United States
Environmental Protection
Agency

Robert S. Kerr Environmental Research
Laboratory
Ada OK 74820

EPA-600/2-79-171b
August 1979

Research and Development

Long-Term Effects of Land Application of Domestic Wastewater

Tooele, Utah, Slow Rate Site Volume 2: Engineering Soil Properties

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-79-171b
August 1979

LONG-TERM EFFECTS OF LAND APPLICATION OF DOMESTIC WASTEWATER: TOOELE, UTAH, SLOW RATE SITE

Volume II: Engineering Soil Properties

by

Loren R. Anderson, J. H. Reynolds, R. W. Miller
W. F. Campbell, D. G. Beck, and J. A. Caliendo
Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

Contract No. 68-03-2360

Project Officer

Curtis C. Harlin, Jr.
Wastewater Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs including the development and demonstration of soil and other natural systems for the treatment and management of municipal wastewaters.

Although land application of municipal wastewaters has been practiced for years, there has been a growing and widespread interest in this practice in recent years. The use of land application received major impetus with the passage of the 1972 amendments to the Federal Water Pollution Control Act. The 1977 amendments to the Act gave further encouragement to the use of land application and provided certain incentives for the funding of these systems through the construction grants program. With the widespread implementation of land application systems, there is an urgent need for answers to several major questions. One of these questions regards the long-term effects of land application on the soil, crops, groundwater, and other environmental components. This report is one in a series of ten which document the effects of long-term wastewater application at selected irrigation and rapid infiltration study sites. These case studies should provide new insight into the long-term effects of land application of municipal wastewaters.

This report contributes to the knowledge which is essential for the EPA to meet the requirements of environmental laws and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

William C. Galegar
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

A high quality secondary sewage effluent was applied to three soil types and its effect on the shear strength, consolidation properties, and permeability of the soils was studied. The three soil types were a poorly graded sand, a clayey silt, and a highly plastic clay. Each soil was divided into nine samples. Six samples were leached with secondary sewage effluent and three with distilled water. Three of the effluent samples were then re-leached with distilled water in order to investigate the possibility of any reversible phenomenon.

After a suitable amount of leachate had passed through the samples, direct shear tests, standard consolidation tests, and falling head permeability tests were performed. The shear strengths of the sand and silt were not appreciably affected by the application of wastewater. The shear strength of the clay was slightly increased by the wastewater effluent. The compressibility, rate of consolidation, and permeability of the silt increased with application of the effluent whereas the clay samples were not affected by the application. Except for the rate of consolidation at high stress levels, application of distilled water to treated samples did not reverse changes in the above properties.

This report was submitted in fulfillment of Contract No. 68-03-2360 by Utah State University under the partial sponsorship of the U. S. Environmental Protection Agency. This report covers a period from January 2, 1976, to June 15, 1978, and work was completed as of December 15, 1978.

CONTENTS

FIGURES

FIGURES (Continued)

FIGURE (Continued)

TABLES

TABLES (Continued)

LIST OF ABBREVIATIONS AND SYMBOLS

LIST OF ABBREVIATIONS

BOD_5	=	five day biochemical oxygen demand
Ca	=	calcium
cc	=	cubic centimeters
CEC	=	cation exchange capacity
COD	=	chemical oxygen demand
ESP	=	exchangeable sodium percentage
ft	=	feet
I.D.	=	inside diameter
in.	=	inches
K	=	potassium
kg	=	kilograms
kN	=	kilonewtons
kPa	=	kiloPascals
lb	=	pound
m	=	meter
Mg	=	magnesium
mg/ℓ	=	milligrams per liter
mm	=	millimeter
N	=	Newton
Na	=	sodium
NO_3N	=	nitrate nitrogen
P	=	phosphorus
psf	=	pounds per square foot
psi	=	pounds per square inch
SAR	=	sodium adsorption ratio
SS	=	suspended solids
VSS	=	volatile suspended solids

SYMBOLS

C	=	Slope of the ε-log $\bar{\sigma}$ curves
c_v	=	Coefficient of consolidation
C_c	=	Compression index
e_o	=	Initial void ratio
H_{DP}	=	Length of the longest drainage path of a sample
k	=	Coefficient of permeability
LL	=	Liquid Limit
PI	=	Plastic Index
t	=	Time
t_{50}	=	Time at 50 percent consolidation
V	=	Total volume of sample
V_v	=	Volume of voids
$\alpha(0.10)$	=	10 percent significance level
α_s	=	Rate of secondary consolidation
ε	=	Strain
$\bar{\sigma}$	=	Intergranular or effective stress
ϕ	=	Friction angle

ACKNOWLEDGMENTS

Mr. Rene Winward, of the Utah State University Civil Engineering Department, manufactured most of the equipment used in this study. His skills and helpful suggestions are greatly appreciated. Acknowledgment and thanks are also extended to Dr. Donald V. Sisson, of the USU Applied Statistics Department, for his assistance with the statistical analysis.

This work was performed under a U. S. Environmental Protection Agency Contract Number 68-03-2360. The support of the Robert S. Kerr Environmental Research Laboratory is greatly appreciated, especially the direction of Dr. Curtis C. Harlin, Jr., who served as the EPA Project Officer.

SECTION 1

INTRODUCTION

Present methods of discharging treated and untreated domestic wastes have exceeded the capacity of many receiving streams. The resulting pollution poses a threat to the usable water supply. Controlled land application of these wastewaters has potential as a means of reducing the load on the present surface water supplies. If the wastewater is used for agricultural purposes, it promotes the growth of plants, provides economical treatment of wastewater, conserves water and nutrients normally wasted and thereby makes more freshwater available for domestic use.

An understanding of the effects of domestic wastewater on the physical engineering properties of soil could be very important for land use planning of existing and potential land disposal sites. Consideration must be given to the effects on the physical engineering properties of the soil not only during the period of application of effluent to the site, but also to the long-term effects after the site is no longer receiving the effluent.

The effects on the permeability of a soil from wastewater application has been investigated by a number of researchers. *De Vries* [1972], *Allison* [1947], *Day, et al.* [1972], *Lance and Whisler* [1972], and *Rice* [1974] all reported a decrease in permeability from wastewater treatment. Various reasons were suggested: pore clogging from biological activity [*Allison*, 1947], impermeable surface mat formation [*de Vries*, 1972], insoluble gas blocking the pores [*Lance and Whisler*, 1972; *Rice*, 1974], and deterioration of the surface soil structure [*Day, et al.*, 1972].

The nature of the adsorbed cations has been shown to influence the engineering properties of soils. *Shainberg and Caiserman* [1971], *Mitchell* [1976], and *Olsen and Mesri* [1970] suggested that adsorbed ions of a higher valence create a more permeable soil than lower valence ions. *Aziz, et al.* [1966] indicated that a loss in shear strength occurs with an increase in exchangeable sodium percentage. *Mesri and Olsen* [1971] showed the influence of the electrolyte concentration on the compressibility of montmorillonite clays.

The existence of large amounts of organic matter in soil is generally not desirable from an engineering standpoint. This organic material may cause high plasticity, low permeability and low strength. Also an increase in the amount of organic matter causes an increase in the optimum water content for compaction. This leads to a reduction in the maximum unconfined compressive strength [*Mitchell*, 1976]. *Andersland and Matthew* [1973] made a study on papermill sludges consisting mainly of kaolinite clay and found that the compression index, C_c, increased linearly with an increased organic content.

The purpose of this study was to investigate the influence of the application of secondary wastewater effluent on the engineering properties of soil. The specific effects on compressibility, consolidation, and shear strength of three different soils were studied.

The study was carried out in the laboratory on samples of sand, silt, and clay. Nine remolded samples of each soil were prepared for each test. The nine samples were divided into three groups and subjected to treatments that represented a base line condition, a condition during and immediately after application of secondary wastewater effluent, and a long-term condition after application of wastewater had stopped and fresh water had been allowed to leach through the soil.

SECTION 2

CONCLUSIONS

This study investigated the effects of a high quality secondary wastewater effluent on the engineering properties of three different soils. The soils used in this study were classified by the Unified Soil Classification System as a poorly graded sand (SP), an inorganic clayey silt to silty clay (CL-ML), and an inorganic clay of high plasticity (CH). Based on the results of this study the following conclusions can be made.

1. The shear strength of samples of sand prepared to a relative density near 100 percent was not affected by leaching the samples with secondary wastewater effluent.

2. The shear strength of normally consolidated samples of clayey silt to silty clay was not affected by leaching the samples with secondary wastewater effluent.

3. The shear strength of normally consolidated samples of a highly plastic clay was slightly increased by the application of a secondary wastewater effluent. The change in shear strength did not reverse after application of distilled water to the treated samples.

4. The compression index, C, of normally consolidated samples of clayey silt to silty clay soil increased with application of the secondary wastewater effluent. This increase in compressibility did not reverse when treated samples were leached with distilled water.

5. At high stress levels, the coefficient of consolidation, c_v, of normally consolidated samples of clayey silt to silty clay soil increased with application of the secondary wastewater effluent. Application of distilled water to treated samples caused a reverse in the process at high stress levels.

6. The secondary consolidation characteristics of normally consolidated samples of clayey silt to silty clay were not affected by application of the secondary wastewater effluent.

7. The consolidation characteristics of normally consolidated samples of the highly plastic clay were not affected by application of the secondary wastewater effluent.

8. The coefficient of permeability of normally consolidated samples of the clayey silt to silty clay increased with application of the effluent.

SECTION 3

RECOMMENDATIONS

Further research is recommended to more clearly define the effect of wastewater effluent on the engineering properties of soil. Of particular concern would be the following.

1. Using a wastewater effluent of much poorer quality to treat the samples (primary treatment only).

2. Using a clay soil with a much lower exchangeable sodium percentage (ESP) than the 54.8 used in this study.

3. Using samples of sand prepared to a relative density less than 50 percent.

4. Separating the chemical and biological effects on the engineering properties.

SECTION 4

METHODS

GENERAL

A laboratory study was conducted to evaluate changes in engineering soil properties from applying domestic wastewater to the soil and to determine if these changes were irreversible. The methodology involved applying three different treatment combinations of sewage and/or distilled water to three different soil types (sand, silt, and clay) and then testing each group for various engineering properties. The main properties investigated were consolidation, permeability, and shear strength.

Each soil type was initially divided into nine samples and soaked in distilled water to achieve saturation. After the initial soaking period (which varied depending on soil type), the soil was carefully placed in the appropriate testing apparatus for treatment and laboratory testing. One of three different treatments was used on samples of each soil type:

- Leaching the soil with distilled water and then performing the tests.
- Leaching the soil with sewage and then performing the tests.
- Leaching the soil first with sewage followed by distilled water and then performing the tests.

Three replications of each test were used in each group and the results were averaged. To avoid the effects of sample disturbance, the samples were prepared, treated and tested in the same container. To accomplish this it was necessary to design and fabricate nearly all of the testing equipment. The samples were prepared, treated, and tested under the same general environmental conditions in a constant temperature room.

SOIL DESCRIPTION

The names referring to the soils used in the laboratory study were chosen for convenience only and have no relation to the United States Department of Agriculture soil survey names. Atterberg Limits, specific gravity, and a grain size analysis were run on each soil type in accordance with ASTM specifications. Table 1 shows the results of these tests.

The Nibley sand was obtained in Nibley, Utah, from stockpiles at the wash plant of a local concrete producer. The absence of any clay size particles in this sand is due to the washing process the sand went through before the samples were obtained. The textural classification system used by the U.S. Department of Agriculture designates the soil as a sand. Using

TABLE 1. CHARACTERISTICS OF THE TOOELE SILT, THE NIBLEY SAND, AND THE SMITHFIELD CLAY

Soil Type	Atterberg Limits		Specific Gravity	Composition			Cation Exchange Capacity (me/100 g)
	LL	PI		% Sand	% Silt	% Clay	
Nibley Sand	N.P.*	N.P.	2.73	96	4	0	1.5
Tooele Silt	25	4	2.62	34	53	13	15.1
Smithfield Clay	59	38	2.72	4	54	42	22.8

* N.P. = Non Plastic

the Unified Soil Classification System, the soil is classed as SP. A grain size distribution curve for this soil is shown in Figure 1.

The Tooele silt was taken from near the surface in fields directly north of the Tooele Army Depot in Tooele, Utah. Based on the USDA textural classification, the Tooele silt is classified as a silt loam. According to the Unified Soil Classification System, the Tooele silt possesses characteristics of two groups and is designated by the combination of both group symbols as CL-ML. A grain size distribution curve for this soil is shown in Figure 1.

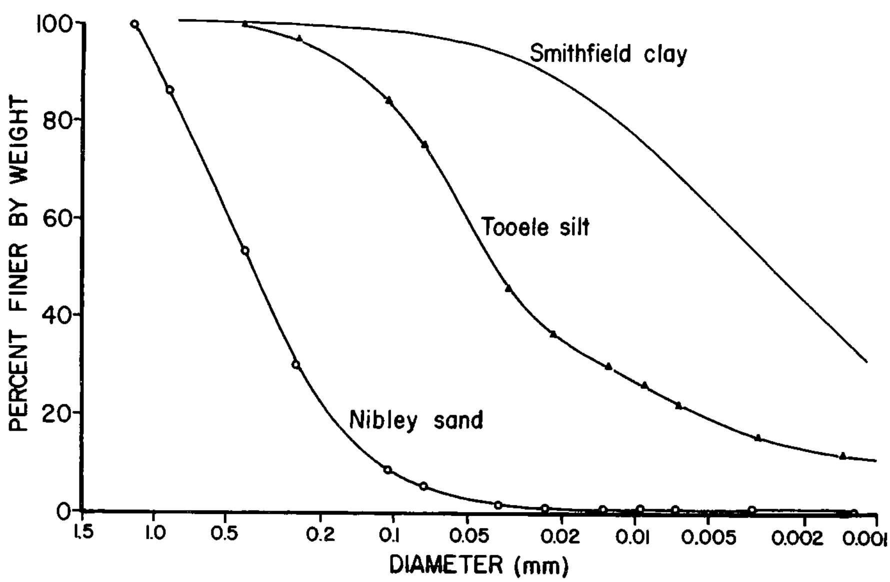


Figure 1. Grain size distribution curve for Nibley sand, Tooele silt, and Smithfield clay.

The Smithfield clay was obtained from a location northwest of Smithfield, Utah. The USDA textural classification designates the soil as clay. By the Unified Soil Classification System, Smithfield clay has the group symbol CH and is described as an inorganic clay of high plasticity. A grain size distribution curve for this soils is shown in Figure 1.

EFFLUENT DESCRIPTION

The treated wastewater effluent used for the laboratory study was obtained from the Preston, Idaho, sewage treatment plant located 40 km (25 miles) north of Logan. This facility serves the City of Preston which has a population of approximately 3,300. The facility has a design capacity of 7500 m^3/day (two mgd). The plant employs primary and secondary treatment. The secondary treatment consists of a standard trickling filter and anaerobic digestor. Final settling is followed by chlorination to a chlorine residual of 2.0 mg/ℓ.

Effluent was collected at the treatment plant by placing a container in the effluent from the chlorine contact chamber. The chemical composition of the effluent was determined according to Standard Methods [*APHA*, 1976] at the beginning and end of each application period. The suspended solids concentration ranged from 7 to 15 mg/ℓ and the biochemical oxygen demand (BOD_5) concentration ranged from 7 to 30 mg/ℓ.

APPARATUS DESCRIPTION

General

Special equipment was designed and fabricated for both the shear tests and consolidation tests. Falling head permeability tests were run on the consolidation samples at the end of the last loading increment. The shear strength was measured in a direct shear apparatus on 101.6 mm (4 in.) diameter double drained consolidometers. The apparatus for both the direct shear samples and consolidation samples were equipped so that the specific treatments could be leached up through the soil from the bottom to the top.

Direct Shear Apparatus

The equipment required for the laboratory study of shear strength included the following: split cylinders, filter stones, loading yokes, weights, loading frame, water reservoirs, and a direct shear machine. Some of this equipment could be purchased commercially but much of it had to be designed and constructed specifically for the needs of this study.

The split cylinder shown in Figure 2 was used to contain the sample. This allowed all the loading, treatment, and testing of the sample to be done in a single container and thus, minimized sample disturbance in transferring the sample from the loading frame to the direct shear apparatus. The split cylinders were constructed of clear acrylic tubing having an outside diameter of 127.0 mm (5 in.) and a wall thickness of 12.7 mm (0.5 in.). Each cylinder consisted of two separate parts. The lower half was

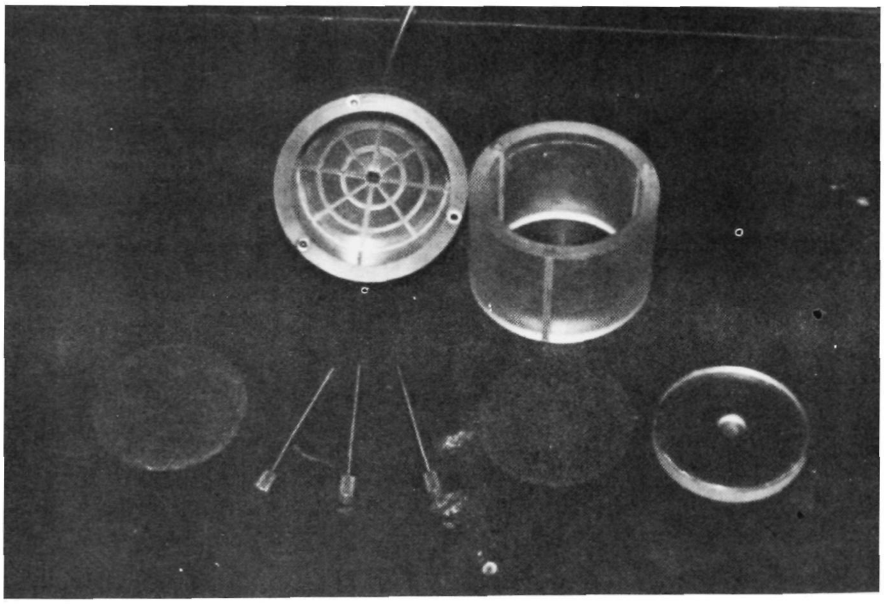


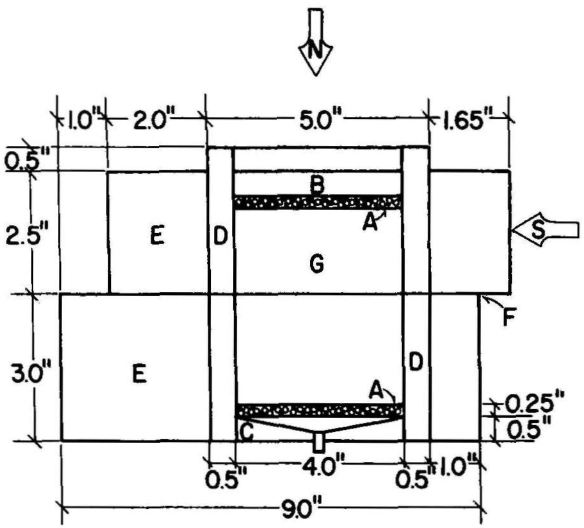
Figure 2. Disassembled split cylinder used to contain the shear samples.

76.2 mm (3 in.) high and the upper half was 88.9 mm (3.5 in.) high. The two sections were connected together by stainless steel bolts which passed through holes in the upper half and were threaded into the lower half. These bolts were removed during testing. When the cylinders were assembled, a thin coating of petroleum jelly was applied to the two contact surfaces. This not only provided a watertight seal at that joint, but also helped to reduce the friction between the upper and lower halves of the plastic cylinder when the samples were sheared. The bottom plate in the lower half of the cylinder, shown in the apparatus cross section in Figure 3, was made from 12.7 mm (0.5 in.) thick clear plexiglass. Two concentric circular and eight radial grooves were cut into the plate on the inside surface to provide a more even distribution of the water entering the sample through the bottom plate.

Two corundum stones of medium porosity were used in each cylinder. The stones were 6.35 mm (0.25 in.) thick and 101.6 mm (4 in.) in diameter. One stone was inserted directly over the bottom plate of the shear cylinder and the other was placed on top of the soil surface after the sample was in place. A loading disc of 12.7 mm (0.5 in.) thick plexiglass was placed above the upper stone. In the center of the loading disc was a concave seat to aid in the proper positioning of the loading yoke.

The loading yoke, shown in Figure 4, transferred the load from the weights to a normal load acting on the top of the soil sample. Two different sizes of steel weights, 4 kg mass (8.82 lbs) and 5 kg mass (11.03 lbs), were used in varying combinations to obtain the three different normal pressures of approximately 20.7 kPa (3 psi), 41.4 kPa (6 psi), and 62.1 kPa (9 psi).

A reservoir for each sample was provided by 250 mℓ glass bottles as



A -- Porous stone
B -- Loading disc
C -- Bottom plate
D -- Shear cylinder walls
E -- Shear blocks
F -- Shear plane
G -- Soil sample

N -- Normal force
S -- Shearing force

Figure 3. Cross section of apparatus.

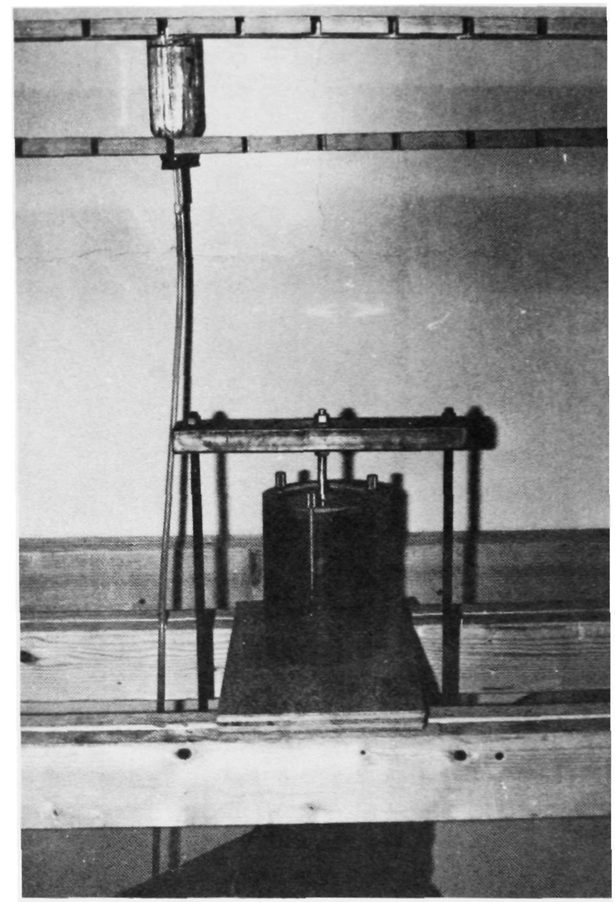


Figure 4. Split cylinder on the loading frame with the water reservoir bottle and loading yoke in place.

shown in Figure 4. A piece of flexible tygon tubing connected the reservoir bottles to a brass fitting in the bottom of the split cylinder. By raising the bottle above the elevation of the soil in the shear cylinder, a hydraulic head was provided and the water in the bottle flowed up through the sample.

