00	1.80	1750.
164.5	154.5	38.58	60.0	141.08	1.81	1751.
164.5	154.5	38.64	80.0	187.23	1.81	1752.
164.5	154.5	38.66	100.0	233.39	1.81	1753.

Table B-48 Permeability Test Data for Sludge C-1 + 10 percent flyash,
38.2 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability ft/yr	Permeability cm/sec
cm	cm	min	psi	ft water		$\times 10^{-8}$
164.5	154.5	3.58	0.0	2.62	18.35	1780.
164.5	154.5	3.62	5.0	14.15	18.50	1795.
164.5	154.5	3.64	10.0	25.69	18.65	1809.
164.5	154.5	3.63	15.0	37.23	18.80	1823.
164.5	154.5	3.61	20.0	48.77	18.96	1839.
164.5	154.5	3.60	22.5	54.54	19.07	1849.
164.5	154.5	3.60	25.0	60.31	19.11	1854.
164.5	154.5	3.60	27.5	66.08	19.15	1857.
164.5	154.5	3.60	30.0	71.85	19.16	1859.
164.5	154.5	3.62	35.0	83.39	19.12	1854.
164.5	154.5	3.62	40.0	94.92	19.13	1856.
164.5	154.5	3.63	45.0	106.46	19.13	1856.
164.5	154.5	3.63	50.0	118.00	19.16	1858.
164.5	154.5	3.64	60.0	141.08	19.14	1856.
164.5	154.5	3.64	80.0	187.23	19.17	1860.
164.5	154.5	3.65	100.0	233.39	19.14	1857.

Table B-49 Permeability Test Data for Sludge C-1 + 10 percent flyash,
46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	7.10	0.0	2.62	9.25	897.
164.5	154.5	7.08	5.0	14.15	9.46	918.
164.5	154.5	7.01	10.0	25.69	9.68	939.
164.5	154.5	6.90	15.0	37.23	9.89	959.
164.5	154.5	6.77	20.0	48.77	10.11	981.
164.5	154.5	6.74	22.5	54.54	10.18	988.
164.5	154.5	6.72	25.0	60.31	10.24	993.
164.5	154.5	6.71	27.5	66.08	10.27	996.
164.5	154.5	6.71	30.0	71.85	10.28	997.
164.5	154.5	6.72	35.0	83.39	10.30	999.
164.5	154.5	6.72	40.0	94.92	10.31	1000.
164.5	154.5	6.73	45.0	106.46	10.32	1001.
164.5	154.5	6.74	50.0	118.00	10.32	1001.
164.5	154.5	6.75	60.0	141.08	10.32	1001.
164.5	154.5	6.75	80.0	187.23	10.34	1003.
164.5	154.5	6.76	100.0	233.39	10.34	1003.

Table B-50 Permeability Test Data for Sludge C-1 + 10 percent flyash,
52.5 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-9}$
164.5	154.5	13.09	0.0	2.62	5.02	4867.
164.5	154.5	13.24	5.0	14.15	5.06	4907.
164.5	154.5	13.31	10.0	25.69	5.10	4947.
164.5	154.5	13.28	15.0	37.23	5.14	4984.
164.5	154.5	13.21	20.0	48.77	5.18	5026.
164.5	154.5	13.20	22.5	54.54	5.20	5044.
164.5	154.5	13.20	25.0	60.31	5.21	5056.
164.5	154.5	13.21	27.5	66.08	5.22	5061.
164.5	154.5	13.21	30.0	71.85	5.22	5066.
164.5	154.5	13.24	35.0	83.39	5.23	5070.
164.5	154.5	13.24	40.0	94.92	5.23	5075.
164.5	154.5	13.28	45.0	106.46	5.23	5073.
164.5	154.5	13.29	50.0	118.00	5.23	5076.
164.5	154.5	13.31	60.0	141.08	5.23	5077.
164.5	154.5	13.34	80.0	187.23	5.23	5075.
164.5	154.5	13.35	100.0	233.39	5.23	5077.