The direct shear apparatus is shown in Figure 5. The upper half of the direct shear apparatus moved freely on ball bearings located between the two sections. The split cylinder fit snugly into the shear box. The horizontal split between the two halves of the split cylinder matched exactly with the juncture between the box sections. The soil sample in the split cylinder was subjected to a constant normal load while an increasing horizontal force was applied to the upper section of the shear box. After the three bolts connecting the two halves of the split cylinder were removed, the applied horizontal force caused the soil sample to shear along the juncture between the shear box sections. Loading for the horizontal shearing force was by means of a hand crank operating through a gear system. A proving ring was used to measure the horizontal load applied to the sample. The shear displacement was measured with a dial indicator.

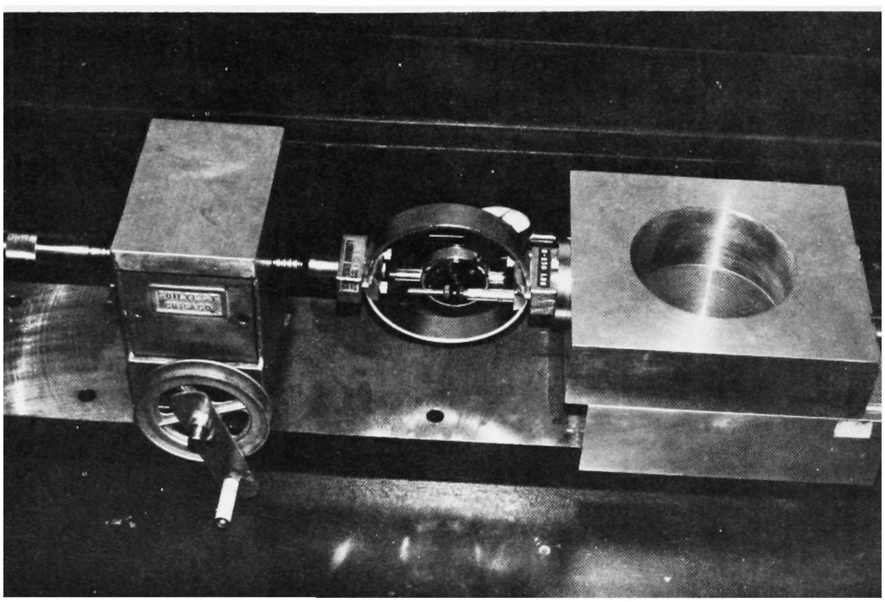


Figure 5. Direct shear apparatus employed in this study.

Consolidation Apparatus

The equipment used in the consolidation phase of this study consisted of a standard consolidation test loading frame, nine double drained consolidometers, loading yokes for each consolidometer, a sample treatment loading frame and a falling head permeability apparatus.

A standard consolidation test loading frame manufactured by Soiltest, Inc. was used during the consolidation tests on each sample. Three bays of the loading frame were used simultaneously in order to accommodate the three replications of each specific treatment.

The consolidometers shown in Figure 6 were about 95.25 mm (3.75 in.) high and were fabricated from 114.3 mm (4.5 in.) I.D. aluminum pipe of 6.35 mm (0.25 in.) wall thickness. The aluminum was lined with 6.35 mm (0.25 in.) thick plexiglass tubing, to provide smooth walls, and a plexiglass disc formed the bottom. Corundum stones were used at the top and bottom of the sample to provide double drainage of the sample. Prior to placing soil in the consolidometers, the sides were lightly coated with Vaseline to reduce wall friction during testing.

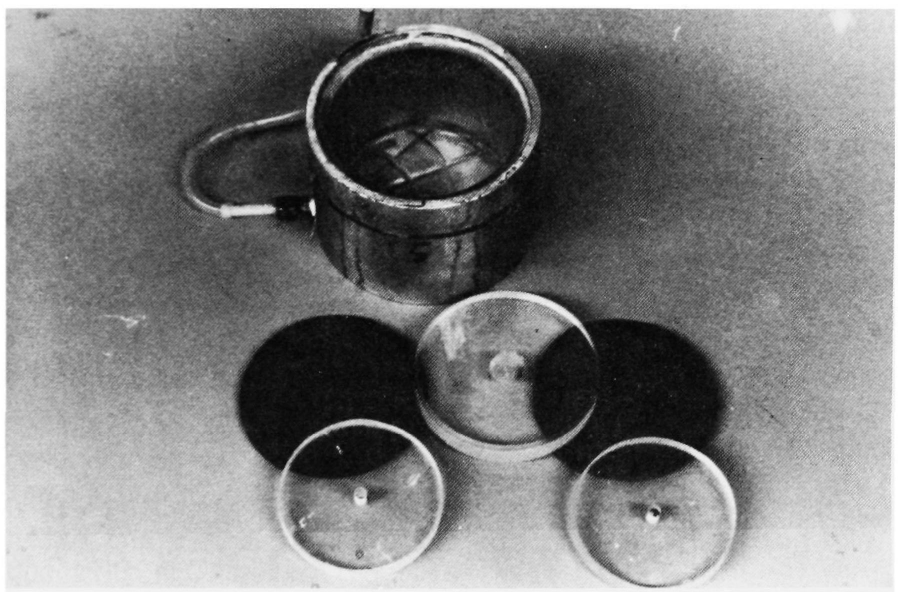


Figure 6. Consolidometer used in this study.

A special loading yoke and frame, similar to that for the direct shear samples shown in Figure 4, were used to consolidate the samples under an initial vertical pressure of 13.3 kPa (278 lb/ft^2) and to maintain the load during application of the specific treatment required for each sample. Distilled water and/or wastewater effluent were stored in 250 mℓ bottles mounted on the loading frame and connected to the bottom of the samples with a polyethylene tube. The bottles were positioned on the frame to maintain an elevation head of about 0.61 m (2 ft) above the top of the samples.

PREPARATION OF SAMPLES AND TREATMENT

General

Samples of Nibley sand, Tooele silt, and Smithfield clay were prepared in a manner to achieve identical initial conditions prior to application of the three different treatments. Essentially the same procedure was used to prepare the Tooele silt samples and the Smithfield clay samples except that the clay was initially dried and pulverized and the soaking period was longer for the clay. A slightly different procedure was used to prepare the Nibley sand. Only direct shear tests were run on the Nibley sand.

Preparation of the Nibley Sand Samples

Preparation of the Nibley sand started by retaining only that portion passing a #16 (1.18 mm) sieve. Nine samples of approximately equal volume were obtained by systematically passing the soil through a sample splitter. The direct shear test split cylinders were then assembled and a porous stone was placed in the bottom of each cylinder. To maintain a close uniformity among the samples, the soil in each cylinder was compacted to approximately the same density. To do this, the initial volume and weight of each cylinder was carefully measured and recorded. The air dried sand was poured into the cylinders through a small funnel. A low distance of fall for the soil of 0.50 mm (0.2 in.) and rotating the funnel in a circular pattern over the inside area of the cylinder helped to avoid particle segregation when filling the cylinders with the sand. The cylinder was then placed on a pneumatically powered vibrating table to densify the sand. After densification, volume and weight measurements were again taken and the density of the soil in the cylinder was calculated. The densities of the nine samples ranged between 17.13 - 17.44 kN/m^3 (109 - 111 lbs/ft^3).

The upper porous stone and the plastic loading disc were placed on top of the sample and a normal load of approximately 41 kPa (6 psi) was applied to each of the nine samples.

To saturate the samples, flexible polyethylene tubing was connected to the brass fitting in the bottom of each split cylinder and extended up alongside the cylinder. Distilled water was applied through this tube under a head of only a few inches until the sample was completely saturated and water was ponded above the plastic loading disc.

Preparation of the Tooele Silt and Smithfield Clay Samples

Preparation of the Tooele silt and Smithfield clay samples began by screening the soil. Only the material passing the #40 (0.425 mm) sieve was used. This material was obtained using a 20 cm (8 in.) round brass sieve on a mechanical shaker. To secure a uniform sample, the soil was stirred and mixed by hand to eliminate any segregation that may have occurred during the sieving process. To further insure uniformity among the samples, all the material was repeatedly passed through a sample splitter and broken down into 10 equal samples. Distilled water, which had been boiled under a vacuum, was added to each of the 10 samples. The soil and water were carefully mixed into a slurry with the consistency slightly less than that at the liquid limit. The slurry was then submerged in the distilled water and placed in a constant temperature room. Frequently a large knife was used to slowly slice through the sample to allow any air bubbles that may have been trapped to escape. The Tooele silt samples were allowed to soak in this manner for 10 weeks to assure complete saturation, and the Smithfield clay samples were soaked for approximately 6 months.

When the soaking period was completed, the samples were placed in the shear and consolidometer cylinders. The cylinders were connected and filled approximately one-fourth full of distilled water. The bottom porous stone, which had been soaked in distilled water, was placed at the bottom of the cylinders. The soil was scooped out of the soaking container by large spoonfuls and placed into the water in the cylinders. Care was taken to avoid inducing any air bubbles as each spoonful was slowly submerged in the water. When the soil had filled the cylinders to the desired depth, the upper porous stone was placed directly on top of the soil. The plastic loading disc was then set on top of the upper porous stone and the samples were loaded with an initial seating load of approximately 41.4 kPa (6 psi). The normal load was added in small increments until the desired load was on the sample. After the samples had consolidated under the applied normal seating load, the various treatments were applied to the samples.

The permeability of the Smithfield clay was much lower than that of the Tooele silt and so a thinner sample was used for both the shear tests and consolidation tests. This enabled the various treatments to be applied to the soil in a reasonable length of time.

Treatment Methods

The soil properties of the Tooele silt, the Smithfield clay, and the Nibley sand were very different, as would be expected. Because of this, a different method of applying the water to each soil type was used.

The permeability of the Tooele silt and Smithfield clay were both rather low. Therefore, a continuous flow was maintained through the samples. As the water flowed up through the samples, the head varied between 0.483 and 0.406 m (19 and 16 in.). To maintain a somewhat consistent quality of water being leached through the sample, the water was changed at intervals of 3 to 4 days. The 250 mℓ reservoir bottles had sufficient volume to supply all the water that would permeate through the sample during this period.

The sides of the reservoir bottles were calibrated and the volume of water passing through the sample in any given period of time was determined. The water level in each reservoir bottle was read to the nearest 5 mℓ and recorded daily to determine the flow through the soil sample.

The Nibley sand was much more permeable than the Tooele silt and Smithfield clay. Water would flow through the samples very easily under a head of less than 25 mm (1 in.). Because of these conditions, it was not practical to maintain a continuous flow through the sand samples. Instead, at intervals of 3 to 4 days, approximately 500 mℓ of water was placed in the reservoir bottles and allowed to flow through the sample. As the displaced water exited from the top of the sample, it was drained off. The hydraulic head during the flow of water through the soil varied from 0 cm (0 in.) to 25.4 cm (10 in.). During the days between treatments, water was intermittently added to the top of the sample to overcome the effects of evaporation and to maintain the sample in a saturated condition.

Types of Treatment

Treatment of the soil samples was divided into three different groups. Each group was representative of a different condition in the field. One group received only distilled water during the leaching process. This represented and established the engineering properties of the soil prior to land disposal of the treated effluent. The second group received only sewage treatment plant effluent for the entire length of the leaching period This represented the soil during land disposal of the treated effluent and the test results on these samples indicated whether the treated effluent had any effect on the engineering properties of the soil. The third group of samples received a third type of treatment. These samples having first received sewage treatment plant effluent for a period of time, were leached with distilled water for the remainder of the leaching process. This attempted to establish the long-term engineering properties of the soil and to indicate whether changes in the properties as a result of receiving treated effluent were reversible.

TESTS TO DETERMINE ENGINEERING PROPERTIES

Direct Shear Tests

When a direct shear test was to be performed, the weights were removed from the loading yoke and the yoke was taken off the sample. The split cylinder, with the tubing still attached, was then removed from the loading frame and carefully placed into the shear box of the direct shear apparatus. The loading yoke was put back on the sample and the same weights were replaced. The hand crank was turned just enough to make contact with the proving ring. Both the dial indicator on the proving ring and the one used to measure displacement were zeroed. The three bolts connecting the two halves of the split cylinder were removed.

To apply the shearing force, the hand crank was turned at the rate of six revolutions per minute. This produced a strain rate, based upon the diameter of the soil sample, of 2 percent per minute. Readings from both dial indicators were recorded at 10 second intervals. Testing was continued until the total strain was over 20 percent. The split cylinder was then removed from the shear box. The soil samples from one-third of the tests on the Tooele silt were dried in the oven and the water content and void ratio were calculated. The remaining two-thirds of the Tooele silt samples were frozen and stored until a chemical composition analysis could be performed on them to identify any differences caused by the different treatments. Only two of the Nibley sand samples were saved and chemical composition analysis was performed on them.

Consolidation Tests

Standard consolidation tests were performed on both soil types for all three treatments. After enough distilled water or sewage effluent had passed through the samples to replace the pore water, the consolidometers were placed in the standard consolidation loading frame. The samples were allowed to consolidate under the initial pressure of 13.17 kPa (275 psf) for approximately 24 hours before the actual consolidation tests were started. Consolidation pressures of approximately 19.6 kPa (410 psf), 39.2 kPa (820 psf), 78.5 kPa (1640 psf), 156 kPa (3260 psf), and 1312 kPa (6520 psf) were used. The duration of each load increment was approximately 48 hours. Two rebound points were determined for each sample. These points typically corresponded with consolidating pressures of approximately 78.5 kPa (1640 psf) and 19.6 kPa (410 psf). The samples were allowed to rebound under each pressure for approximately 24 hours before a dial reading was recorded.

Permeability Tests

Permeability tests were performed on the consolidation samples. Once the final rebound had occurred and the dial reading had been recorded, the consolidation samples were subjected to a falling head permeability test. The 19.6 kPa (410 psf) load was left in place on the sample during the permeability test. The permeability apparatus described earlier was filled with distilled water and connected to the consolidometers. Head loss versus time was recorded.

Permeability tests were not performed on the clay samples 1, 2, and 3. These samples were subjected to sewage effluent and it was felt that by adding distilled water to the system, the cation exchange properties might be altered.

SECTION 5

RESULTS AND DISCUSSION

OBJECTIVE

The principal purpose of this study was to investigate whether or not the effect of chemical and biological activity in the porewater of soil caused by the application of secondary treated effluent for an extended period of time changes the principal engineering properties of the soil; and if so, are the changes reversible upon leaching freshwater through the soil.

SHEAR STRENGTH

General

The results of all the shear tests performed on the sand and silt samples indicated that the shear strength was not appreciably affected by the application of the sewage treatment plant effluent. A slight increase in the shear strength of the clay was observed.

Quantity of Water Added to Samples

The total volume of distilled water and treated sewage effluent applied to each sample of Tooele silt is shown in Figures 7 through 15. The volume varied from a minimum of 155 mℓ to a maximum of 810 mℓ and averaged about 450 mℓ. The time periods over which the applications took place were 30 and 56 days. The wide variation in the total volume applied to each sample was partially due to the formation of an insoluble gas in some of the samples being treated with sewage effluent, which accumulated and blocked the flow of water through the sample. Frequently, this gas was bled off by momentarily disconnecting the tubing from the bottom of the split cylinder.

The same amount of distilled water or treated sewage effluent was applied to each of the Nibley sand samples during the 28 day treatment period. This volume was 4750 mℓ.

The total volume of distilled water and treated sewage effluent applied to each sample of Smithfield clay is shown in Table 2. Since the permeability of the clay was very low, a much thinner sample was used. The time period over which the application of the various treatments took place was 92 days. Three samples were leached with distilled water for the full 92 days and three samples were leached with sewage effluent for the full 92 days. The third set of three clay samples was leached with sewage effluent for the first 63 days and then leached with distilled water for the remaining 27 days.

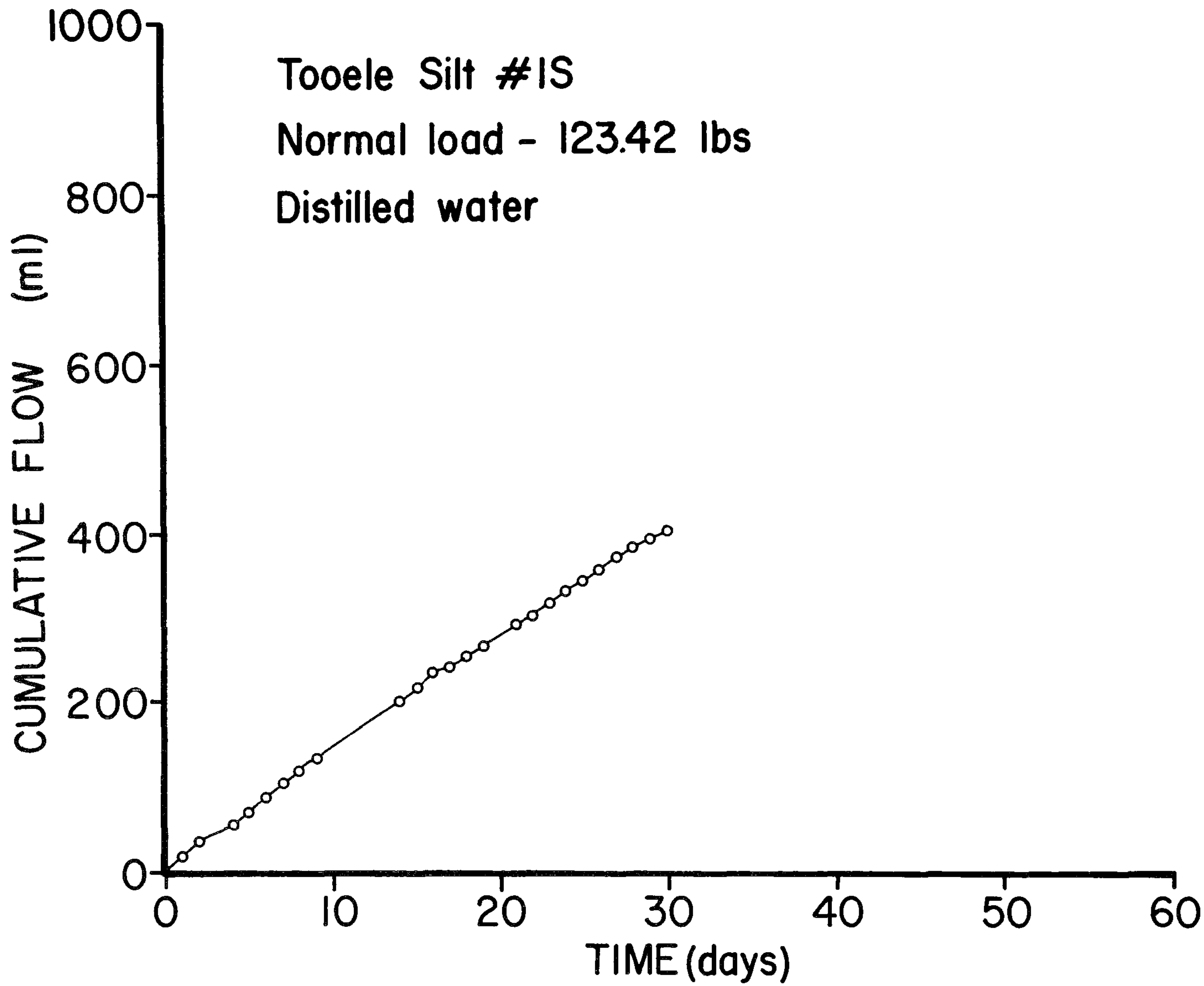


Figure 7. Cumulative flow versus time.

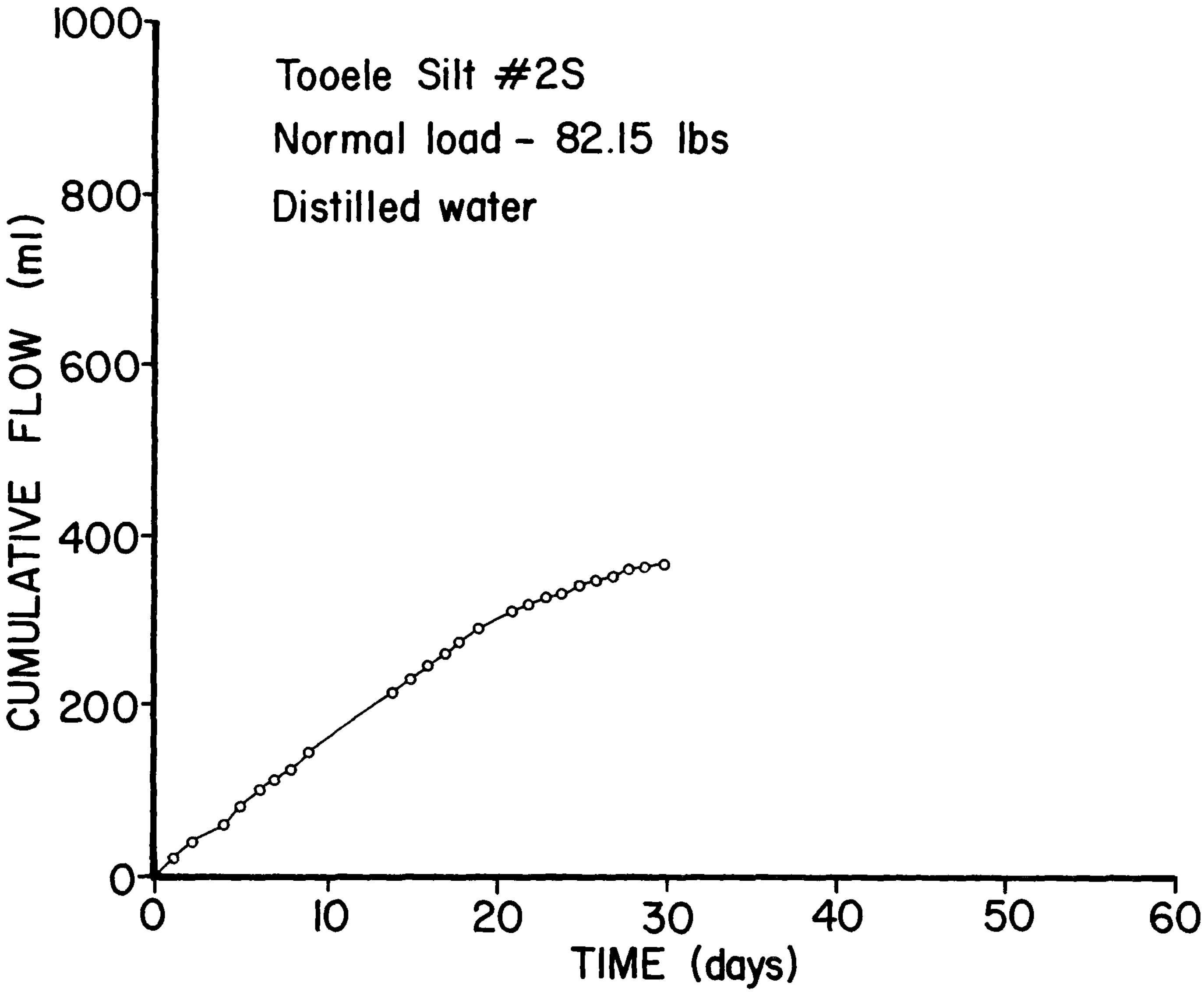


Figure 8. Cumulative flow versus time.

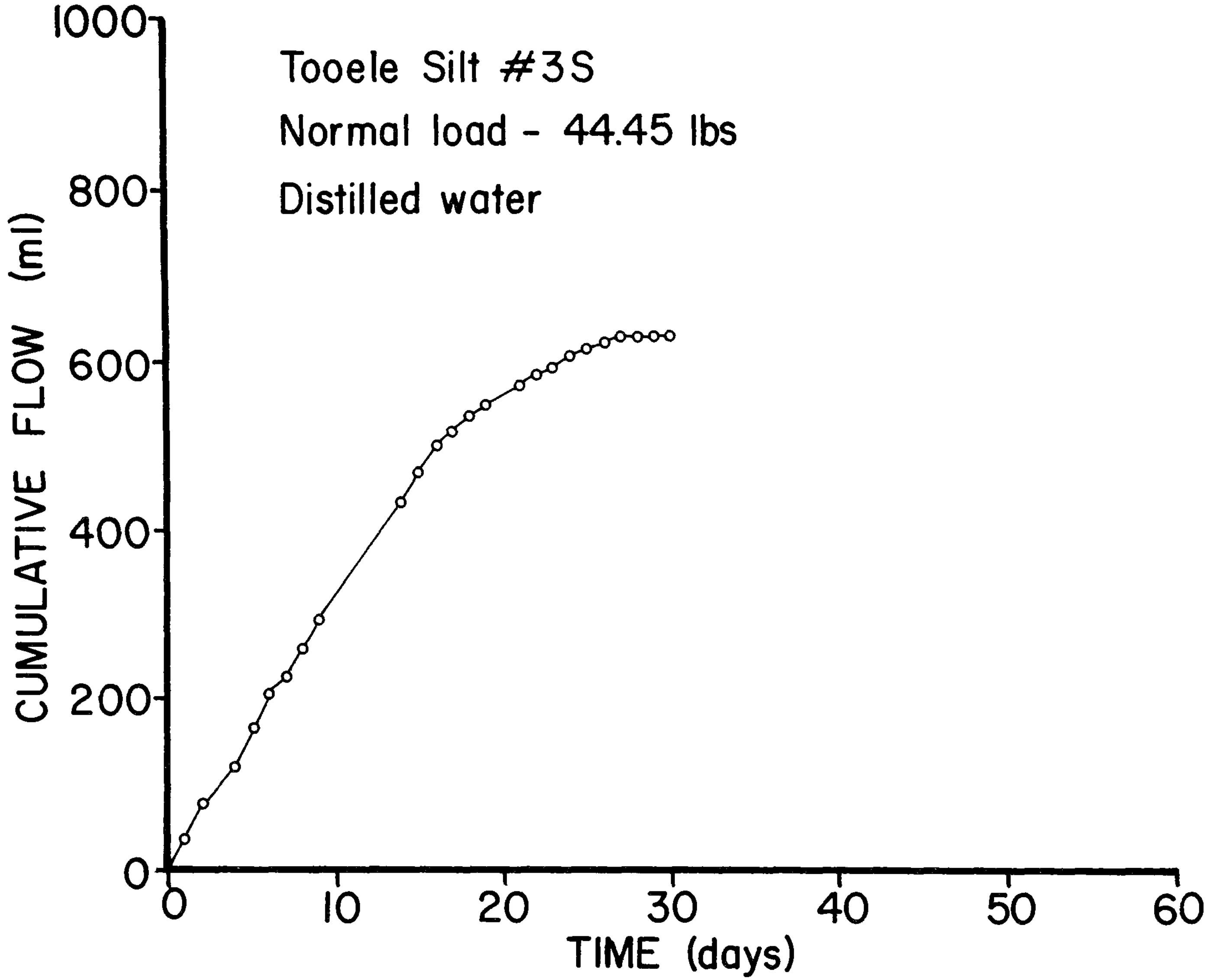


Figure 9. Cumulative flow versus time.

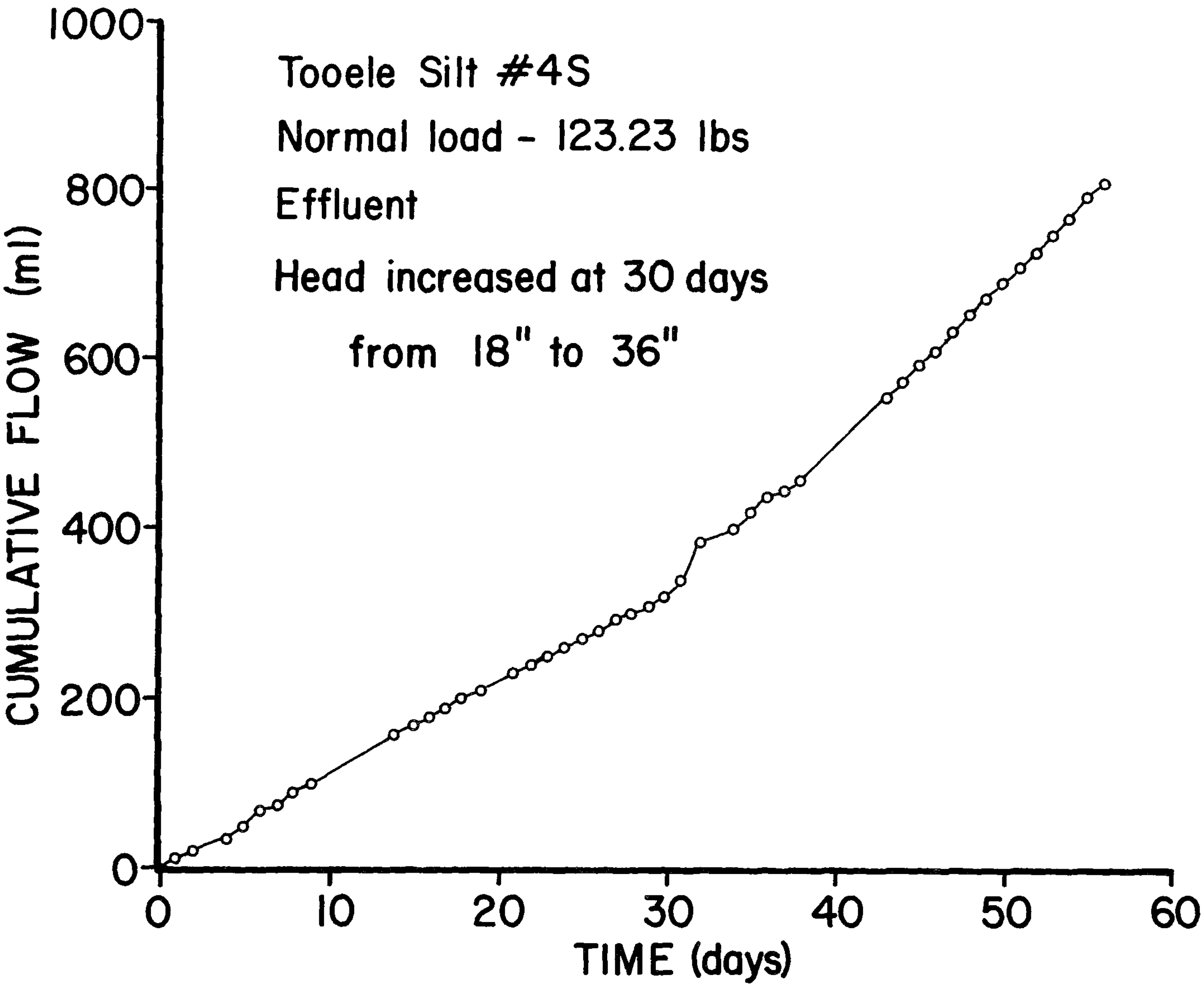


Figure 10. Cumulative flow versus time.

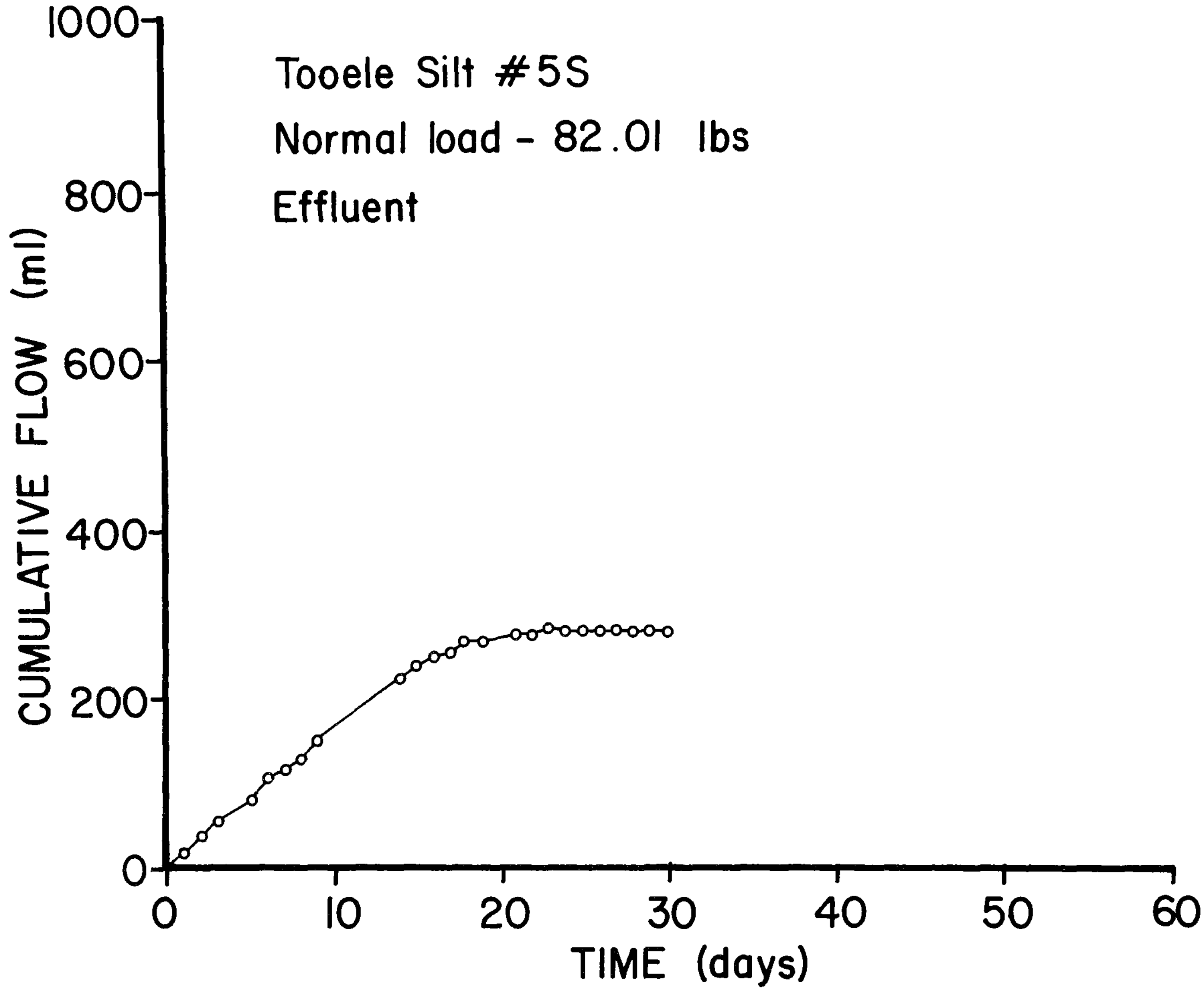


Figure 11. Cumulative flow versus time.

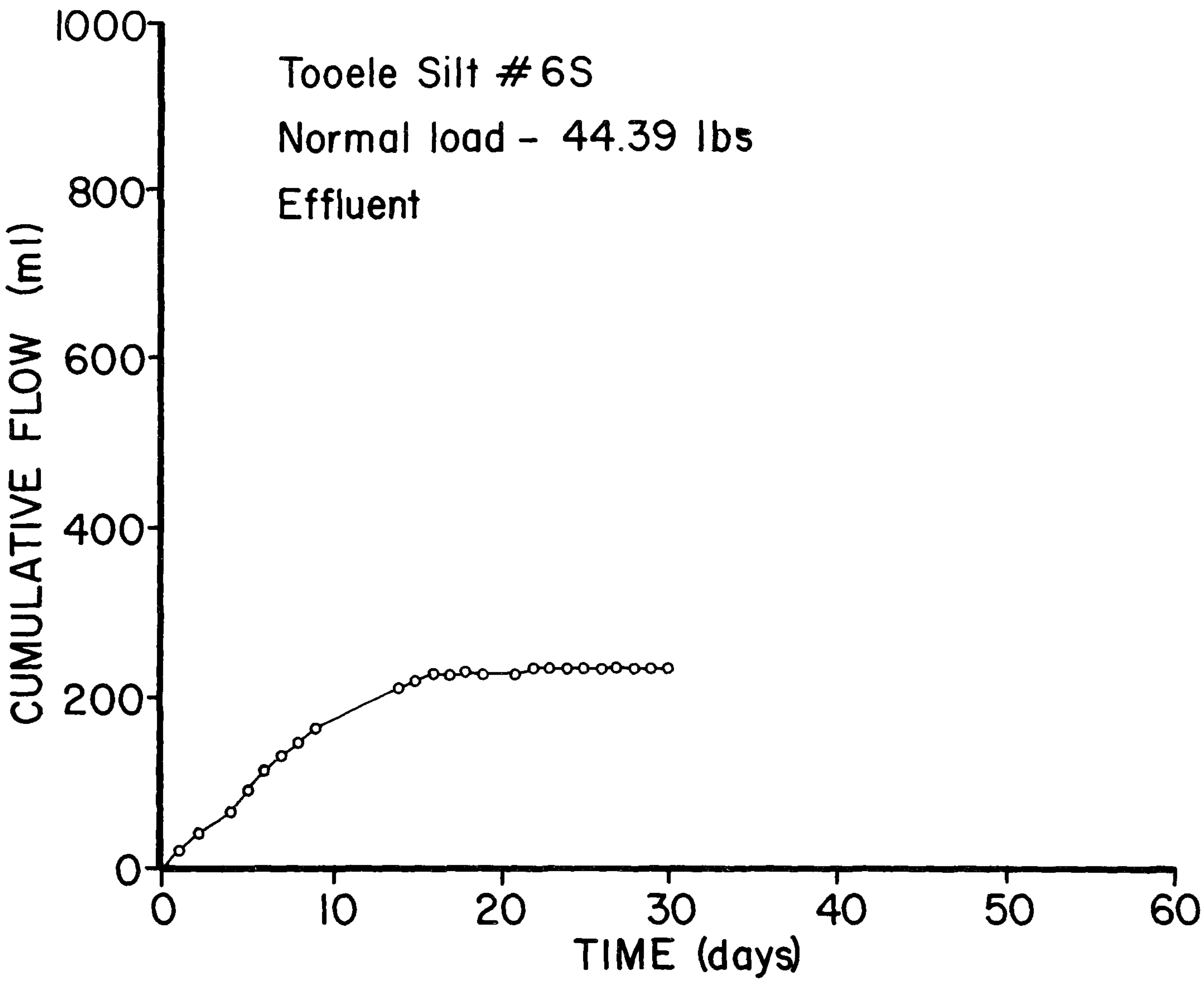


Figure 12. Cumulative flow versus time.

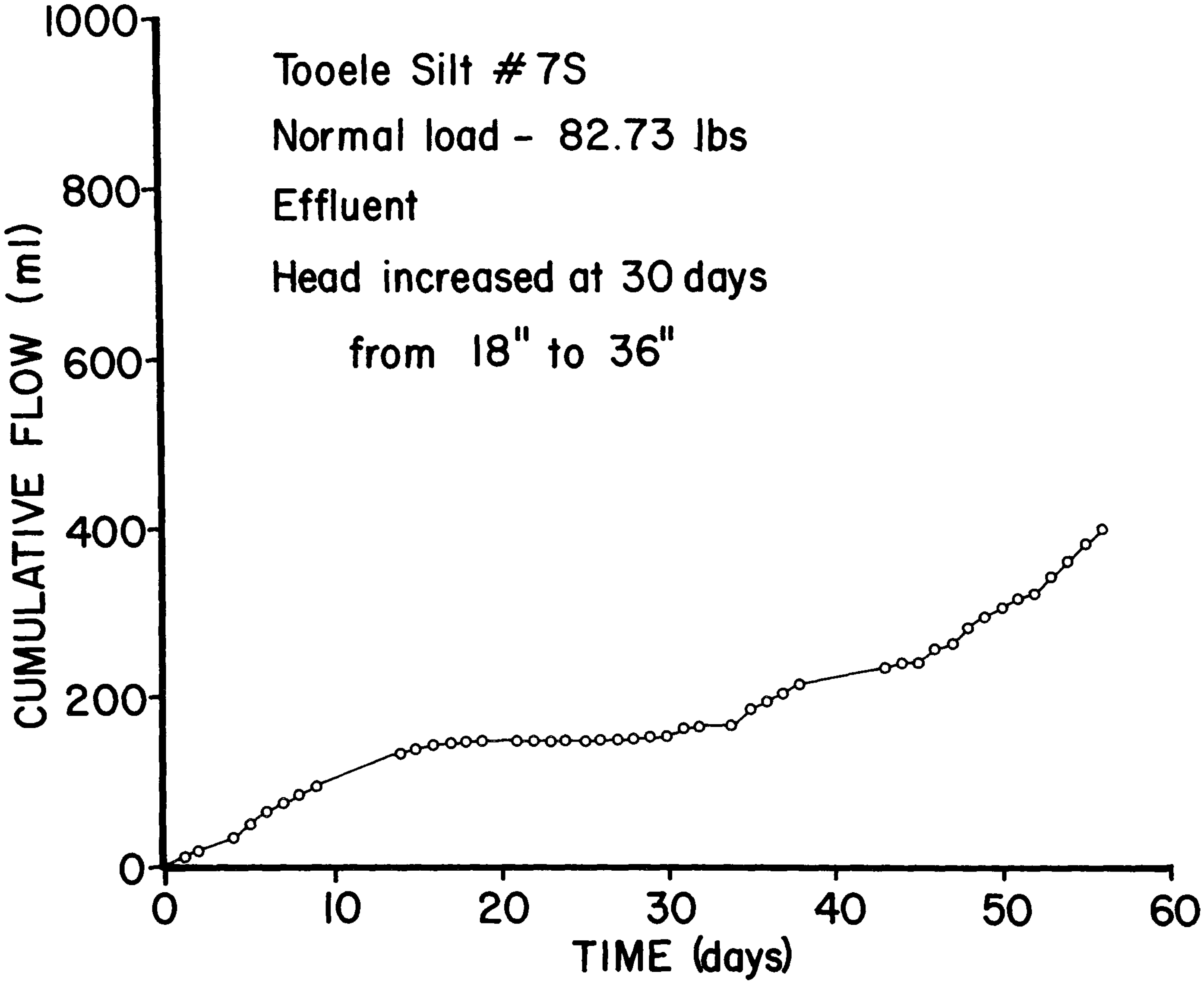


Figure 13. Cumulative flow versus time.

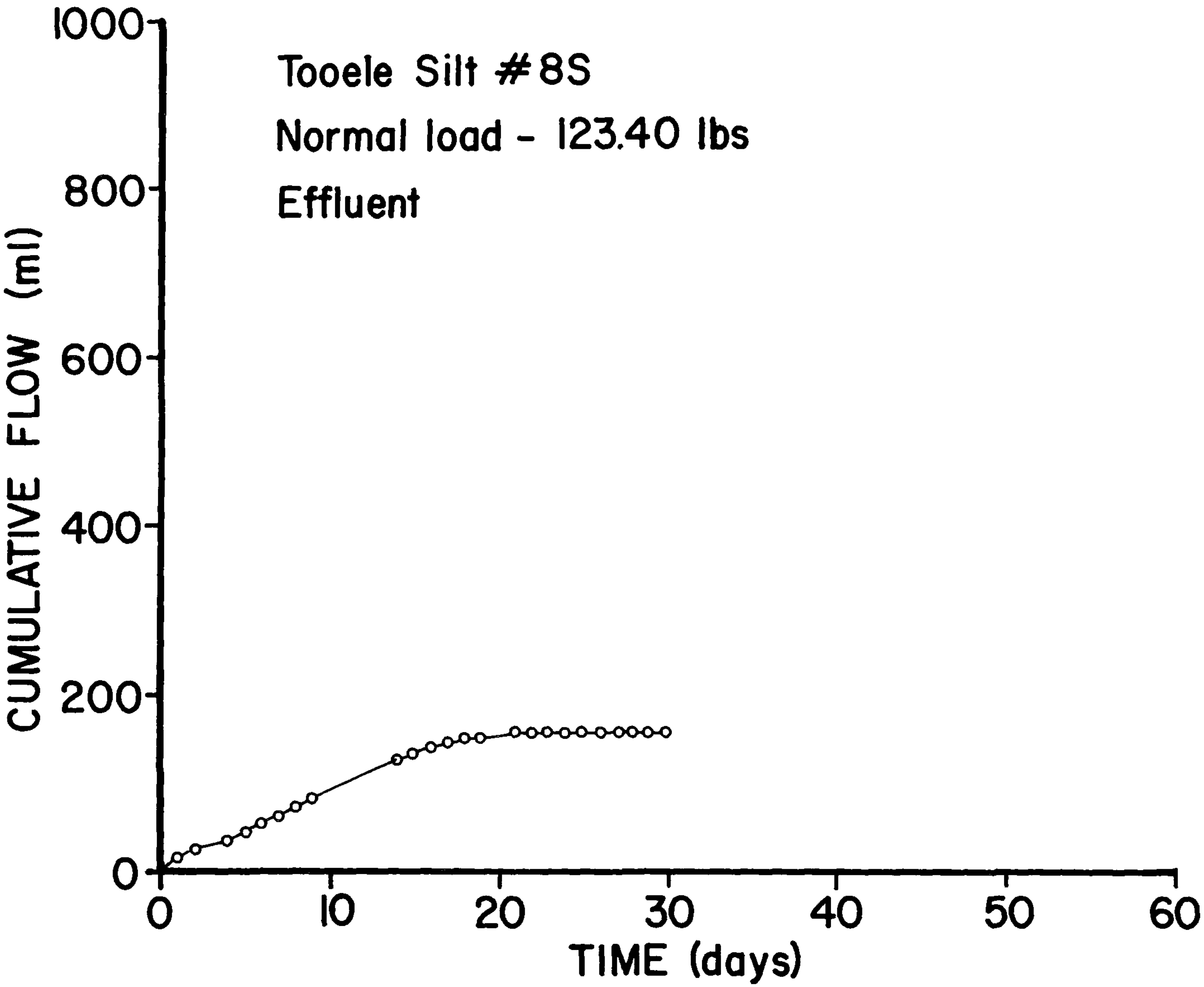


Figure 14. Cumulative flow versus time.