Table B-51 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, sterilant and vacuum pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.76	0.0	2.62	86.43	8383.
164.5	154.5	0.77	5.0	14.15	86.99	8438.
164.5	154.5	0.77	10.0	25.69	88.16	8552.
164.5	154.5	0.77	15.0	37.23	88.61	8596.
164.5	154.5	0.76	20.0	48.77	90.07	8737.
164.5	154.5	0.76	22.5	54.54	90.31	8760.
164.5	154.5	0.76	25.0	60.31	90.53	8782.
164.5	154.5	0.77	27.5	66.08	89.52	8683.
164.5	154.5	0.77	30.0	71.85	89.59	8691.
164.5	154.5	0.77	35.0	83.99	89.88	8718.
164.5	154.5	0.77	40.0	94.92	89.96	8726.
164.5	154.5	0.77	45.0	106.46	90.21	8750.
164.5	154.5	0.77	50.0	118.00	90.32	8761.
164.5	154.5	0.77	60.0	141.08	90.47	8776.
164.5	154.5	0.78	80.0	187.23	89.48	8680.
164.5	154.5	0.78	100.0	233.39	89.58	8690.

Table B-52 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, sterilant pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	1.45	0.0	2.62	45.30	4394.
164.5	154.5	1.26	5.0	14.15	53.16	5156.
164.5	154.5	1.12	10.0	25.69	60.61	5879.
164.5	154.5	0.99	15.0	37.23	68.92	6685.
164.5	154.5	0.90	20.0	48.77	76.06	7378.
164.5	154.5	0.86	22.5	54.54	79.81	7741.
164.5	154.5	0.82	25.0	60.31	83.91	8139.
164.5	154.5	0.81	27.5	66.08	85.10	8254.
164.5	154.5	0.80	30.0	71.85	86.23	8365.
164.5	154.5	0.79	35.0	83.39	87.60	8498.
164.5	154.5	0.78	40.0	94.92	88.80	8614.
164.5	154.5	0.78	45.0	106.46	89.05	8638.
164.5	154.5	0.78	50.0	118.00	89.17	8649.
164.5	154.5	0.78	60.0	141.08	89.31	8663.
164.5	154.5	0.78	80.0	187.23	89.48	8680.
164.5	154.5	0.78	100.0	233.39	89.58	8690.

Table B-53 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, vacuum pretreated,
25.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.94	0.0	2.62	69.88	6778.
164.5	154.5	0.92	5.0	14.15	72.80	7062.
164.5	154.5	0.88	10.0	25.69	77.14	7483.
164.5	154.5	0.85	15.0	37.23	80.27	7787.
164.5	154.5	0.82	20.0	48.77	83.48	8097.
164.5	154.5	0.80	22.5	54.54	85.79	8322.
164.5	154.5	0.79	25.0	60.31	87.10	8448.
164.5	154.5	0.78	27.5	66.08	88.37	8572.
164.5	154.5	0.78	30.0	71.85	88.45	8579.
164.5	154.5	0.77	35.0	83.39	89.88	8718.
164.5	154.5	0.77	40.0	94.92	89.96	8726.
164.5	154.5	0.78	45.0	106.46	89.05	8638.
164.5	154.5	0.78	50.0	118.00	89.17	8649.
164.5	154.5	0.78	60.0	141.08	89.31	8663.
164.5	154.5	0.78	80.0	187.23	89.48	8680.
164.5	154.5	0.78	100.0	233.39	89.58	8690.

Table B-54 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, sterilant and vacuum pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.13	0.0	2.62	10.72	1039.
164.5	154.5	6.23	5.0	14.15	10.75	1043.
164.5	154.5	6.30	10.0	25.69	10.78	1045.
164.5	154.5	6.29	15.0	37.23	10.85	1052.
164.5	154.5	6.30	20.0	48.77	10.87	1054.
164.5	154.5	6.31	22.5	54.54	10.88	1055.
164.5	154.5	6.30	25.0	60.31	10.92	1059.
164.5	154.5	6.28	27.5	66.08	10.98	1065.
164.5	154.5	6.27	30.0	71.85	11.00	1067.
164.5	154.5	6.28	35.0	83.39	11.02	1069.
164.5	154.5	6.29	40.0	94.92	11.01	1068.
164.5	154.5	6.30	45.0	106.46	11.03	1069.
164.5	154.5	6.31	50.0	118.00	11.02	1069.
164.5	154.5	6.32	60.0	141.08	11.02	1069.
164.5	154.5	6.33	80.0	187.23	11.03	1070.
164.5	154.5	6.34	100.0	233.39	11.02	1069.