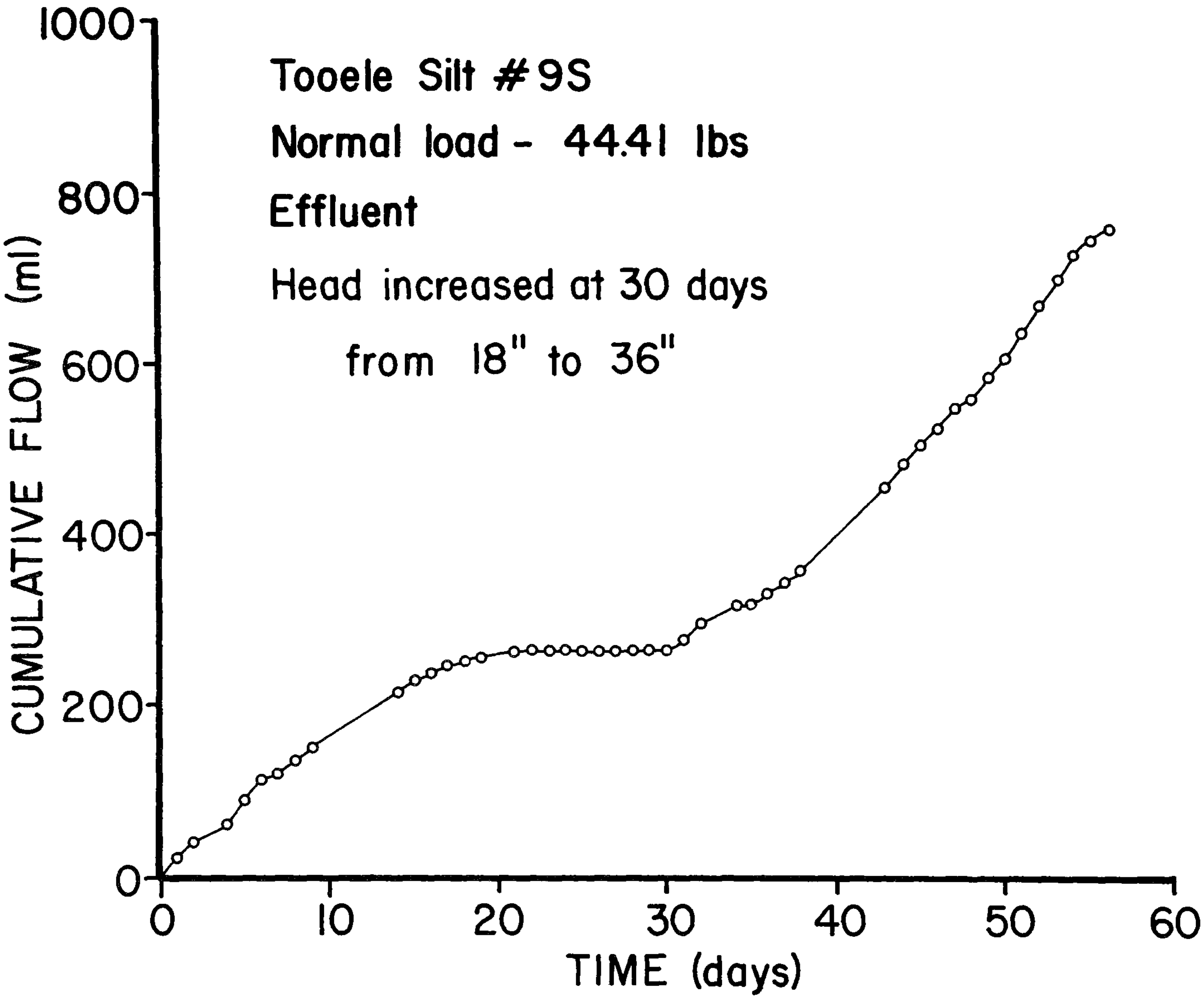


Figure 15. Cumulative flow versus time.

TABLE 2. QUANTITY OF WATER APPLIED TO SMITHFIELD CLAY SAMPLES FOR DIRECT SHEAR TESTS

Sample	Treatment	Time (days)	Accumulated Volume of Distilled Water (mℓ)	Accumulated Volume of Effluent (mℓ)
1	Distilled	92	380	-
2	water	92	435	-
3	only	92	365	-
4	Effluent followed	92	90	205
5	by distilled	92	105	220
6	water	92	110	260
7		92	-	335
8	Effluent only	92	-	350
9		92	-	335

Quality of Water Added to Samples

The results of the water quality analysis of the sewage treatment plant effluent samples indicate that the effluent was of high quality. The composition of the distilled water and the effluent applied to both the Tooele silt and the Nibley sand samples is shown in Tables 3 and 4. The effluent used to treat the Smithfield clay samples was obtained from the same point in the treatment process and generally at about the same time of day.

Chemical Description of Soils

A chemical characteristic description for both kinds of soil samples treated with effluent and for those treated with distilled water is shown in Table 5. The soil tests performed showed no appreciable differences among the samples of each kind of soil in the water soluble salts, the total extractable cations, and the cation exchange capacity. Tests were not performed on the Smithfield clay samples used for the shear tests. However, the soil and treatment procedures were the same for the shear test samples as for the consolidation samples. The chemical characteristics of the Smithfield clay consolidation samples is given in Table 20.

Direct Shear Test Results

Test results for the Tooele silt, the Nibley sand and the Smithfield clay samples are shown in Tables 6, 7, and 8. Shearing force versus displacement curves for the Tooele silt samples are shown in Figure 16. A shearing force versus displacement envelope for the Nibley sand samples is

TABLE 3. WATER QUALITY TEST RESULTS FOR EFFLUENTS USED ON THE TOOELE SILT SAMPLES

Day #	Sample Type	pH	NO_3-N mg/ℓ as Nitrogen	mg/ℓ					mg/ℓ			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total P	SS	VSS	BOD_5	COD
0	Distilled Water	5.62	--	--	--	--	--	--	--	--	--	--
	Old Effluent	--	--	--	--	--	--	--	--	--	--	--
	Fresh Effluent	7.30	4.19	82.8	11.2	38	7.3	4.13	10.6	--	--	--
	Average	7.30	4.19	82.8	11.2	38	7.3	4.13	10.6	--	--	--
3	Distilled Water	6.35	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.18	3.66	78.2	17.2	39	7.2	3.23	14.4	10.2	9.0	--
	Fresh Effluent	7.41	6.50	94.5	14.3	105	8.0	3.76	10.3	7.2	6.0	--
	Average	7.30	5.08	86.4	15.8	72	7.6	3.50	12.4	8.7	7.5	--
7	Distilled Water	4.45	--	0.88	--	--	--	--	--	--	--	--
	Old Effluent	7.55	6.37	98.5	8.2	105	8.0	3.98	11.0	8.3	--	46.0
	Fresh Effluent	7.28	9.19	68.5	21.0	43	7.3	3.71	19.6	13.0	--	43.7
	Average	7.42	7.78	83.5	14.6	74	7.7	3.85	15.3	10.7	--	44.9
14	Distilled Water	6.48	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.19	5.95	87.7	11.0	48	7.3	4.38	9.6	7.0	10.0	42.2
	Fresh Effluent	7.32	6.28	88.2	8.7	43	7.5	4.24	12.8	8.8	8.8	48.3
	Average	7.26	6.12	88.0	9.9	45.5	7.4	4.31	11.2	7.9	9.0	45.3
17	Distilled Water	7.19	--	--	--	--	--	--	--	--	--	--
	Old Effluent	8.55	7.39	78.8	15.3	43	7.6	4.11	--	--	12.0	36.7
	Fresh Effluent	8.26	4.93	81.1	25.0	150	7.8	4.32	--	--	9.0	44.7
	Average	8.41	6.16	80.0	20.2	96.5	7.7	4.22	--	--	10.5	40.7

(continued)

TABLE 3 (continued)

Day #	Sample Type	pH	NO_3-N mg/ℓ as Nitrogen	mg/ℓ Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total P	mg/ℓ SS	VSS	BOD_5	COD
21	Distilled Water	6.21	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.58	1.51	93.7	15.5	150	7.8	4.62	--	--	--	37.3
	Fresh Effluent	7.35	6.44	82.3	15.6	46	6.9	3.88	--	--	--	44.3
	Average	7.47	3.98	88.0	15.6	98	7.3	4.25	--	--	--	40.8
24	Distilled Water	--	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.21	6.22	94.7	0	48	7.0	3.75	--	--	--	--
	Fresh Effluent	--	--	--	--	--	--	--	--	--	--	--
	Average	7.21	6.22	94.7	0	48	7.0	3.75	--	--	--	--

TABLE 4. WATER QUALITY TEST RESULTS FOR EFFLUENTS USED ON THE NIBLEY SAND SAMPLES

Day #	Sample Type	pH	NO_3-N mg/ℓ as Nitrogen	mg/ℓ Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total P	mg/ℓ SS	VSS	BOD_5	COD
0	Distilled Water	5.9	--	--	--	--	--	--	--	--	--	--
	Old Effluent	--	--	--	--	--	--	--	--	--	--	--
	Fresh Effluent	7.6	2.14	84.2	--	60	7.1	--	--	--	--	--
	Average	7.6	2.14	84.2	--	60	7.1	--	--	--	--	--
7	Distilled Water	5.8	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.6	1.53	63.8	2.2	--	--	7.73	8.52	7.21	3.6	39.5
	Fresh Effluent	7.6	2.17	89.7	8.5	--	--	9.80	5.92	3.67	3.9	52.5

(continued)

TABLE 4 (Continued)

Day #	Sample Type	pH	NO_3-N mg/ℓ as Nitrogen	mg/ℓ Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total P	mg/ℓ SS	VSS	BOD_5	COD
	Average	7.6	1.85	76.8	5.4	--	--	8.77	7.22	5.44	3.8	46.0
14	Distilled Water	6.1	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.3	--	104.1	--	98	8.1	4.00	5.56	4.67	21.8	54.3
	Fresh Effluent	7.6	2.38	77.1	--	104	8.1	4.16	10.83	10.56	37.6	60.5
	Average	7.5	2.38	90.6	--	101	8.1	4.08	8.20	7.62	29.7	57.4
21	Distilled Water	5.8	--	--	--	--	--	--	--	--	--	--
	Old Effluent	8.0	1.98	87.6	5.4	105	7.8	3.56	4.58	3.13	7.5	35.6
	Fresh Effluent	8.0	2.34	79.3	5.6	88	8.0	4.94	16.14	12.95	26.3	91.1
	Average	8.0	2.66	83.7	5.5	96.5	7.9	4.25	10.36	8.04	16.9	63.4
28	Distilled Water	5.6	--	--	--	--	--	--	--	--	--	--
	Old Effluent	7.7	--	72.1	10.8	69	7.2	3.41	20.28	19.72	21.6	42.4
	Fresh Effluent	7.7	--	66.1	12.1	68	7.9	4.28	16.29	12.86	37.5	91.4
	Average	7.7	--	69.1	11.5	68.5	7.55	3.85	18.29	16.29	29.6	66.9

TABLE 5. CHEMICAL CHARACTERISTICS DESCRIPTION OF THE TOOELE SILT AND THE NIBLEY SAND SAMPLES AFTER TESTING

Soil Type	Treatment Type	Sample Number	H_2O - Solubility (me/100g) Ca	Mg	Na	K	NH_4OAC extract (me/100g) Ca	Mg	Na	K	Cation Exchange Capacity (me/100g)
Tooele Silt	Distilled Water	2	0.2	0.1	0	0	39	3.7	0.4	0.6	14.2
		3	0.2	0.1	0	0	40	3.8	0.4	0.6	16.0
	Effluent	4	0.2	0.1	0.1	0	38	3.5	0.4	0.6	11.2
		6	0.2	0.1	0.1	0	38	3.8	0.5	0.6	14.6
		8	0.1	0.1	0.1	0	36	3.5	0.4	0.5	15.3
		9	0.2	0.1	0.1	0	36	3.4	0.5	0.5	18.5
Nibley Sand	Distilled Water	1	0	0	0	0	24	0.8	0.2	0	1.5
	Effluent	4	0	0	0.1	0	21	0.7	0.3	0	1.5

TABLE 6. SHEAR TEST DATA FROM THE TOOELE SILT SAMPLES

Sample Number	Treatment Type	Time (days)	Normal Stress (kPa)	Shearing Force @ 125 mm Displacement (Newtons)	ϕ @ 125 mm* Displacement (degrees)
1	Distilled	30	67.8	246.8	24.2
2	Distilled	30	45.1	170.5	25.0
3	Distilled	30	24.4	92.6	25.1
4	Effluent	56	67.7	236.0	23.3
5	Effluent	30	45.1	159.3	23.6
6	Effluent	30	24.4	112.9	29.8
7	Effluent	56	45.4	186.9	26.9
8	Effluent	30	67.8	242.8	23.9
9	Effluent	56	24.4	105.9	28.2

ϕ = friction angle

TABLE 7. SHEAR TEST DATA FROM THE NIBLEY SAND SAMPLES TREATED FOR 28 DAYS

Sample Number	Treatment Type	Void Ratio	Normal Stress (kPa)	Peak Point Shearing Force (Newtons)	Relative Peak Point ϕ* (degrees)
1	Distilled	0.549	24.4	417.8	64.7
2	Distilled	0.540	24.4	400.5	63.7
3	Distilled	0.535	24.5	418.0	64.6
4	Effluent	0.561	24.6	333.1	59.1
5	Effluent	0.541	24.4	467.9	67.1
6	Effluent	0.544	24.4	420.8	64.9
7	Effluent	0.557	24.4	384.3	62.8
8	Effluent	0.542	24.4	427.5	65.2
9	Effluent	0.551	24.4	441.95	65.9

ϕ = friction angle

TABLE 8. SHEAR TEST DATA FROM THE SMITHFIELD CLAY SAMPLES

Sample Number	Treatment Type	Normal Load (Newtons)	Maximum Shearing Force (Newtons)	Ratio of Maximum Shearing Force / Normal Load
1	Distilled	194.9	97.3	0.499
2	Distilled	195.1	109.9	0.563
3	Distilled	195.2	94.6	0.485
4	Effluent-Distilled	194.9	105.9	0.543
5	Effluent-Distilled	195.3	102.0	0.522
6	Effluent-Distilled Average	195.1	106.8	0.547
7	Effluent	194.7	109.4	0.562
8	Effluent	195.1	104.8	0.537
9	Effluent Average	195.2	109.4	0.560

shown in Figure 17. Figures 18 through 20 show individual curves of shearing force versus displacement for each of the Nibley sand samples. Figures 21 through 23 show the shearing force versus displacement curves for the Smithfield clay samples.

Discussion of Shear Test Results

Water Quality Analysis for Shear Strength Samples--

At the time new water was placed in the reservoir bottles, during the treatment period, samples were taken of the distilled water, the old effluent, and the fresh effluent just obtained from the sewage treatment plant. Water quality tests were performed on both the effluent samples and the sample of distilled water. In the analysis of the results of these tests, the data from the fresh effluent samples and the old effluent sample were combined to obtain an average value for each particular test. The test results are presented in Tables 3 and 4. Water samples were analyzed only during the first 24 days of the treatment period for the Tooele silt samples. Water samples were analyzed throughout the entire treatment period for the Nibley sand samples. Water samples were not analyzed for the Smithfield clay samples.

During this study, the BOD_5 ranged from 3.8 mg/ℓ to 29.7 mg/ℓ with an

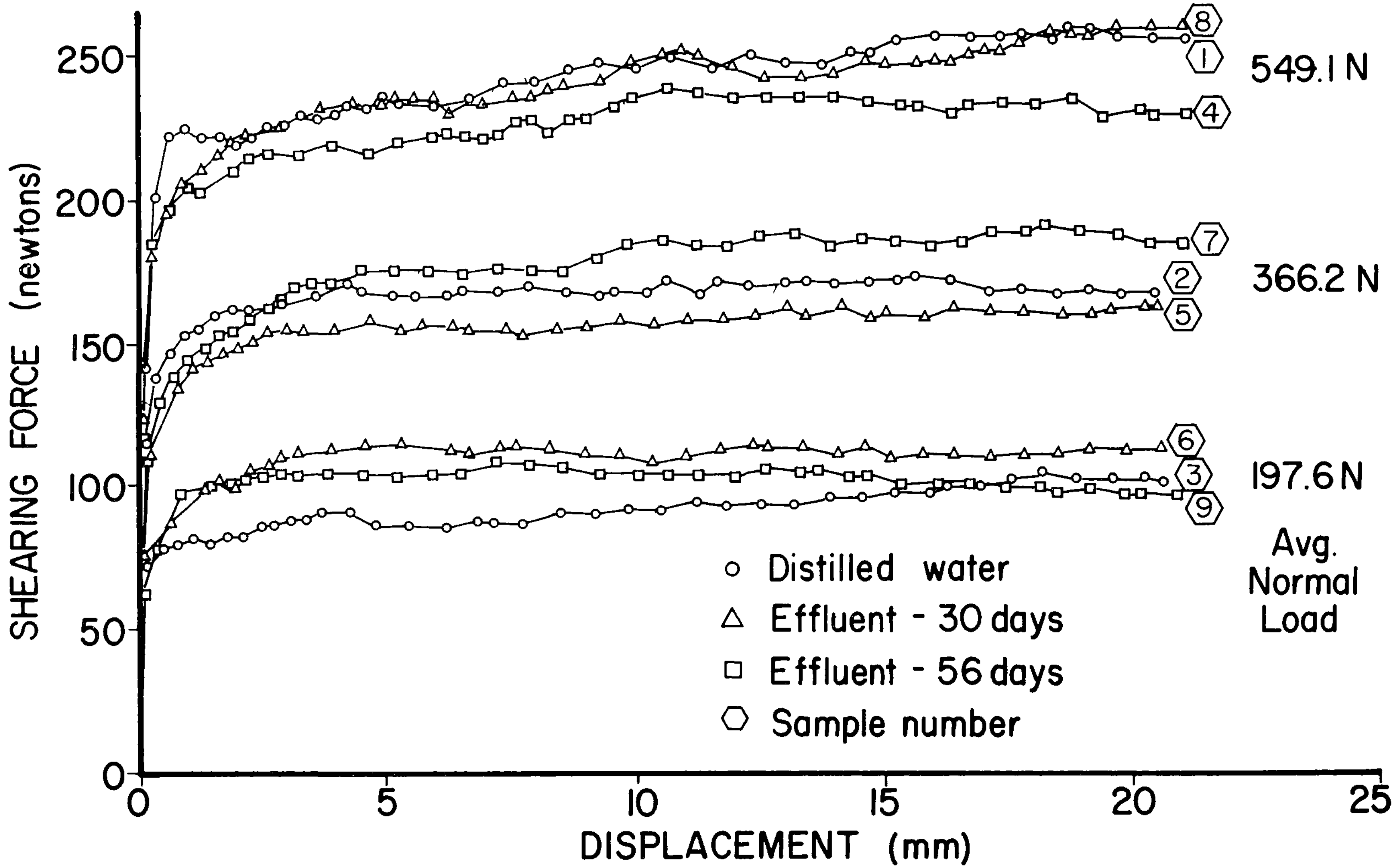


Figure 16. Shearing force versus displacement curves for the Tooele silt.

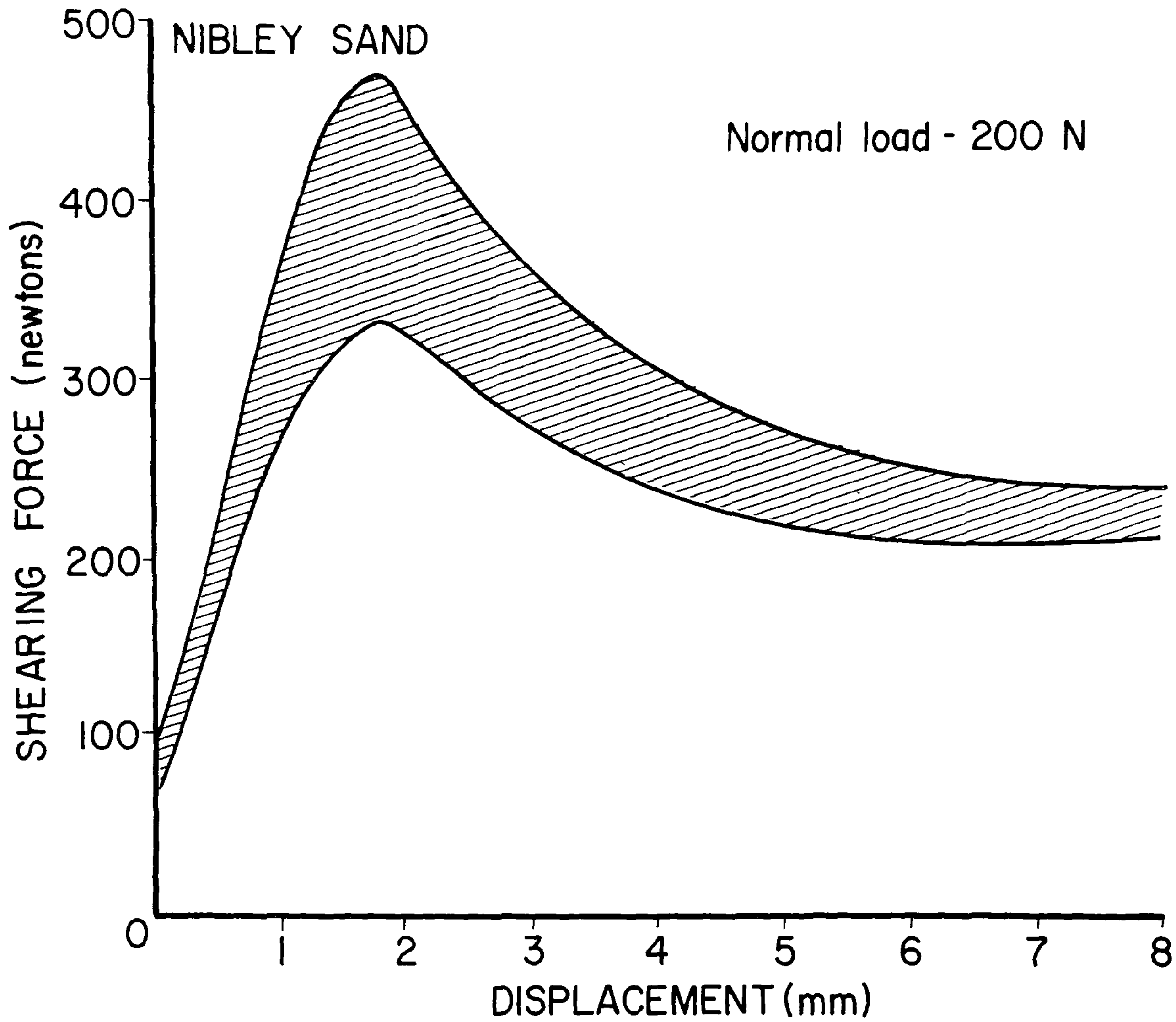


Figure 17. Shearing force versus displacement envelope for the Nibley sand.

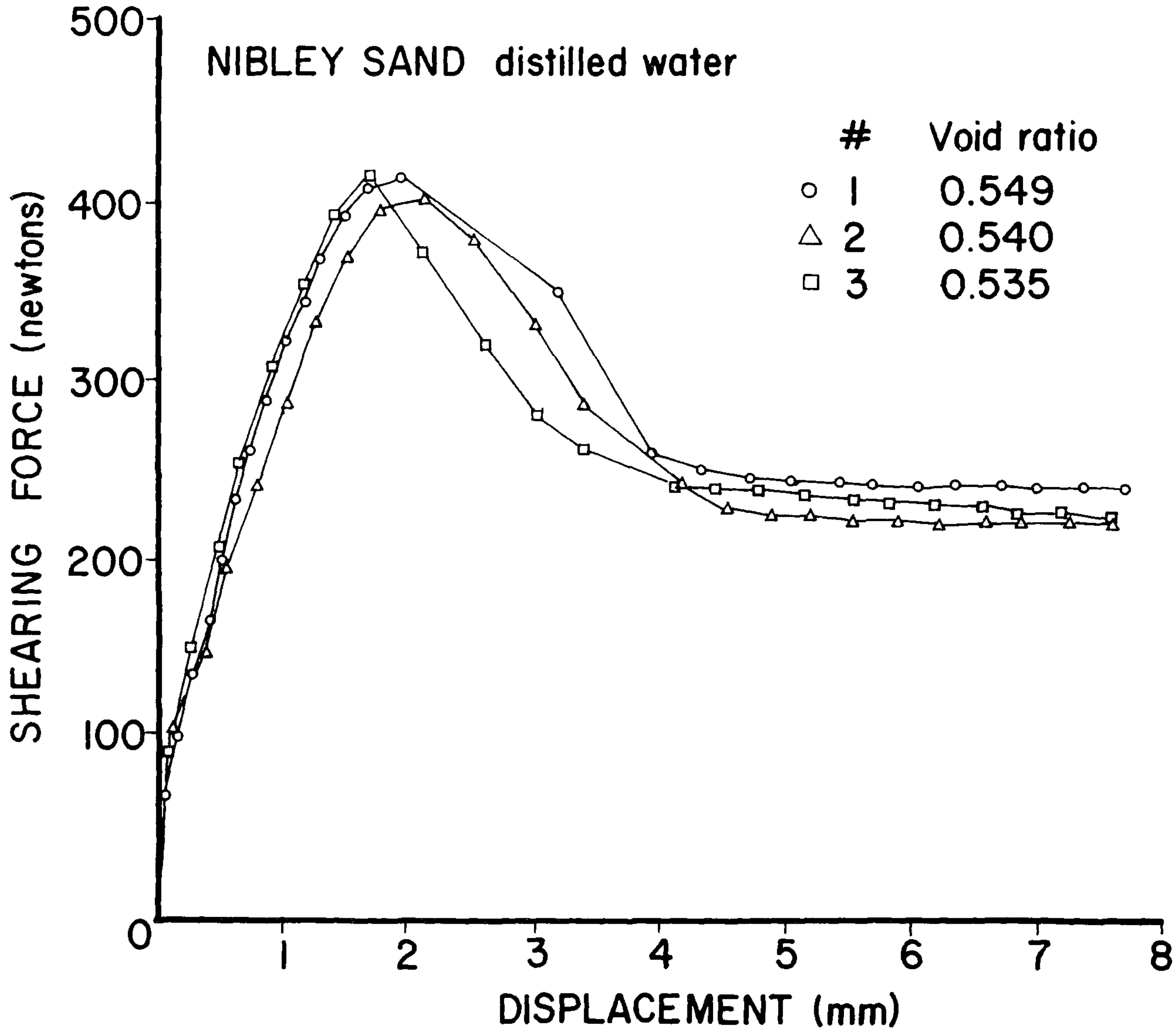


Figure 18. Shearing force versus displacement.

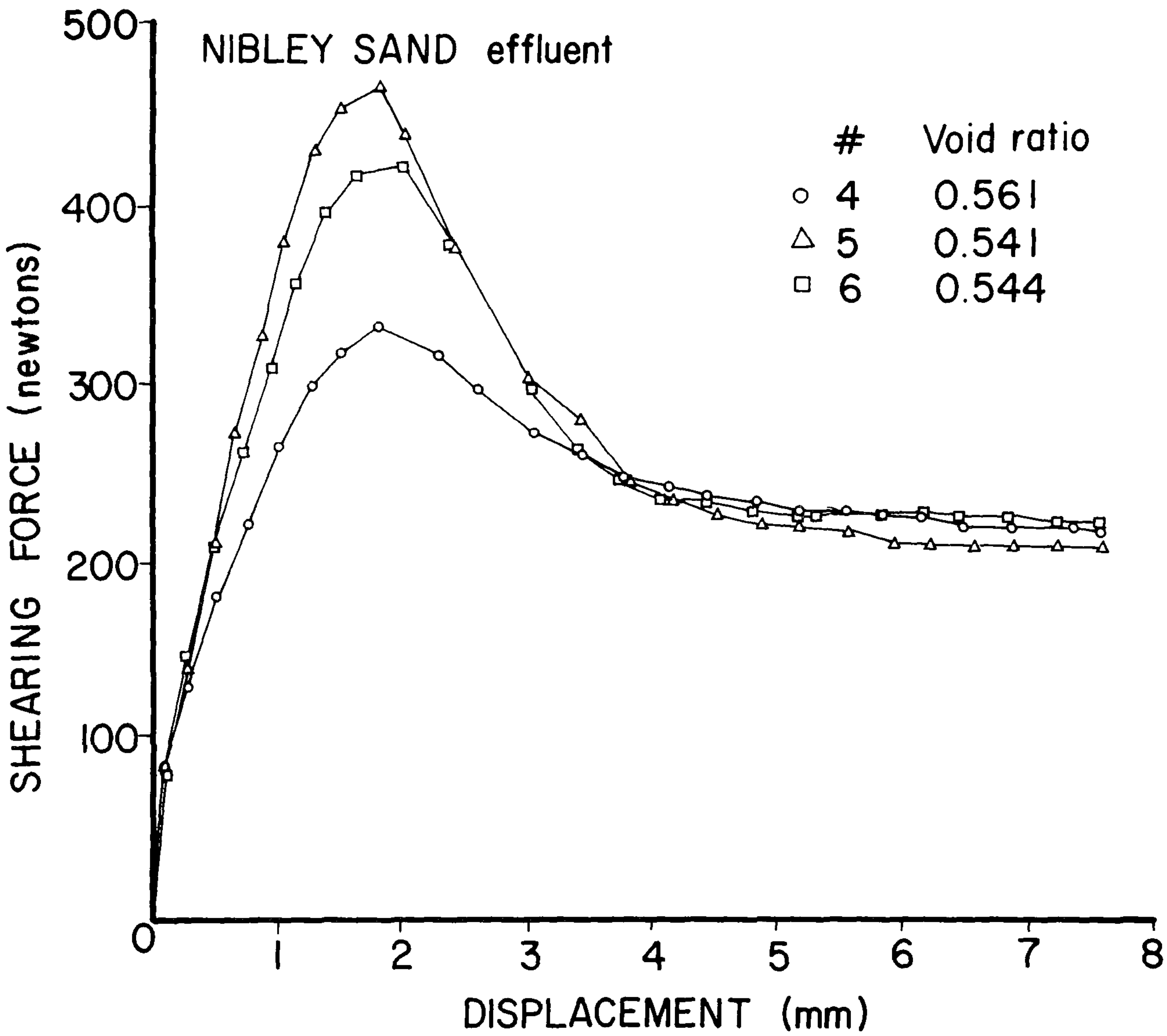


Figure 19. Shearing force versus displacement.

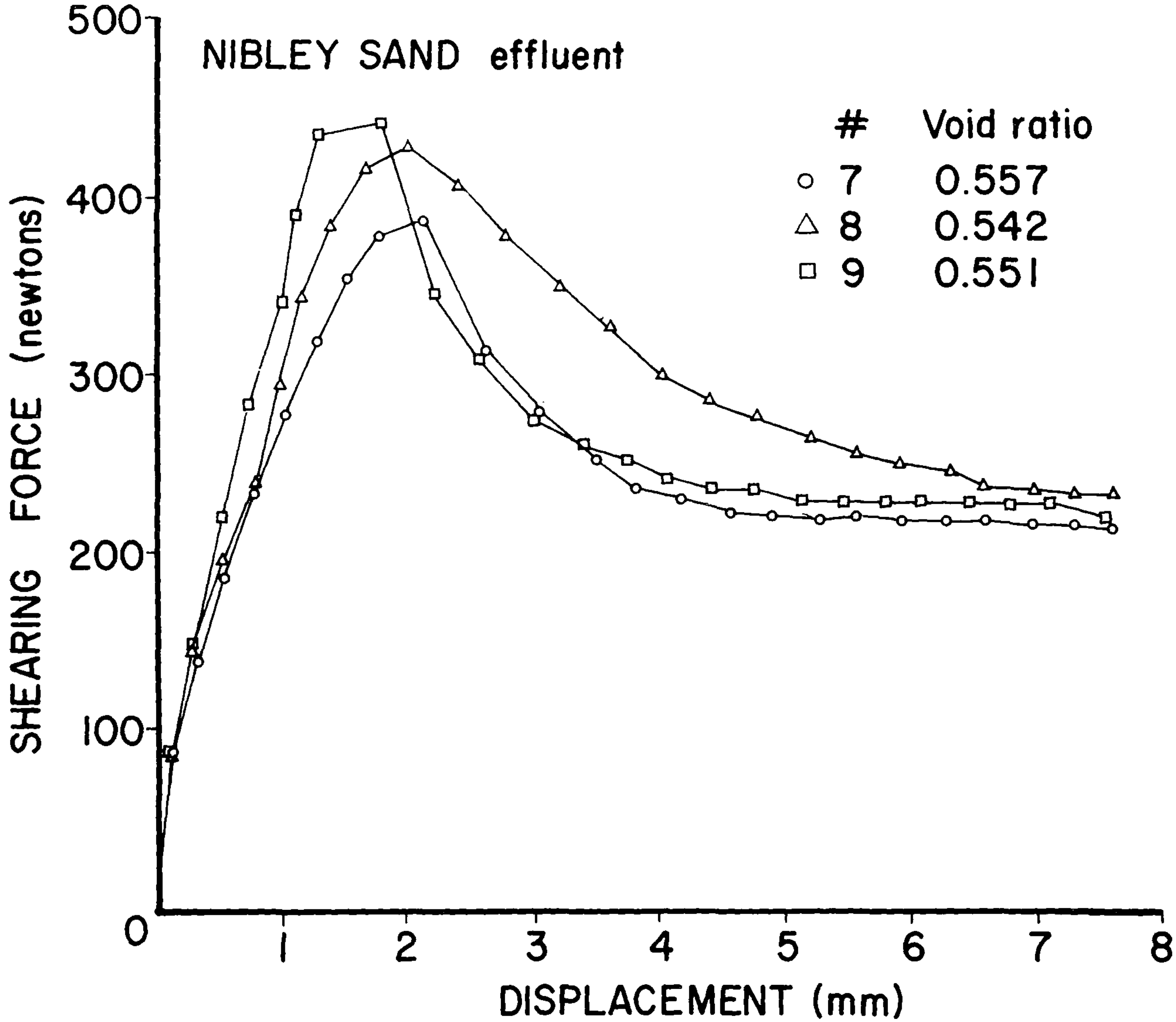


Figure 20. Shearing force versus displacement.

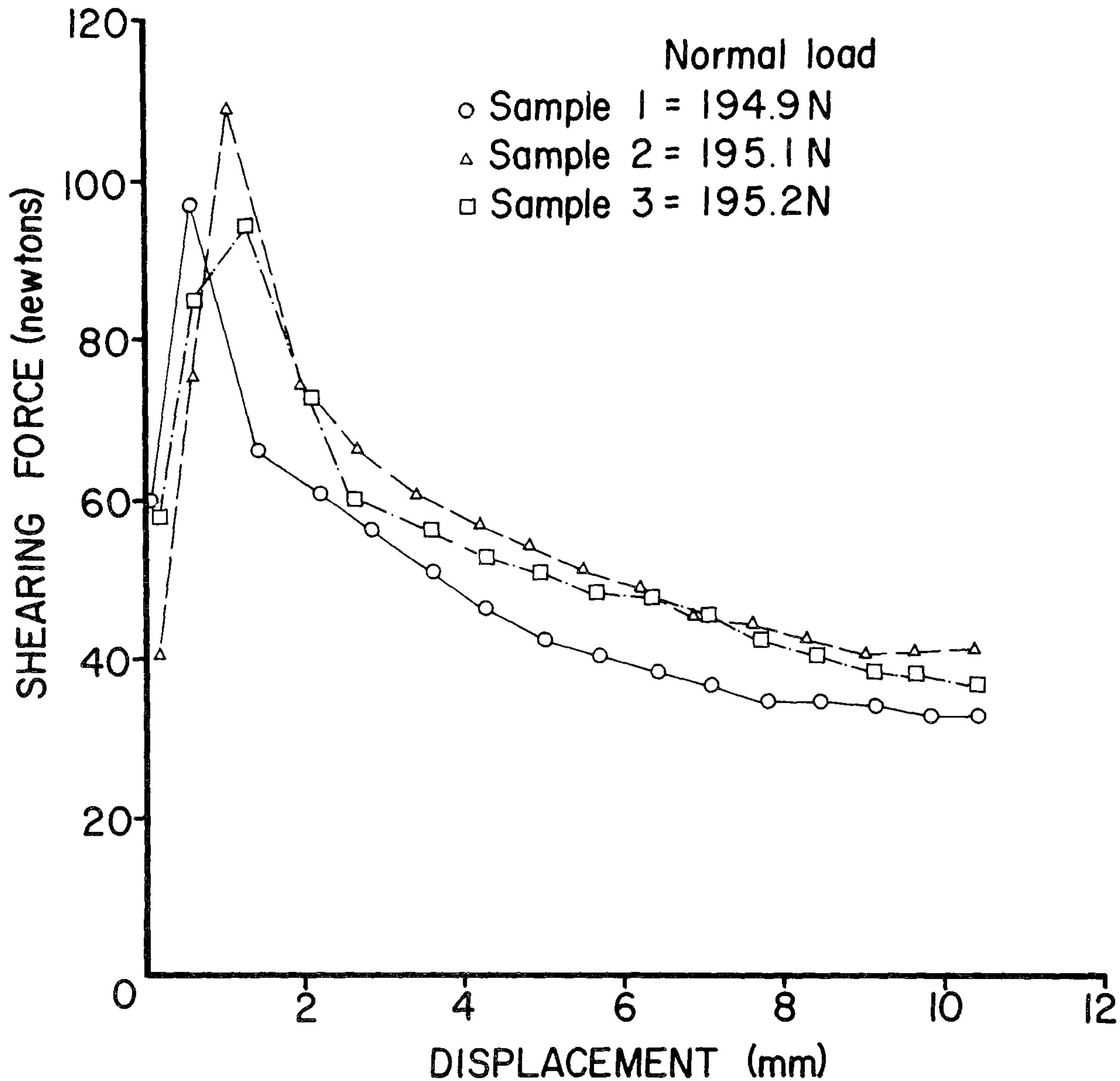


Figure 21. Shearing force versus displacement curves, Smithfield clay distilled water treatment.

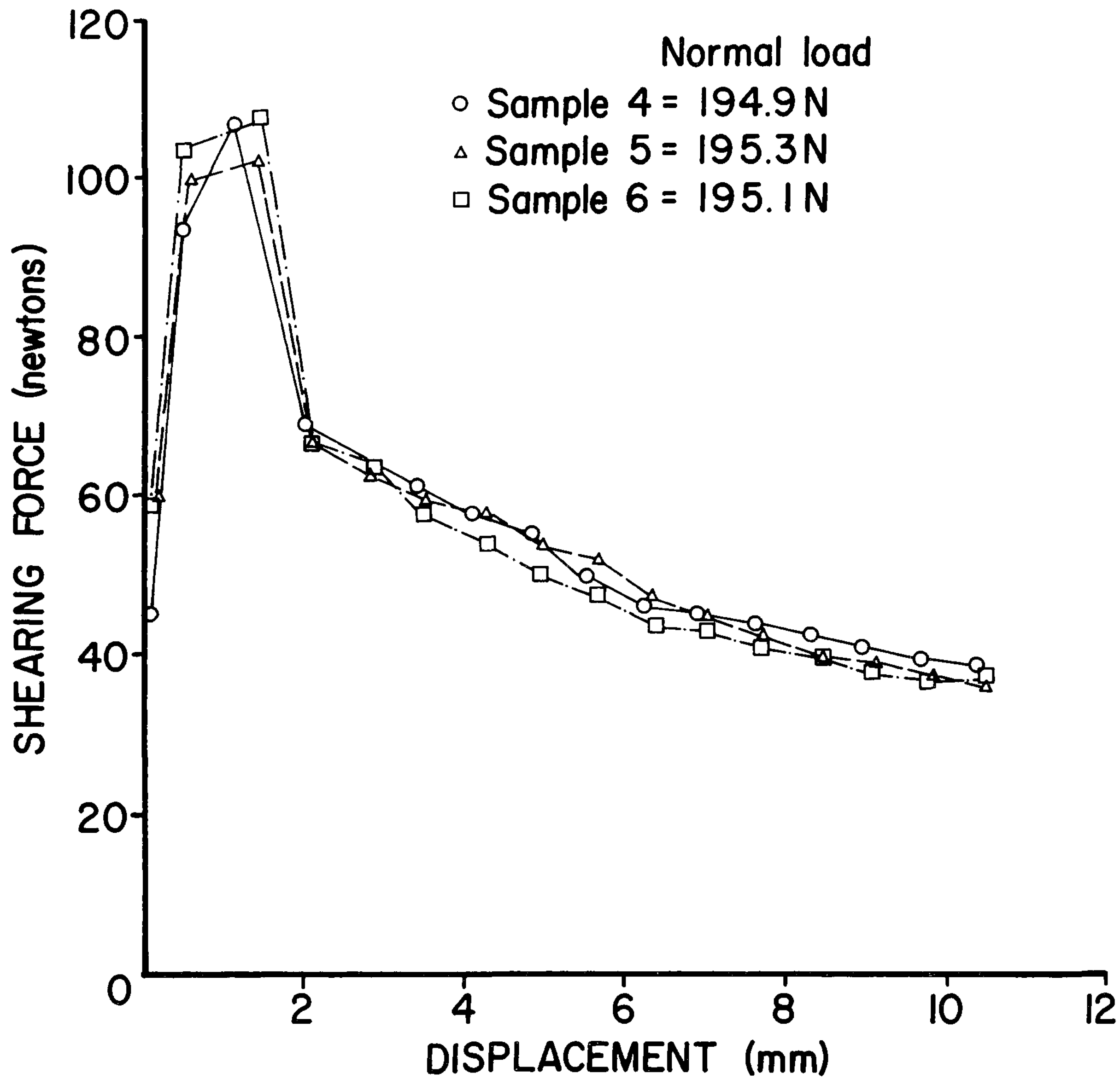


Figure 22. Shearing force versus displacement curves, Smithfield clay, effluent - distilled water treatment.

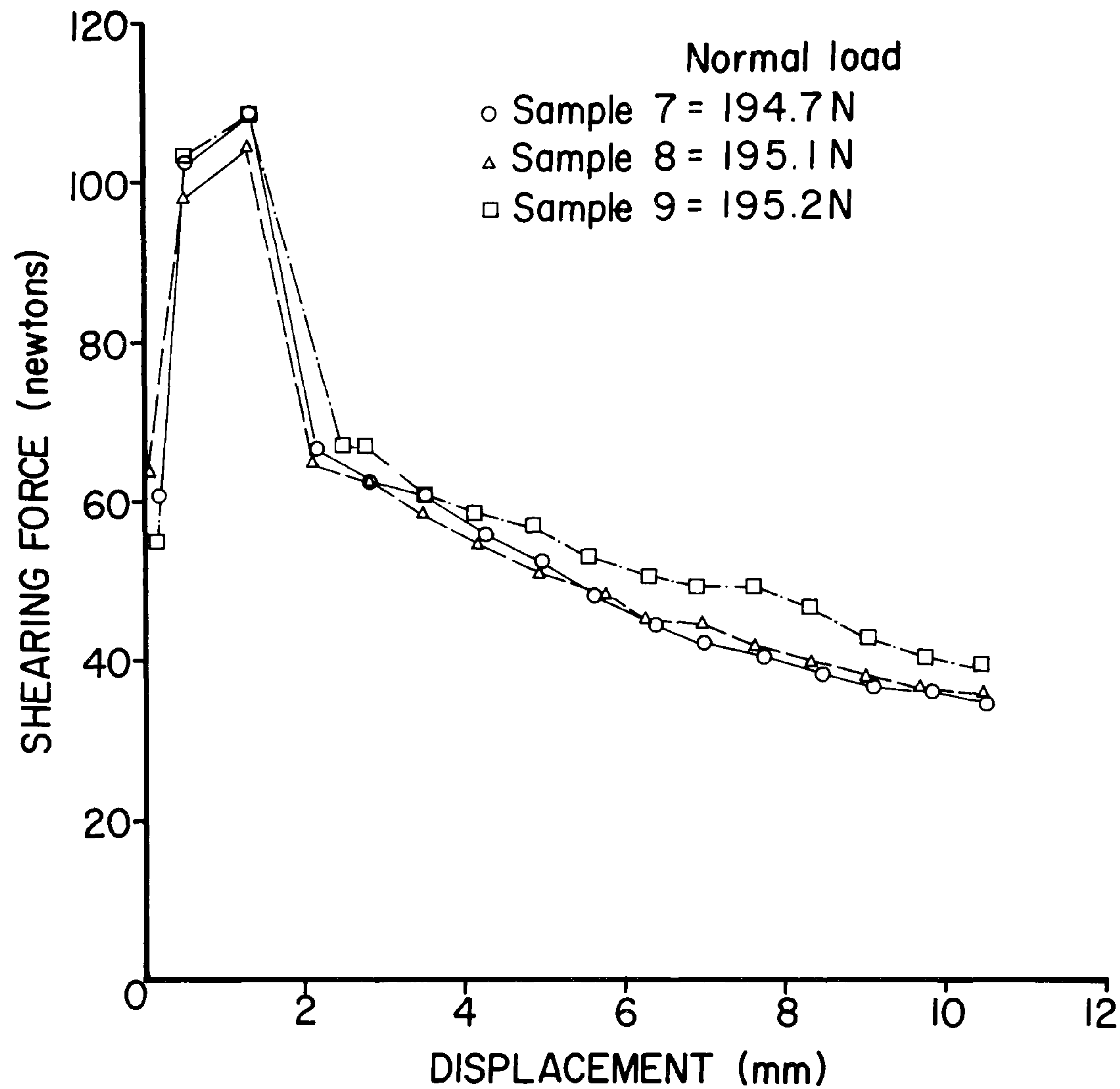


Figure 23. Shearing force versus displacement, Smithfield clay effluent treatment.

average value of 15.3 mg/ℓ. The SS varied from 7.2 mg/ℓ to 18.3 mg/ℓ and averaged 10.4 mg/ℓ. These concentrations are well below the federal standards for secondary treated effluents [*U.S. Government*, 1973]. The high quality of the effluent may have had a restrictive effect on biological growth in the samples.

Shearing Force Versus Displacement Curves--

Tooele silt --The shearing force versus displacement curves for the Tooele silt samples, as shown in Figure 16, display a close comparison between the results of those samples treated only with distilled water for 30 days and those samples treated only with effluent for the same period of time. Because no major differences occurred between the two groups, the remaining samples were not leached with distilled water but continued to receive effluent for an additional 26 days before being sheared. Figures 13 and 15 show that after the initial 30 days, the flow through two of the remaining three samples that had not been sheared (Sample Numbers 7 and 9) had reduced to zero. This reduction of flow was attributed to the formation of an insoluble gas as discussed by *Lance and Whisler* [1972] and *Rice* [1974] The gas was discovered by observing the formation and growth of air blocks in the tubing connecting the water reservoir bottles to the bottom of the shear cylinders. To resume the flow of effluent through these samples, the hydraulic head on all three remaining samples was increased from 460 mm (18 in.) to 910 mm (36 in.). Also, whenever such blocks occurred, the gas was bled off in an attempt to resume the flow. This procedure was effective in maintaining flow through the samples for the remaining 26 days of the treatment period. Results of the tests on these last three samples after 56 days of treatment correspond with the results of the tests previously performed after 30 days of treatment as shown in Figure 16.