Table B-55 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, sterilant pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	8.00	0.0	2.62	8.21	796.
164.5	154.5	7.70	5.0	14.15	8.70	844.
164.5	154.5	7.36	10.0	25.69	9.22	895.
164.5	154.5	7.87	15.0	37.23	8.67	841.
164.5	154.5	6.71	20.0	48.77	10.20	990.
164.5	154.5	6.58	22.5	54.54	10.43	1012.
164.5	154.5	6.47	25.0	60.31	10.63	1032.
164.5	154.5	6.42	27.5	66.08	10.74	1041.
164.5	154.5	6.35	30.0	71.85	10.86	1054.
164.5	154.5	6.36	35.0	83.39	10.88	1056.
164.5	154.5	6.36	40.0	94.92	10.89	1056.
164.5	154.5	6.38	45.0	106.46	10.89	1056.
164.5	154.5	6.38	50.0	118.00	10.90	1057.
164.5	154.5	6.39	60.0	141.08	10.90	1057.
164.5	154.5	6.41	80.0	187.23	10.89	1056.
164.5	154.5	6.41	100.0	233.39	10.90	1057.

Table B-56 Permeability Test Data for Sludge H-2 + 10 percent flyash,
43 percent organic matter, vacuum pretreated,
40.25 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.86	0.0	2.62	9.58	929.
164.5	154.5	6.84	5.0	14.15	9.79	950.
164.5	154.5	6.75	10.0	25.69	10.06	976.
164.5	154.5	6.63	15.0	37.23	10.29	998.
164.5	154.5	6.50	20.0	48.77	10.53	1022.
164.5	154.5	6.44	22.5	54.54	10.66	1034.
164.5	154.5	6.39	25.0	60.31	10.77	1044.
164.5	154.5	6.35	27.5	66.08	10.85	1053.
164.5	154.5	6.34	30.0	71.85	10.88	1055.
164.5	154.5	6.34	35.0	83.39	10.92	1059.
164.5	154.5	6.33	40.0	94.92	10.94	1061.
164.5	154.5	6.34	45.0	106.46	10.96	1063.
164.5	154.5	6.35	50.0	118.00	10.95	1062.
164.5	154.5	6.36	60.0	141.08	10.95	1062.
164.5	154.5	6.38	80.0	187.23	10.94	1061.
164.5	154.5	6.38	100.0	233.39	10.95	1062.

Table B-57 Permeability Test Data for Sludge C-1 + 10 percent flyash, sterilant and vacuum pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.90	0.0	2.62	72.98	7079.
164.5	154.5	0.91	5.0	14.15	73.60	7140.
164.5	154.5	0.92	10.0	25.69	73.79	7157.
164.5	154.5	0.93	15.0	37.23	73.37	7117.
164.5	154.5	0.93	20.0	48.77	73.60	7140.
164.5	154.5	0.93	22.5	54.54	73.80	7159.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.94	45.0	106.46	73.89	7168.
164.5	154.5	0.94	50.0	118.00	73.99	7177.
164.5	154.5	0.94	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-58 Permeability Test Data for Sludge C-1 + 10 percent flyash, sterilant pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.95	0.0	2.62	69.14	6707.
164.5	154.5	0.96	5.0	14.15	69.77	6768.
164.5	154.5	0.96	10.0	25.69	70.71	6859.
164.5	154.5	0.95	15.0	37.23	71.82	6967.
164.5	154.5	0.94	20.0	48.77	72.82	7064.
164.5	154.5	0.94	22.5	54.54	73.02	7082.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.95	45.0	106.46	73.11	7092.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.4	154.5	0.95	100.0	233.39	73.55	7135.

Table B-59 Permeability Test Data for Sludge C-1 + 10 percent flyash,
vacuum pretreated, 30.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	0.94	0.0	2.62	69.88	6778.
164.5	154.5	0.94	5.0	14.15	71.26	6912.
164.5	154.5	0.95	10.0	25.69	71.46	6931.
164.5	154.5	0.94	15.0	37.23	72.59	7041.
164.5	154.5	0.94	20.0	48.77	72.82	7064.
164.5	154.5	0.94	22.5	54.54	73.02	7082.
164.5	154.5	0.94	25.0	60.31	73.20	7100.
164.5	154.5	0.94	27.5	66.08	73.33	7113.
164.5	154.5	0.94	30.0	71.85	73.39	7119.
164.5	154.5	0.94	35.0	83.39	73.62	7142.
164.5	154.5	0.94	40.0	94.92	73.69	7148.
164.5	154.5	0.94	45.0	106.46	73.89	7168.
164.5	154.5	0.95	50.0	118.00	73.21	7101.
164.5	154.5	0.95	60.0	141.08	73.33	7113.
164.5	154.5	0.95	80.0	187.23	73.47	7127.
164.5	154.5	0.95	100.0	233.39	73.55	7135.