The shearing force versus displacement curves for the samples of Tooele silt show no more variation than would normally be found in tests on samples having all received the same treatment.

Nibley sand --The normal pressure applied to all of the Nibley sand samples was 24.4 kPa (3.53 psi), with only slight variations occurring among the samples. The shearing force versus displacement curve for each of the samples lies within the envelope shown in Figure 17. The maximum shearing force indicated by this envelope is 467.9 N (105.15 lbs) and the minimum is 333 N (84.85 lbs). The relationship between the void ratio and the peak shearing force for the sand samples is shown in Figure 24. The maximum residual strength is 240.6 N (54.07 lbs) and the minimum is 211.7 N (47.58 lbs). The shearing force versus displacement curves are all similar in shape and exhibit typical results of a very dense sand. However, the peak point friction angle, ϕ, is exceptionally high in each of the tests. These values of ϕ varied from 59.1° to 67.1° (Table 7). It was later determined that the point of application of the shearing force on the shear box was too high. After making this modification to the apparatus, correct values of ϕ could be measured. For the purpose of this study, however, the relative results between the samples treated with distilled water and those treated with effluent were of primary concern. The peak point shearing angles obtained allowed a comparison of shear strength between different

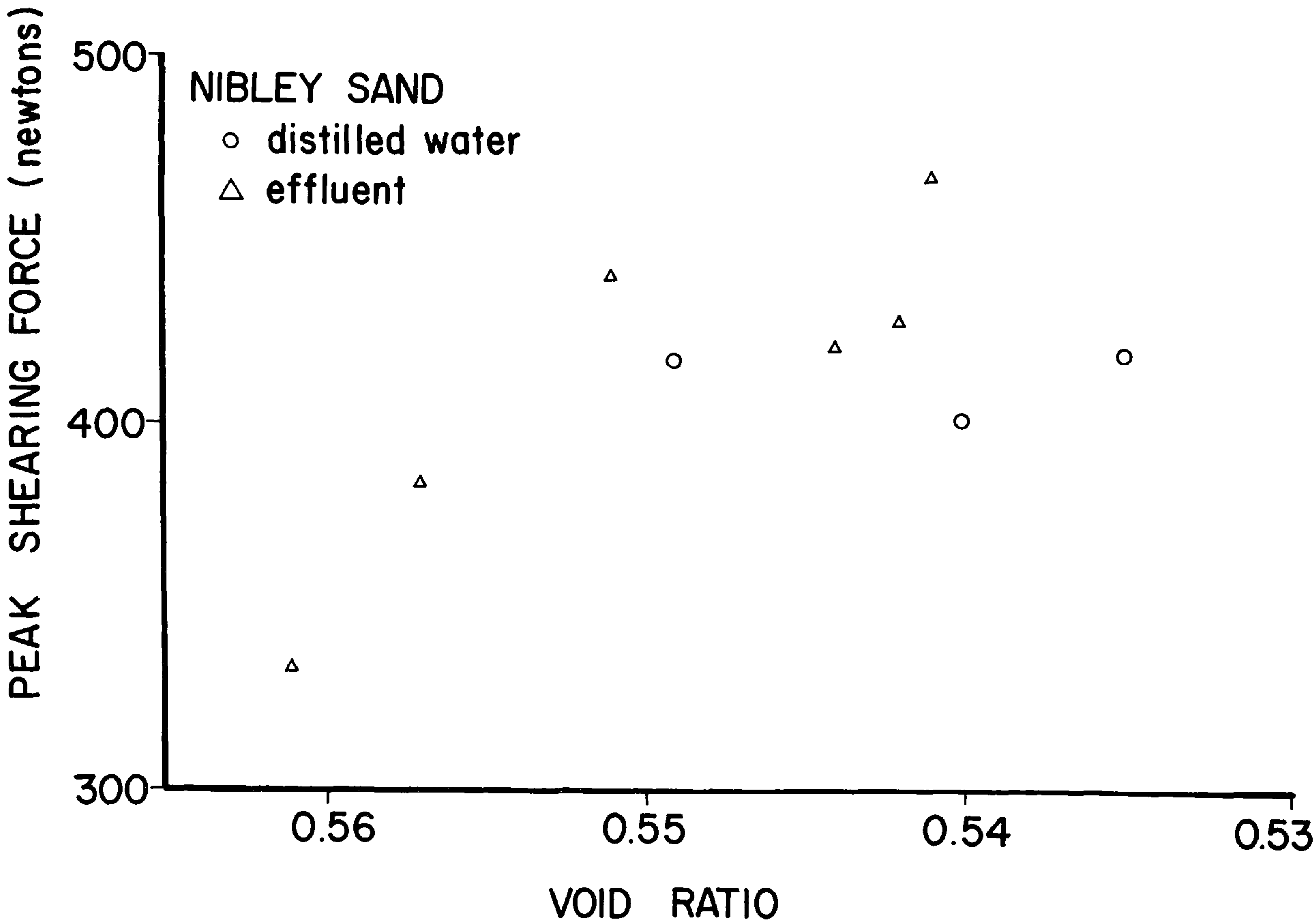


Figure 24. Peak shearing force versus void ratio for the Nibley sand.

treatment methods and did not influence the conclusions of this study.

For the purpose of maintaining uniformity among the sand samples, all samples were prepared to a high density by placing them on a high frequency vibrating table. The densities approached 100 percent relative density. This preparation procedure was successful in obtaining uniform samples with void ratios varying only between 0.535 and 0.561. However, by obtaining such high densities, any effects of chemical or biological activity in the porewater of the soil samples caused by the application of the treated effluent may have been partially or totally masked.

Smithfield clay -- The normal pressure applied to all of the Smithfield clay samples was approximately 24 kPa (3.49 psi) with only slight variations occurring among the samples. The maximum shearing resistance generally occurred at a strain of approximately 1.25 percent. The samples were sheared quickly and therefore the strengths measured represent the undrained shear strength. Even though the normal loads only varied between 194.7 N (43.76 lbs) and 195.3 N (43.89 lbs) (0.3 percent) the best comparison of shear strength between the samples is the ratio of maximum shearing force to normal force. These results are shown in Table 9. As indicated in Table 9, the samples treated with sewage effluent showed a slightly higher shear strength than the samples subjected to distilled water only. The average ratio of shearing force to normal force varied from 0.516 for the distilled water samples to 0.553 for the samples leached with sewage effluent. This is about a 7 percent difference. The three samples that were leached with sewage effluent followed by distilled water had an average ratio of shearing force to normal force of 0.537.

TABLE 9. COMPARISON OF SHEAR TEST RESULTS FOR SMITHFIELD CLAY

Treatment	Mean Ratio of $\frac{\text{Maximum Shearing Stress}}{\text{Normal Stress}}$	Standard Deviation
Distilled water only for 92 days	0.516	0.028
Effluent for 63 days followed by distilled water for 27 days	0.537	0.022
Effluent only for 92 days	0.553	0.011

CONSOLIDATION CHARACTERISTICS

General

Consolidation and permeability tests were performed on treated samples of Tooele silt and Smithfield clay. The compressibility, rate of consolidation, and permeability of the silt increased with application of the sewage effluent whereas the clay samples were not appreciably affected by application of the sewage effluent.

Quantity of Water Added to the Samples

The total accumulated volume of distilled water and/or treated sewage effluent applied to each consolidation sample of Tooele silt is shown in Figures 25 through 29. The total volume (V) of each sample and the computed volume of the voids (V_v) in each sample is also shown on these figures. Samples 1C, 2C and 3C received effluent for 23 days and were then tested. Samples 4C, 5C and 6C received effluent for 23 days, distilled water for an additional 50 days, and were then tested. Samples 7C, 8C and 9C received distilled water for 60 days and were then tested.

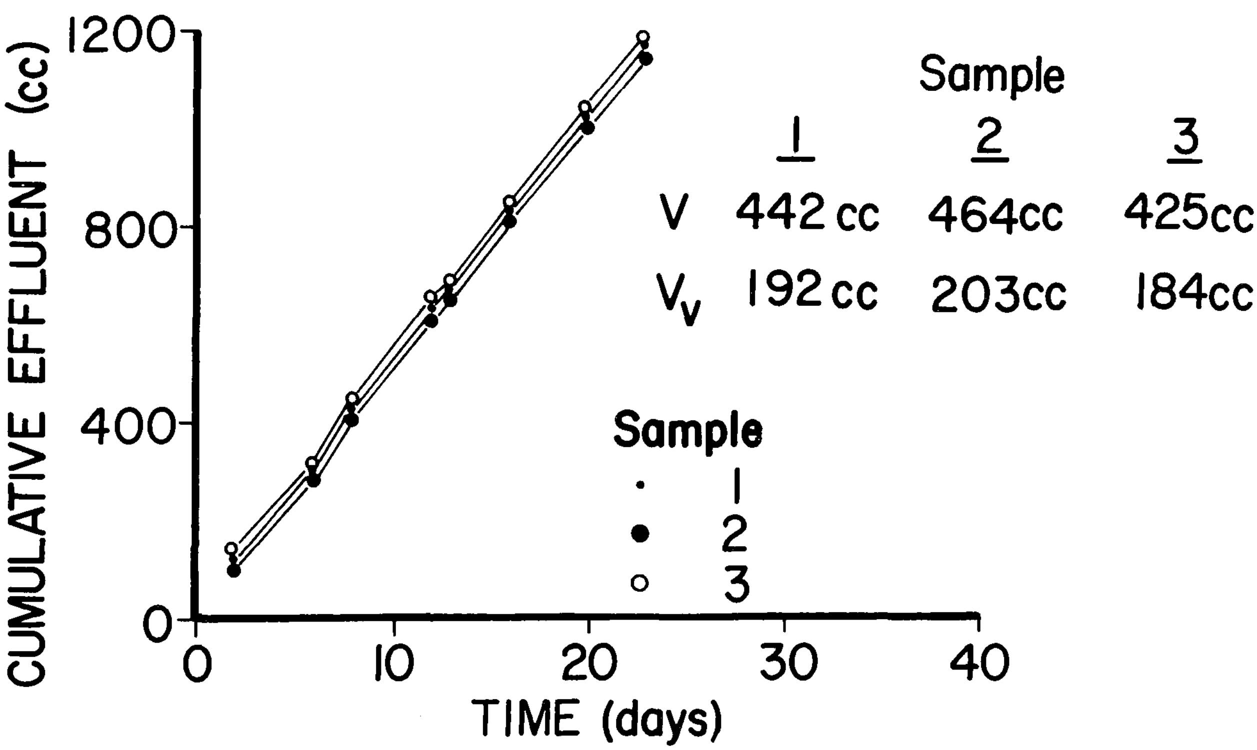


Figure 25. Tooele silt, cumulative effluent versus time.

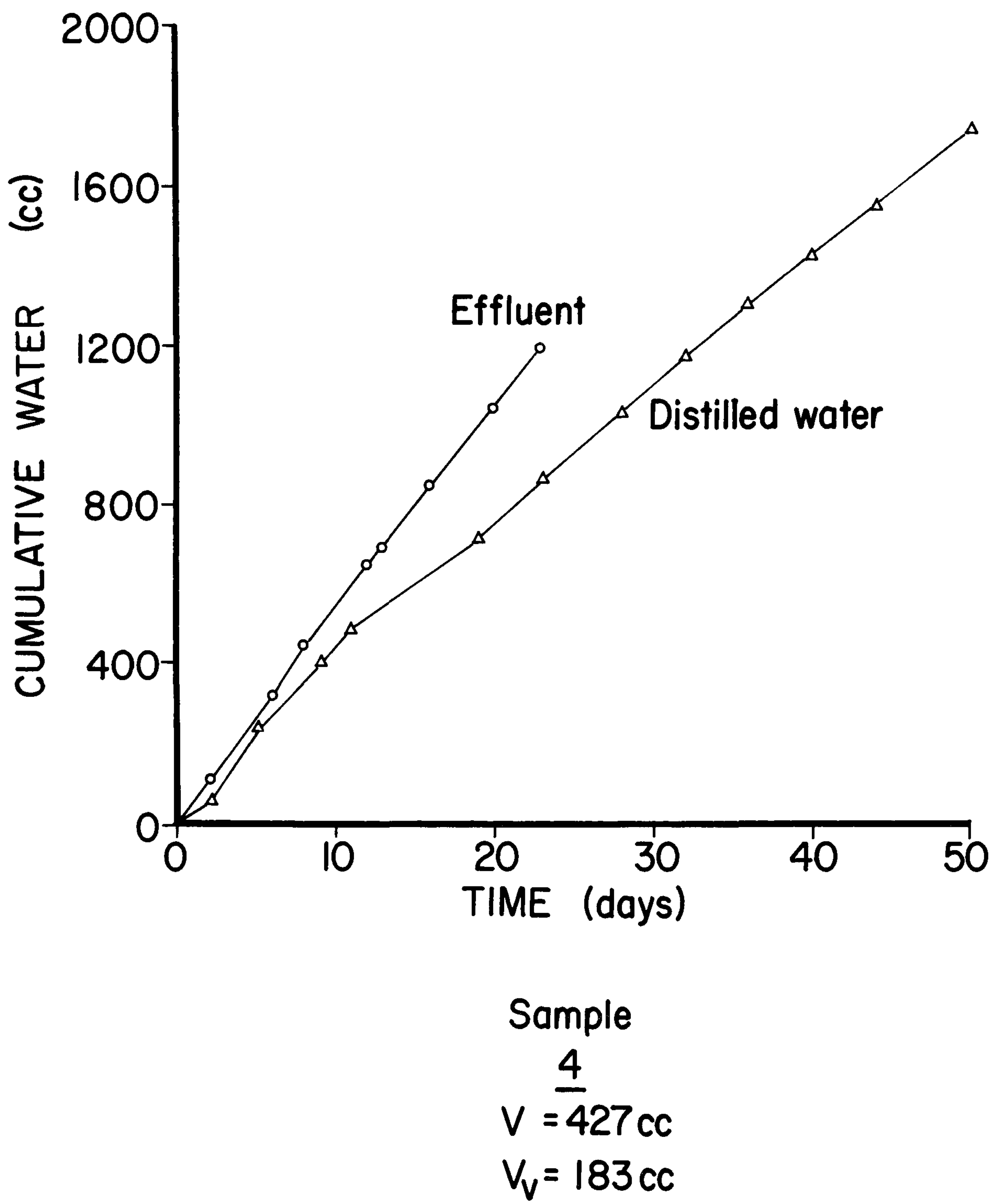


Figure 26. Tooele silt, sample 4C cumulative water versus time.

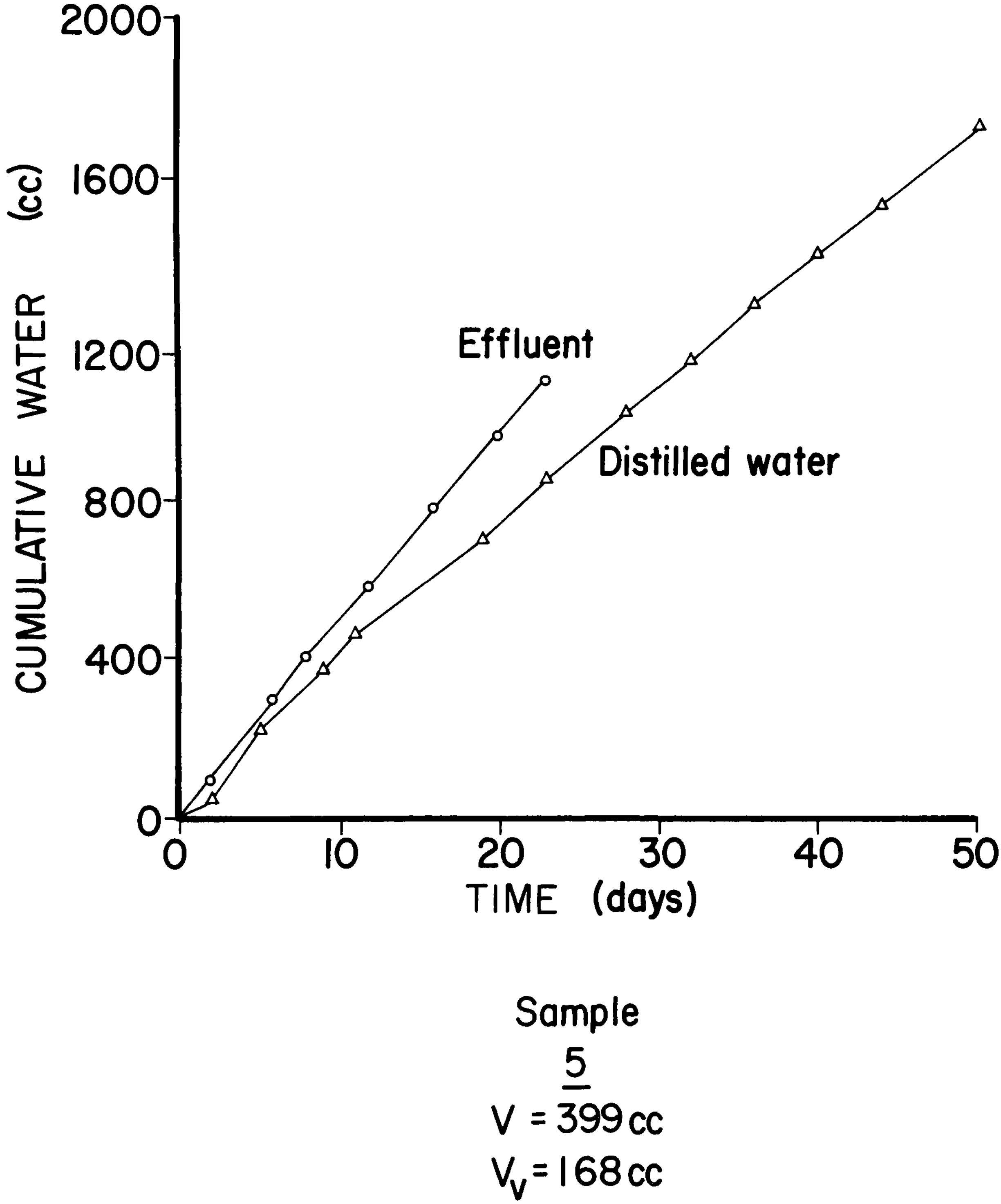


Figure 27. Tooele silt, sample 5C cumulative water versus time.

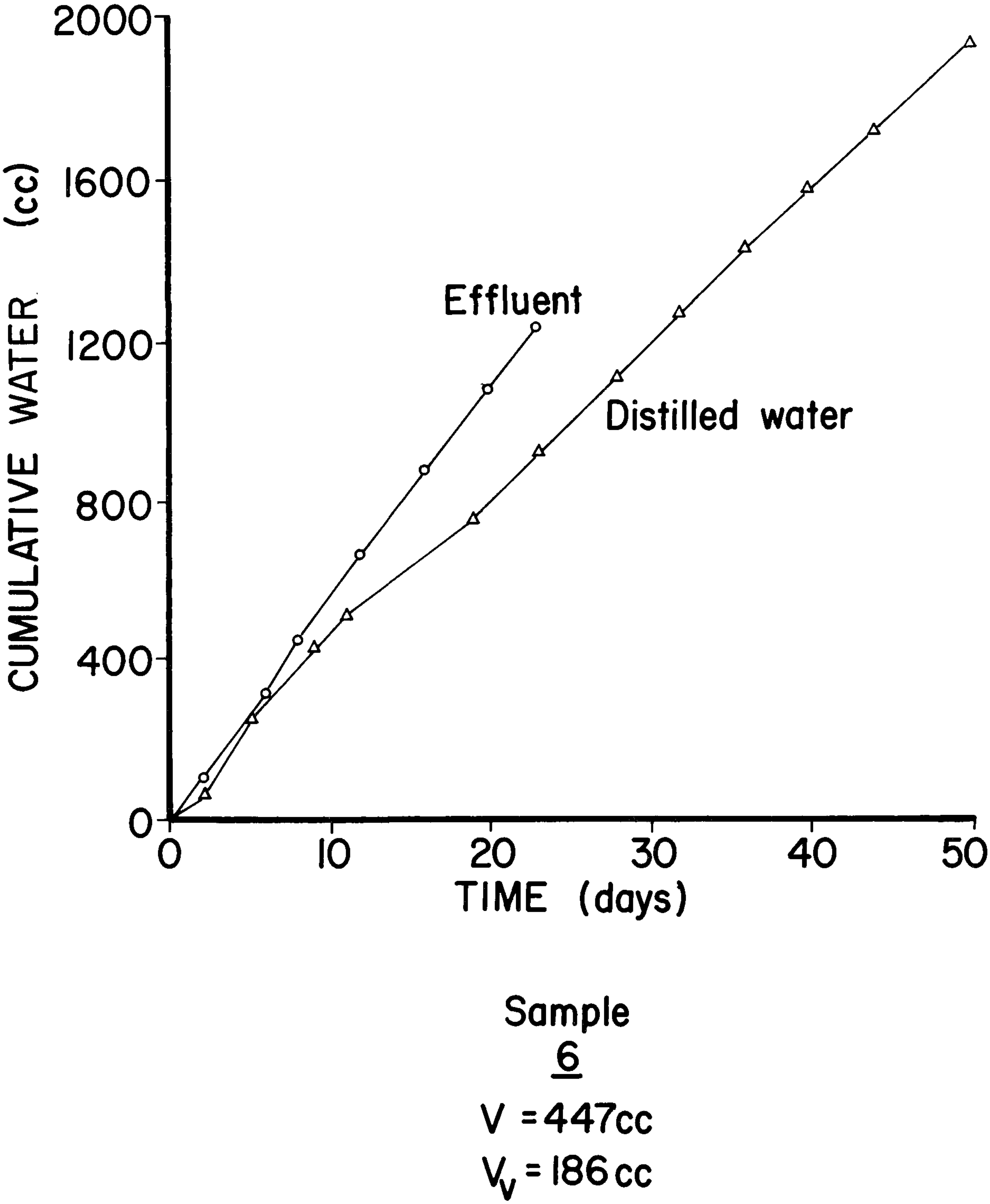


Figure 28. Tooele silt, sample 6C cumulative water versus time.

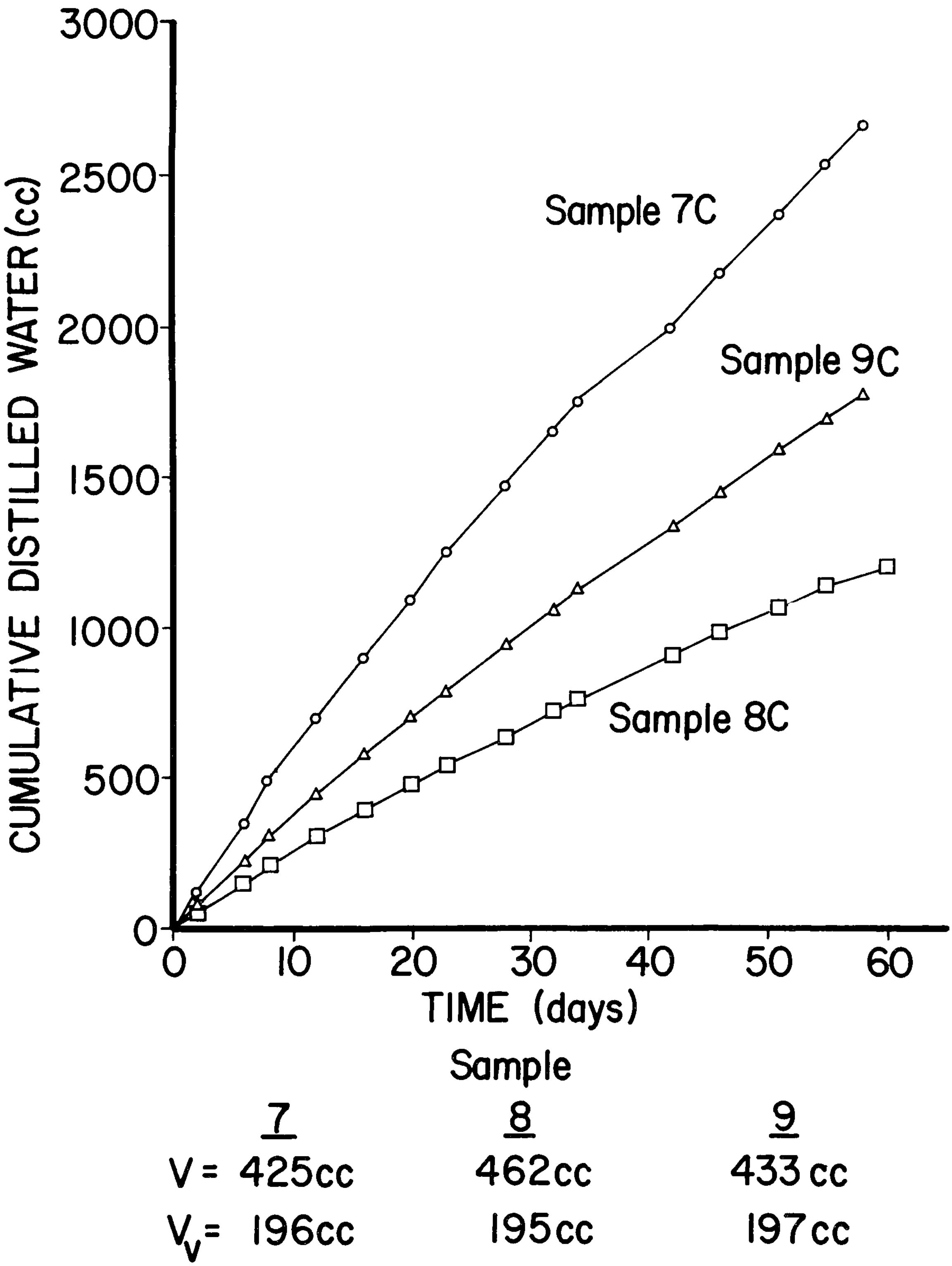
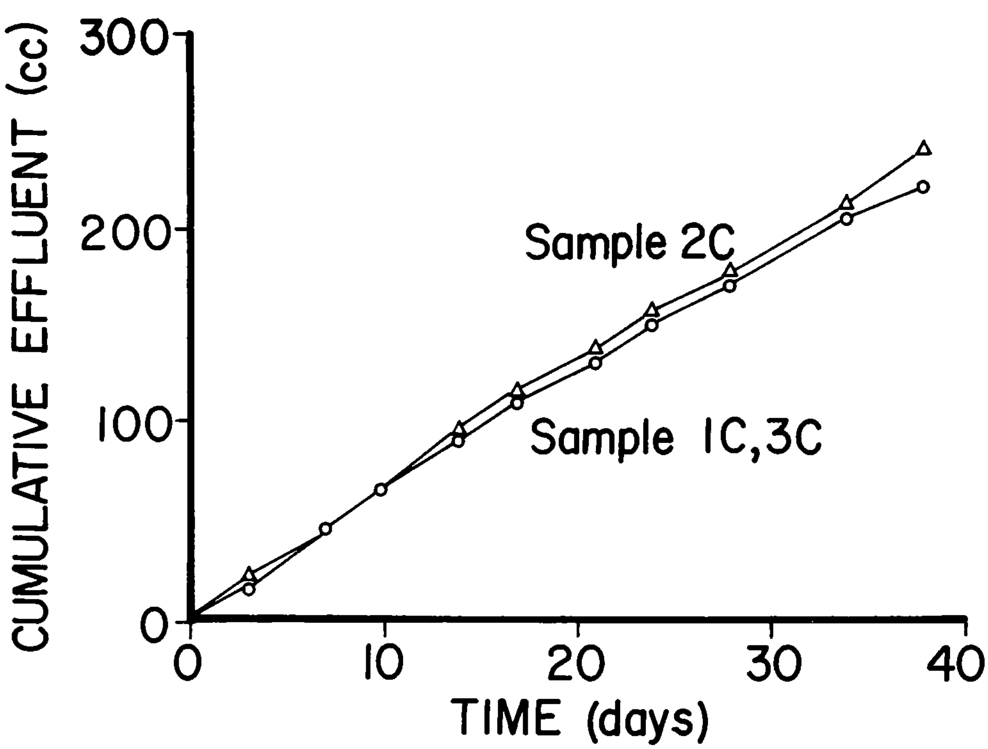


Figure 29. Tooele silt, cumulative distilled water versus time.

The total accumulated volume of distilled water and/or treated sewage effluent applied to each sample of Smithfield clay is shown on Figures 30 through 34. The total volume (V) and volume of the voids (V_v) is also shown on each figure. Samples 1C, 2C and 3C were leached with sewage effluent for 38 days and then tested. Samples 4C, 5C, and 6C were leached with sewage effluent for 34 days and then distilled water for an additional 20 days and then tested. Samples 7C, 8C and 9C were leached with distilled water for 21 days and then tested.



Sample	1	2	3
V	97cc	90cc	85cc
V_v	64cc	59cc	55cc

Figure 30. Smithfield clay cumulative effluent versus time.

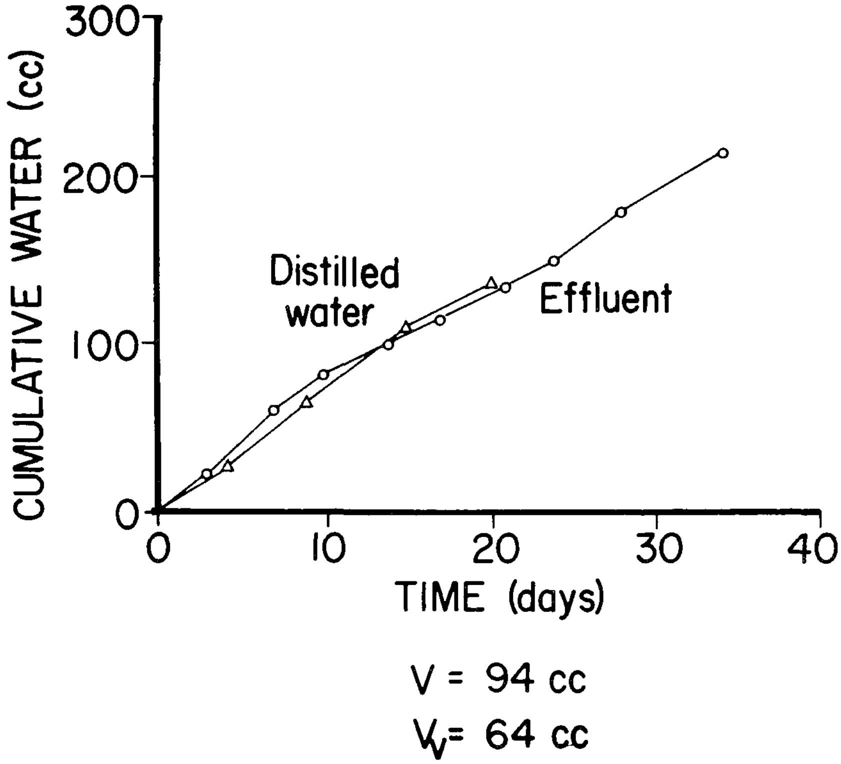


Figure 31. Smithfield clay, sample 4 cumulative water versus time.

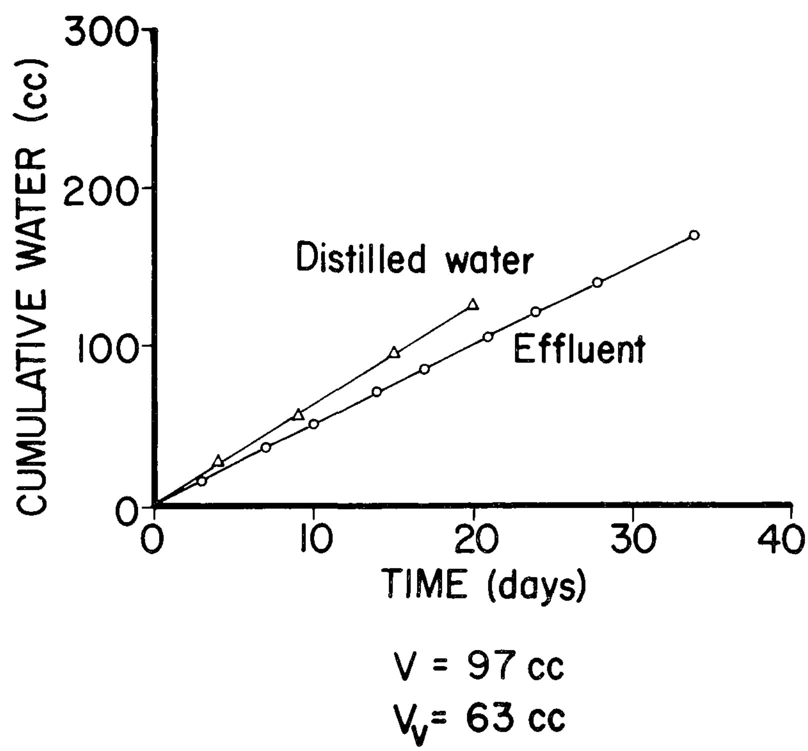
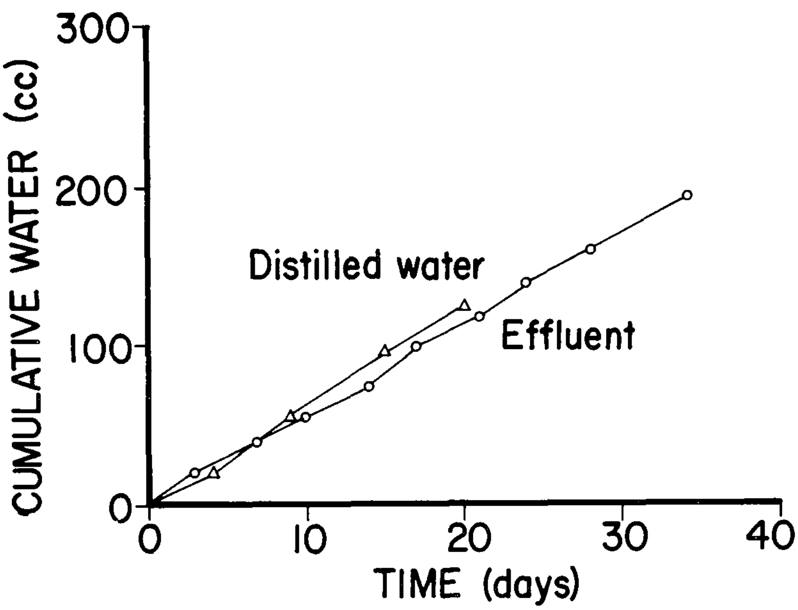


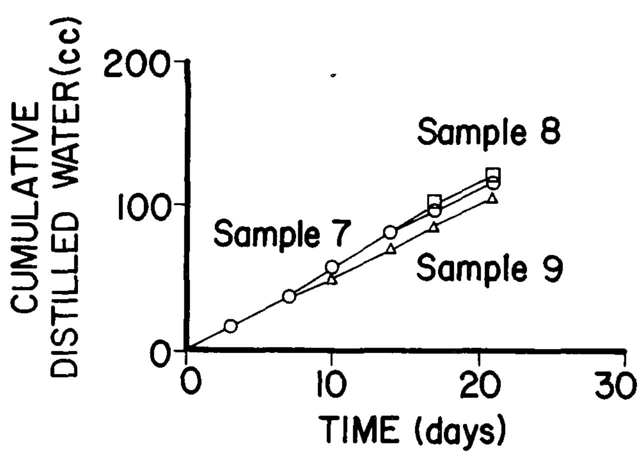
Figure 32. Smithfield clay, sample 5 cumulative water versus time.



$V = 103$ cc

$V_v = 67$ cc

Figure 33. Smithfield clay, sample 6 cumulative water versus time.



	Sample 7	Sample 8	Sample 9
V	112cc	98cc	107cc
V_v	72cc	63cc	69cc

Figure 34. Smithfield clay, cumulative distilled water versus time.

Quality of Water Added to Samples

Effluent was collected from the Preston Sewage Treatment Plant twice a week in the morning by placing a container in the flow as it left the chlorine contact chamber. The chemical composition of the effluent as well as the distilled water is shown in Table 3. Only the chemical analysis for the effluent used on the Tooele silt samples is shown. The results for the Smithfield clay samples are not available; however, the Preston Municipal Sewage Treatment Plant was the sole source of the wastewater effluent and it is reasonable to assume that the effluent applied on the Tooele silt had the same characteristics as that applied on the Smithfield clay.

Dimensions of Samples

The initial heights and the cross-sectional areas of all the samples are shown in Tables 10 and 11. The initial height is the height of the sample after consolidating under the initial 156.1 kPa (22.9 psi) load and after being subjected to the appropriate treatment. As the tables show, the nominal diameter of 101.6 mm (4 in.) varied slightly.

Consolidation Tests

The purpose of consolidation tests is to obtain soil data which can be used to predict the amount and rate of settlement of soil deposits subjected to an increase in intergranular pressure.

It is a well known characteristic of clays that a time lag occurs between the application of a load and the compression of the clay layer. Two factors contribute to this time lag, a hydrodynamic lag and a viscous lag. Although these two phenomena occur simultaneously, the compression is usually divided into primary and secondary phases. Primary consolidation is

TABLE 10. DIMENSIONS OF TOOELE SILT SAMPLES USED IN CONSOLIDATION AND PERMEABILITY TESTS

Sample Number	Initial Height (mm)	Diameter (mm)	Area $(mm)^2$
1	54.9	101.1	3028
2	57.4	101.3	8060
3	52.6	101.3	8060
4	53.1	101.3	8060
5	49.3	101.3	8060
6	55.6	101.3	8060
7	52.8	101.3	8060
8	57.2	101.3	8060
9	54.1	101.1	8028

TABLE 11. DIMENSIONS OF SMITHFIELD CLAY SAMPLES USED IN CONSOLIDATION AND PERMEABILITY TESTS.

Sample Number	Initial Height (mm)	Diameter (mm)	Area $(mm)^2$
1	11.9	101.1	8028
2	11.2	101.3	8060
3	10.4	101.1	8028
4	11.7	101.3	8060
5	11.9	101.3	8060
6	12.4	101.3	8060
7	14.5	101.3	8060
8	11.9	101.3	8060
9	13.2	101.3	8060

attributed to hydrodynamic lag and secondary consolidation to viscous lag. Figure 35 illustrates these two types of consolidation phases. The rate of primary consolidation is generally described by the coefficient of consolidation c_v. Secondary compression has been related to the final slope of the strain versus log of time curve, α_s [*Buisman*, 1936].

A prediction of the magnitude of compression can be obtained from the void ratio versus the log of intergranular pressure curve (or the strain versus the log of intergranular pressure curve). The slope of this curve for normally consolidated soils is the compression index, C_c.

The strain (ε) versus log of effective pressure ($\bar{\sigma}$) relationships were determined from the strains at the end of each load increment. These graphs are shown in Appendix A. The strain was found by dividing the final dial reading for that load increment by the original height of sample. The average curves shown on Figures 36 and 37 were determined by averaging the values of ε at each load for each treatment type and plotting against the log of the applied pressures. The slope of the ε-log $\bar{\sigma}$ curves is defined as C and is related to the compression index, C_c, by $C = C_c/(1 + e_o)$, where e_o is the initial void ratio [*Dunn, et al.*, 1979].

Tables 12 and 13 give the values of C for the different soils and treatments. The C values for the clay samples were slightly curved and, therefore, the higher pressure portions of the ε versus log $\bar{\sigma}$ graphs were averaged to evaluate C for the clay.

The c_v values were determined from the dial reading versus the log of time curves for each loading increment. There are two curve-fitting procedures commonly used to determine c_v, the square-root-of-time fitting method and the logarithm of time fitting method [*Taylor*, 1948]. The logarithm of time method was employed for this study. For the purpose of illustration, a typical graph is shown in Figure 35, and the graphical

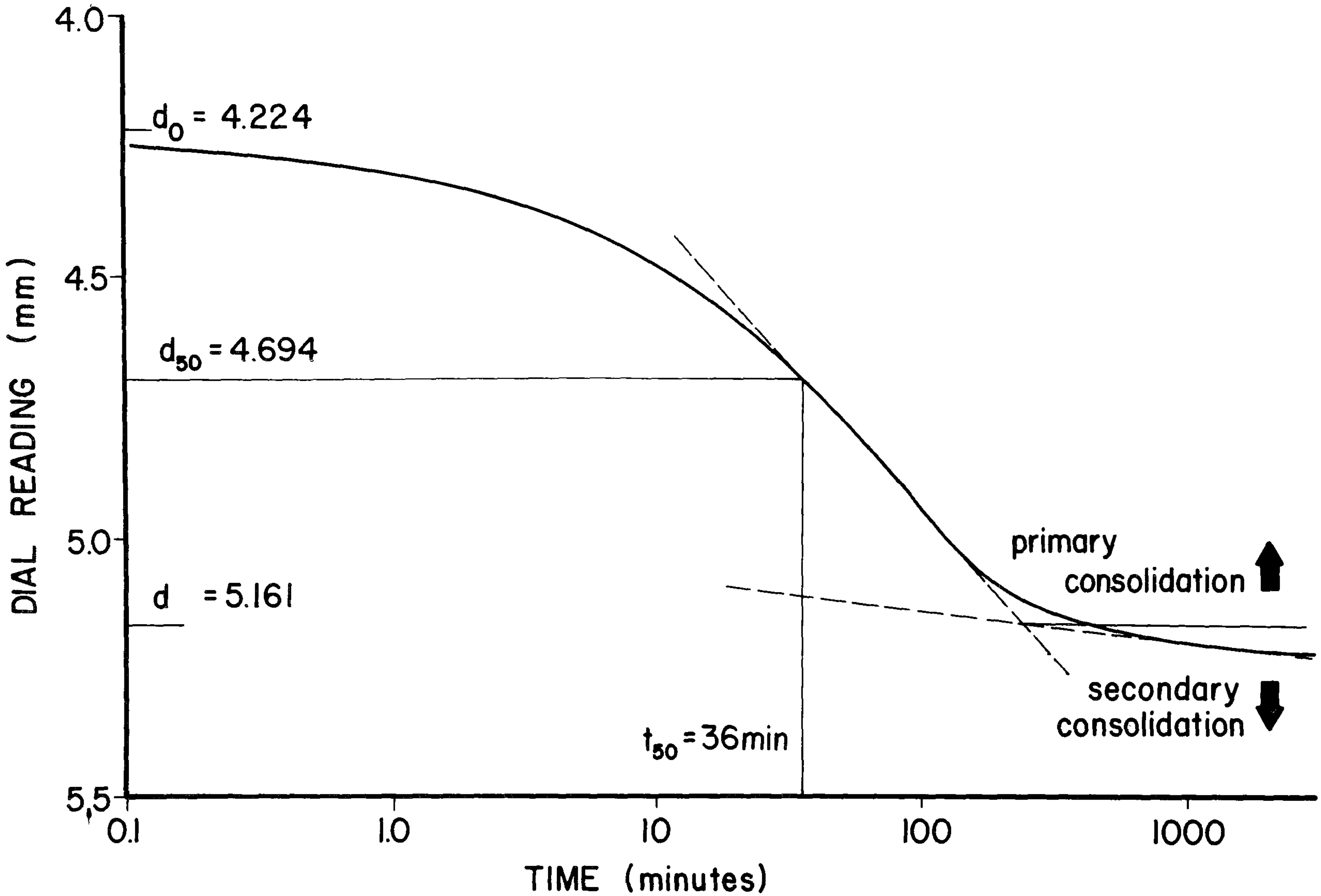


Figure 35. Dial reading versus time. (Smithfield clay sample # 9C)

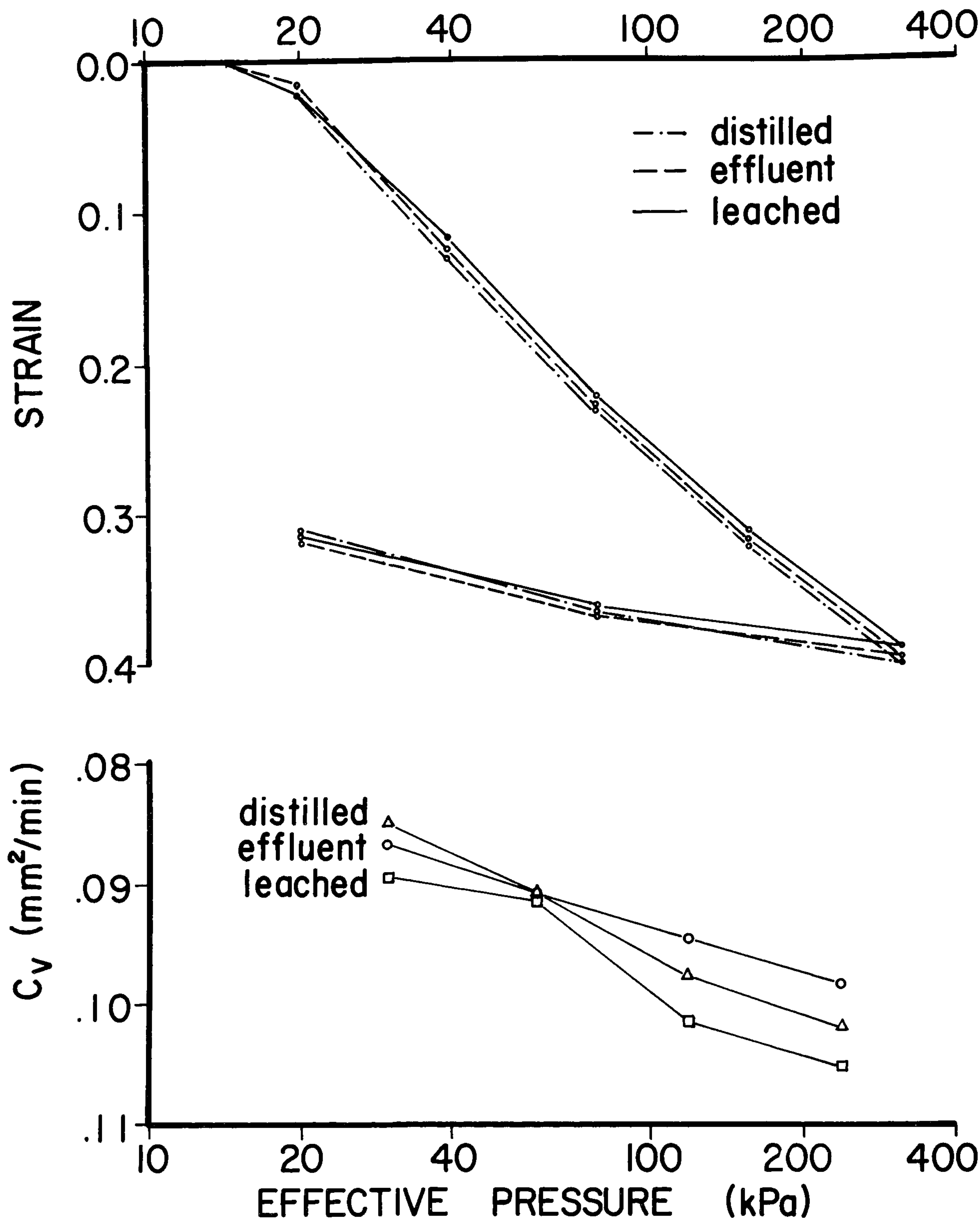


Figure 36. Smithfield clay, average values of strain and c_v versus effective pressure.