Table B-60 Permeability Test Data for Sludge C-1 + 10 percent flyash,
sterilant and vacuum pretreated, 46.7 percent solids

Initial Head	Final Head	Time	Back Pressure	Average Head	Permeability	
cm	cm	min	psi	ft water	ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.37	0.0	2.62	10.31	1000.
164.5	154.5	6.49	5.0	14.15	10.32	1001.
164.5	154.5	6.57	10.0	25.69	10.33	1002.
164.5	154.5	6.61	15.0	37.23	10.32	1001.
164.5	154.5	6.62	20.0	48.77	10.34	1003.
164.5	154.5	6.63	22.5	54.54	10.35	1004.
164.5	154.5	6.65	25.0	60.31	10.35	1004.
164.5	154.5	6.66	27.5	66.08	10.35	1004.
164.5	154.5	6.66	30.0	71.85	10.36	1005.
164.5	154.5	6.68	35.0	83.39	10.36	1005.
164.5	154.5	6.69	40.0	94.92	10.35	1004.
164.5	154.5	6.71	45.0	106.46	10.35	1004.
164.5	154.5	6.72	50.0	118.00	10.35	1004.
164.5	154.5	6.73	60.0	141.08	10.35	1004.
164.5	154.5	6.74	80.0	187.23	10.36	1004.
164.5	154.5	6.75	100.0	233.39	10.35	1004.

Table B-61 Permeability Test Data for Sludge C-1 + 10 percent flyash, sterilant pretreated, 46.7 percent solids

Initial Head cm	Final Head cm	Time min	Back Pressure psi	Average Head ft water	Permeability	
					ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.81	0.0	2.62	9.65	936.
164.5	154.5	6.86	5.0	14.15	9.76	947.
164.5	154.5	6.86	10.0	25.69	9.90	960.
164.5	154.5	6.80	15.0	37.23	10.03	973.
164.5	154.5	6.73	20.0	48.77	10.17	987.
164.5	154.5	6.71	22.5	54.54	10.23	992.
164.5	154.5	6.70	25.0	60.31	10.27	996.
164.5	154.5	6.70	27.5	66.08	10.29	998.
164.5	154.5	6.69	30.0	71.85	10.31	1000.
164.5	154.5	6.70	35.0	83.39	10.33	1002.
164.5	154.5	6.71	40.0	94.92	10.32	1001.
164.5	154.5	6.73	45.0	106.46	10.32	1001.
164.5	154.5	6.74	50.0	118.00	10.32	1001.
164.5	154.5	6.75	60.0	141.08	10.32	1001.
164.5	154.5	6.76	80.0	187.23	10.32	1002.
164.5	154.5	6.77	100.0	233.39	10.32	1001.

Table B-62 Permeability Test Data for Sludge C-1 + 10 percent flyash, vacuum pretreated, 46.7 percent solids

Initial Head cm	Final Head cm	Time min	Back Pressure psi	Average Head ft water	Permeability	
					ft/yr	cm/sec $\times 10^{-8}$
164.5	154.5	6.67	0.0	2.62	9.85	955.
164.5	154.5	6.74	5.0	14.15	9.94	964.
164.5	154.5	6.76	10.0	25.69	10.04	974.
164.5	154.5	6.72	15.0	37.23	10.15	985.
164.5	154.5	6.68	20.0	48.77	10.25	994.
164.5	154.5	6.67	22.5	54.54	10.29	998.
164.5	154.5	6.67	25.0	60.31	10.32	1001.
164.5	154.5	6.68	27.5	66.08	10.32	1001.
164.5	154.5	6.67	30.0	71.85	10.34	1003.
164.5	154.5	6.69	35.0	83.39	10.34	1003.
164.5	154.5	6.70	40.0	94.92	10.34	1003.
164.5	154.5	6.71	45.0	106.46	10.35	1004.
164.5	154.5	6.72	50.0	118.00	10.35	1004.
164.5	154.5	6.73	60.0	141.08	10.35	1004.
164.5	154.5	6.75	80.0	187.23	10.34	1003.
164.5	154.5	6.75	100.0	233.39	10.35	1004.

APPENDIX C
WATER RETENTION DATA

Table C-1 Water Retention Data, Water Contents

Tension	Sludge			
	H-2, Natural	H-2, 35% organic	H-2, 10% lime	H-2, 10% flyash
0.00	193.3	182.1	160.7	187.1
60.0 cm	183.2	172.0	156.3	177.3
0.33 atm	164.6	143.1	142.7	164.1
0.67 atm	148.7	124.7	129.9	153.7
1.00 atm	147.9	91.2	119.4	145.5
5.00 atm	71.5	63.8	67.1	76.1
10.00 atm	64.0	54.7	55.5	61.7
15.00 atm	62.4	53.9	53.6	59.4

APPENDIX D
CALIBRATION OF PERMEAMETER STANDPIPE

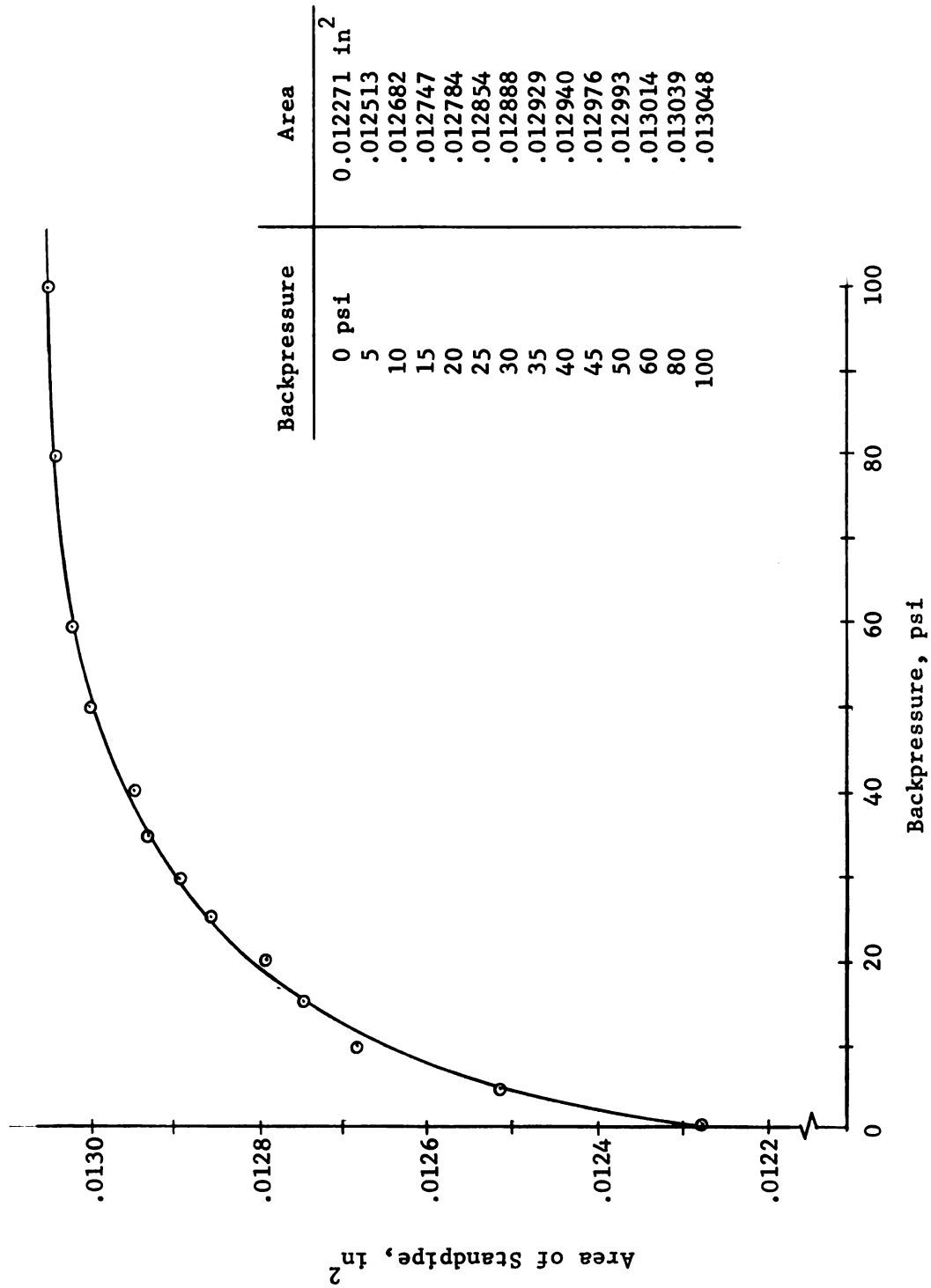


Figure D-1 Calibration Curve for Permeameter Standpipe

MICHIGAN STATE UNIV. LIBRARIES



31293100211089