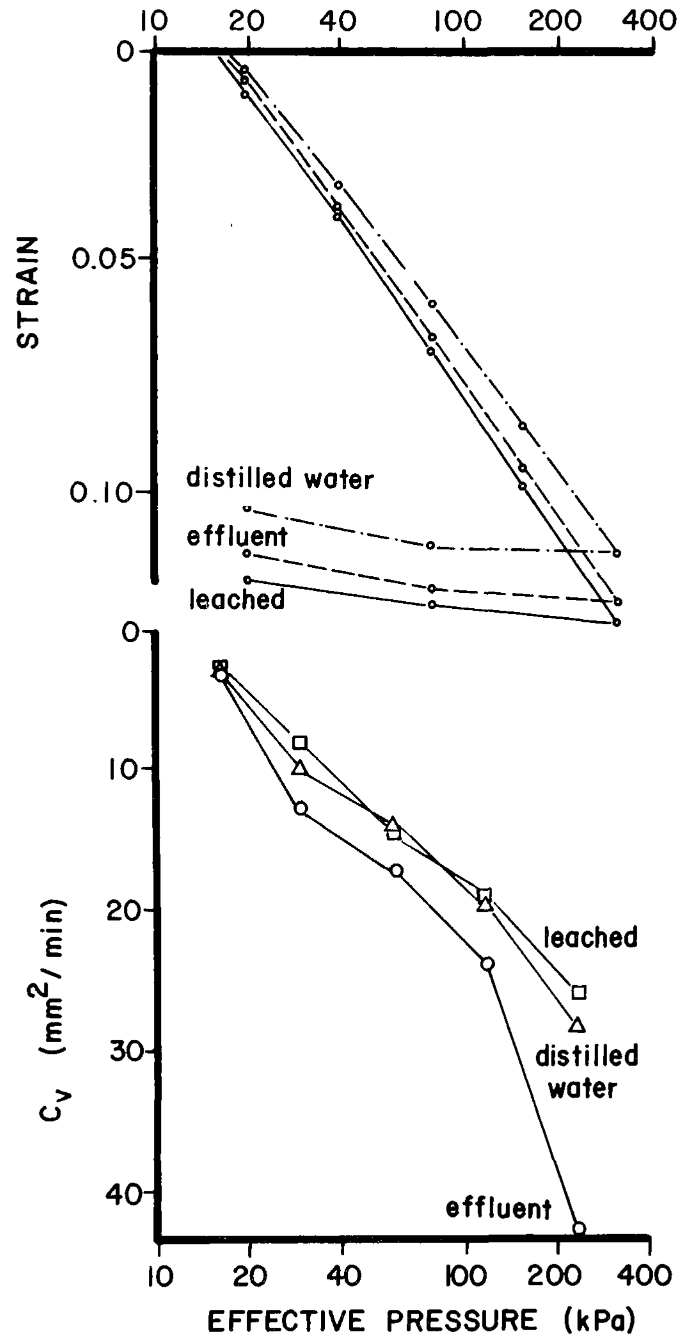


Figure 37. Tooele silt, average values of strain and c_v versus effective pressure.

TABLE 12. SLOPE (C) OF THE STRAIN VS LOG OF EFFECTIVE STRESS CURVE FOR TOOELE SILT

Treatment / Sample	Distilled 7	8	9	Effluent 1	2	3	Leached 4	5	6
C	0.092	0.085	0.085	0.0943	0.0910	0.0955	0.1015	0.0980	0.0940
C_{avg}		0.0873			0.0936			0.0978	
Standard Deviation		0.0040			0.0023			0.0038	

TABLE 13. SLOPE (C) OF THE STRAIN VS LOG OF EFFECTIVE STRESS CURVE FOR SMITHFIELD CLAY

Treatment / Sample	Distilled 7	8	9	Effluent 1	2	3	Leached 4	5	6
C	0.279	0.300	0.279	0.275	0.289	0.283	0.283	0.274	0.279
C_{avg}		0.286			0.282			0.279	
Standard Deviation		0.012			0.010			0.005	

technique for finding c_v by the logarithm of time fitting method is shown. The dial reading representing 100 percent primary consolidation is at the intersection of the straight line portions of the middle and end of the graph. Since the initial shape of the consolidation curve represents a parabola, the dial reading at time zero is found by choosing two times t_a and t_b on the early part of the curve in the ratio $t_a/t_b = 0.25$. The zero time dial reading is located a distance above point a equal to the difference in dial readings between the two. The point representing 50 percent primary consolidation then lies halfway between 0 percent and 100 percent. The coefficient of consolidation, c_v, is calculated by the equation:

$$c_v = \frac{0.197 \, H_{DP}^2}{t_{50}}$$

where t_{50} is the time at 50 percent consolidation and H_{DP} is the length of the longest drainage path of the sample.

The value of c_v varies with each load increment. Appendix B shows c_v plotted against the average pressure of the load increment. Because of the flat shape of the dial readings versus log time curves for the first load increment of the clay samples, c_v values were not determined for that increment. Figures 36 and 37 show the average values of c_v for each soil and type of treatment. Tables 14 and 15 give the c_v values for the average of each pressure increment and the standard deviations from the average.

The mechanism of secondary consolidation is not well defined. However, it is probably associated with an interaction of the double layers associated with an interaction of the double layers associated with each clay particle. *Dunn and Anderson* [1976] explain this secondary consolidation as a viscous resistance to deformation and suggest that it is composed of a volumetric resistance component and a shear resistance component.

The secondary rate of consolidation for this study (α_s) is defined as

$$\alpha_s = \frac{\varepsilon_2 - \varepsilon_1}{\log t_2 - \log t_1}$$

and is the slope of the straight line end portion of the dial reading - log time curve divided by the original height of sample. There is a value of α_s associated with each load increment and these values are given in Tables 16 and 17. The average α_s values for each of the three treatments and soil types are shown in Figures 38 and 39.

Permeability

Permeability is a soil characteristic that is closely associated with the consolidation characteristics of the soil. The higher the permeability, the greater the rate of consolidation. Permeability is expressed by the coefficient of permeability k and is a property of the soil which indicates the ease with which water will flow through the soil. The permeability test results are shown in Tables 18 and 19.

Soil Chemistry Considerations

The proportion of sodium in the adsorbed layer has an important bearing on the structural status of a soil [*Olson and Mesri*, 1970; *Mitchell*, 1976; *Lambe*, 1958; *Mesri and Olson*, 1971]. It is often described in terms of the exchangeable sodium percentage (ESP), defined as

$$\text{ESP} = \frac{\text{Na}^+}{\text{Total Exchange Capacity (CEC)}} \times 100\%$$

Another means of expressing the concentration of Na^+ ions on the adsorbed surface is through the sodium adsorption ratio (SAR) of the soil solution, which is defined as

$$\text{SAR} = \frac{\text{Na}^+}{\left(\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}\right)^{1/2}}$$

TABLE 14. VALUES OF THE COEFFICIENT OF CONSOLIDATION (c_v) FOR SMITHFIELD CLAY IN (mm^2/min)

Treatment Type	Sample	Average Normal Stress (kPa) 29.7	58.9	117.4	233.5
Distilled Water	7	9.03	9.48	10.26	10.07
	8	7.94	8.77	9.16	10.13
	9	8.45	8.77	9.74	10.13
	Avg.	8.45	9.03	9.74	10.13
	Stan. Dev.	0.548	0.410	0.548	0.0372
Effluent	1	8.19	8.58	9.16	9.16
	2	9.10	9.10	9.48	10.52
	3	8.71	9.42	9.61	9.81
	Avg.	8.65	9.03	9.42	9.81
	Stan. Dev.	0.453	0.423	0.233	0.677
Leached	4	8.90	9.68	10.58	11.23
	5	8.45	8.77	9.74	9.29
	6	9.29	8.90	10.07	10.97
	Avg.	8.90	9.10	10.13	10.52
	Stan. Dev.	0.420	0.488	0.423	1.05

TABLE 15. VALUES OF THE COEFFICIENT OF CONSOLIDATION (c_v) FOR TOOELE SILT IN (mm^2/min)

Treatment Type	Sample	Average Normal Stress (kPa) 16.3	29.5	58.7	117.4	233.8
Distilled Water	7	3.03	10.00	15.36	19.94	33.03
	8	--	9.29	12.39	17.27	25.16
	9	3.42	9.42	12.52	19.16	24.45
	Avg.	3.23	9.55	13.42	18.78	27.55
	Stan. Dev.	0.271	0.381	1.678	1.394	4.762
Effluent	1	2.84	10.84	14.77	21.55	32.65
	2	4.13	14.13	18.45	23.94	54.52
	3	2.39	11.74	16.97	23.87	37.10
	Avg.	3.10	12.26	16.71	23.10	41.42
	Stan. Dev.	0.903	1.697	1.845	1.355	11.55
Leached	4	1.74	6.91	11.16	15.10	20.58
	5	1.94	8.13	14.52	15.27	22.90
	6	3.81	8.58	16.26	25.10	32.19
	Avg.	2.52	7.87	14.00	18.45	25.28
	Stan. Dev.	1.136	0.865	2.587	5.736	6.181

TABLE 16. VALUES OF α_s FOR SMITHFIELD CLAY IN (10^{-3})

Treatment Type	Sample	Total Normal Stress (kPa) 39.5	78.6	156.2	311.4
Distilled Water	7	13.2	9.0	6.4	3.7
	8	14.7	9.2	7.1	4.2
	9	16.8	9.2	7.3	4.4
	Avg.	14.9	9.1	6.9	4.1
	Stan. Dev.	1.81	0.12	0.47	0.36
Effluent	1	15.1	10.5	6.3	3.6
	2	14.7	10.4	6.6	4.1
	3	12.7	7.2	5.8	2.6
	Avg.	14.2	9.4	6.2	3.43
	Stan. Dev.	1.29	1.88	0.40	0.76
Leached	4	13.0	8.0	6.5	7.0
	5	13.8	7.7	6.6	2.6
	6	15.4	7.4	6.4	3.8
	Avg.	14.1	7.7	6.5	4.5
	Stan. Dev.	1.22	0.30	0.10	2.27

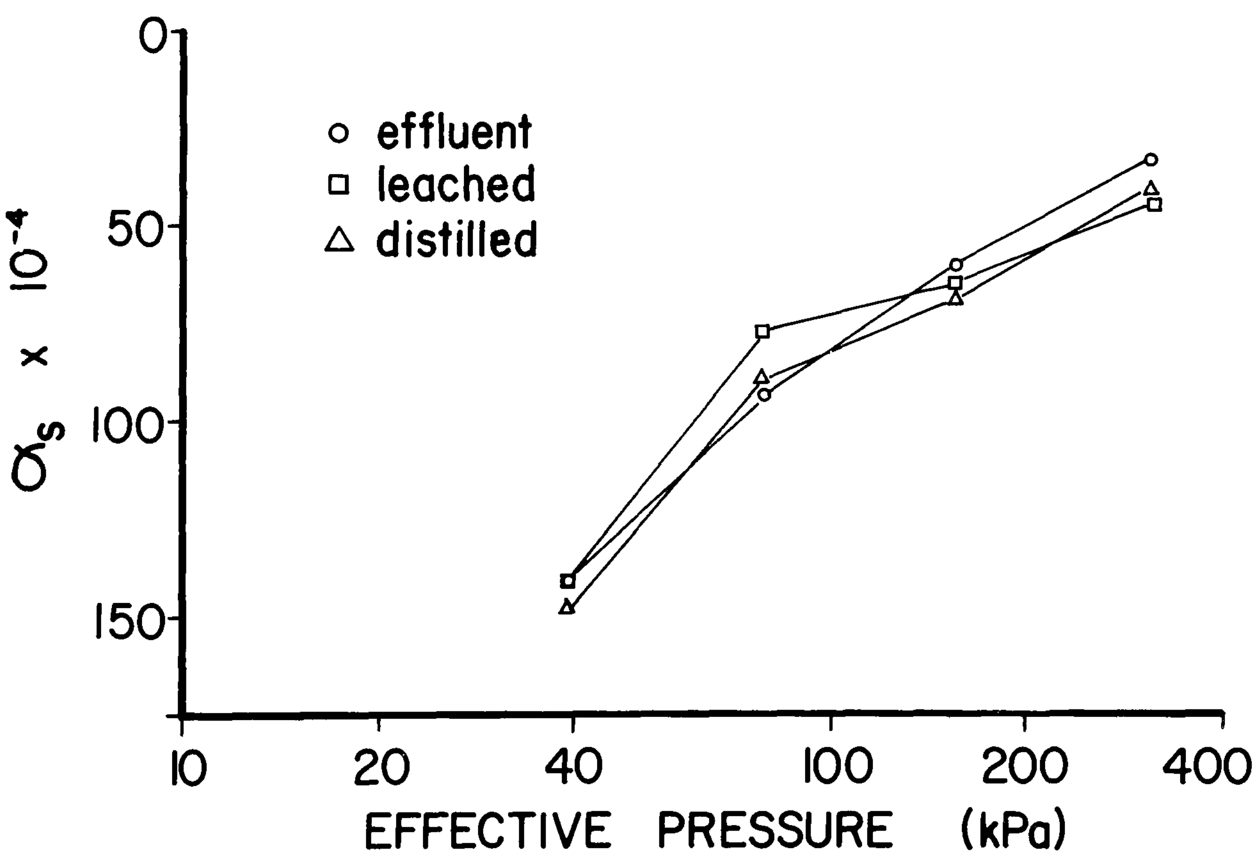


Figure 38. α_s versus effective pressure for Smithfield clay samples.

TABLE 17. VALUES OF α_s FOR TOOELE SILT IN (10^{-3})

Treatment Type	Sample	Total Normal Stress (kPa) 19.6	29.3	78.1	155.8	311.8
	7	3.02	2.88	2.64	1.92	2.98
	8	2.05	2.67	2.22	1.78	2.36
Distilled Water	9	2.73	3.01	2.82	2.26	2.59
	Avg.	2.60	2.85	2.56	1.99	2.64
	Stan. Dev.	0.497	0.171	0.307	0.246	0.313
	1	3.56	2.08	2.54	2.45	2.54
	2	3.53	1.94	2.56	1.77	2.65
Effluent	3	3.72	2.17	2.66	2.80	2.75
	Avg.	3.55	2.06	2.59	2.34	2.65
	Stan. Dev.	0.102	0.120	0.064	0.523	0.105
	4	4.01	2.72	3.01	2.48	2.48
	5	3.20	2.73	2.47	2.73	3.09
Leached	6	2.88	2.06	2.93	2.70	2.51
	Avg.	3.36	2.50	2.80	2.64	2.69
	Stan. Dev.	0.582	0.383	0.291	0.137	0.343

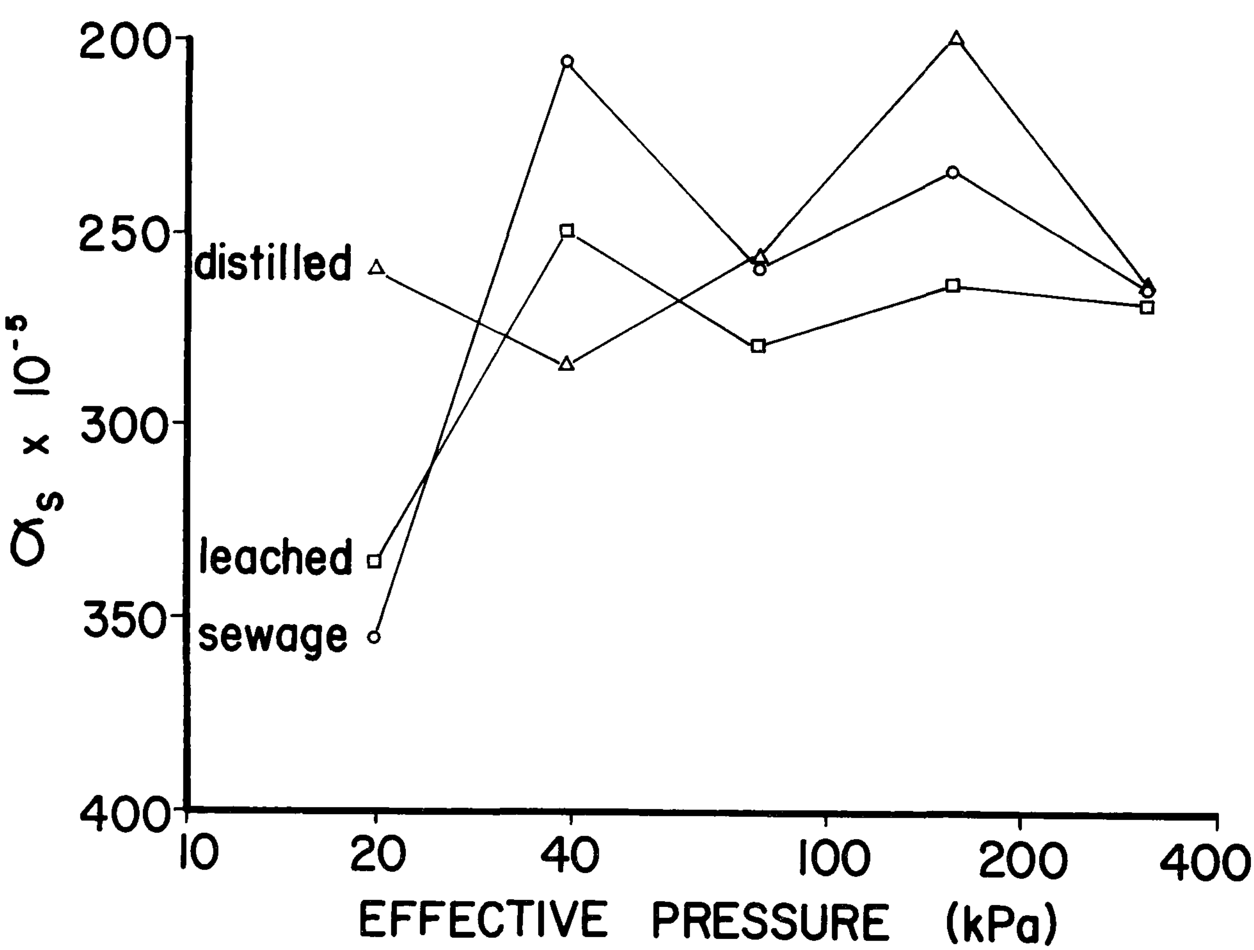


Figure 39. α_s versus effective pressure for Tooele silt samples.

TABLE 18. PERMEABILITY (k) FOR TOOELE SILT

Sample Number	Leachant	k (cm/min × 10^{-6})	Average k (cm/min × 10^{-6})
1	Effluent	6.58	
2	Effluent	7.22	6.74
3	Effluent	6.42	
4	Effluent/Distilled Water	4.55	
5	Effluent/Distilled Water	5.43	5.91
6	Effluent/Distilled Water	7.75	
7	Distilled Water	7.69	
8	Distilled Water	3.92	5.74
9	Distilled Water	5.60	

TABLE 19. PERMEABILITY (k) FOR SMITHFIELD CLAY

Sample Number	Leachant	k (cm/min × 10^{-7})	Average k (cm/min × 10^{-7})
4	Effluent/Distilled Water	1.89	
5	Effluent/Distilled Water	1.88	1.91
6	Effluent/Distilled Water	1.96	
7	Distilled Water	2.17	
8	Distilled Water	1.99	2.35
9	Distilled Water	2.89	

For the results of the chemical analysis of the soil, it was possible to calculate the ESP and SAR values for all the samples. These results are shown in Table 20. The amount of extractable calcium shown includes calcium from carbonates since lime was present in the samples and the ammonium acetate extraction procedure employed brings some of that lime into solution resulting in increased extractable Ca^{++} values. For this reason, the SAR values were calculated from only the water soluble ions and, therefore, are not as good an indication of the soil's actual chemical state as are the ESP values.

When the exchangeable sodium percentage, ESP, of a soil is increased to about 15 percent or greater, a breakdown in the physical structure of the soil may occur. In the presence of a high salt concentration in the soil, the sodic hazard is minimized and the infiltration and permeability of the soil usually remains near its highest values in spite of the increase in ESP. The problem arises when the salt is removed, *e.g.*, by reclamation, and the high exchangeable sodium causes a breakdown of the physical condition of

TABLE 20. RESULTS OF SOIL CHEMISTRY TESTS

		Soluble H_2O-Soluble meq/100 g					Extractable NH_4OA_c meq/100 g					
Treatment	Tooele Silt Sample #	Ca	Mg	Na	K	SAR	Ca	Mg	Na	K	ESP	CEC
Effluent	#1	.1	.1	1	0	.32	34	3.7	.6	.6	3	15.3
Effluent	#3	.1	.1	.1	0	.32	41	3.7	.5	.6	3	12.9
Leached	#5	.1	0	0	0	0	37	3.6	.4	.6	3	13.6
Leached	#6	.1	0	0	0	0	39	3.4	.3	.5	2	15.7
Distilled Water	#7	.1	0	0	0	0	36	2.9	.3	.5	2	14.0
Distilled Water	#9	.1	0	0	0	0	38	3.4	.3	.6	2	17.3
	Smithfield Clay Sample #											
Effluent	#2	5.9	1.3	5.8	.5	3.06	46.8	6.5	11.7	1.4	24.6	24.0
Effluent	#3	3.5	.9	5.3	.3	3.57	40.7	6.1	11.4	1.4	28.1	21.7
Leached	#5	5.5	1.6	7.4	.6	3.93	49.0	6.6	13.2	1.5	25.3	22.9
Leached	#6	3.5	.9	5.3	.3	3.57	29.6	5.9	9.7	1.4	21.0	21.0
Distilled Water	#8	5.4	1.2	9.2	.7	5.06	47.2	6.4	12.8	1.5	15.5	23.3
Distilled Water	#9	1.9	.4	4.8	.2	4.48	34.3	5.8	11.6	1.5	28.8	23.6
None	#10	.4	.3	6.7	.2	11.33	44.1	6.5	19.2	1.6	54.8	22.8

the soil. This breakdown in the soil structure is the result of the swelling of clays and eventual dispersion of the soil fraction. The effect of the swelling and dispersion is to effectively plug the conducting pore system of the soil matrix by lodged particles, thereby reducing the hydraulic conductivity to a very low level. The mechanism by which the sodium ion promotes swelling-dispersion is based on the repulsion of the clay particles when their sodium-ion-dominated diffuse double layers interact. The presence of salts with higher valence tends to compress the double layer, to make it more dense, thereby reducing the repulsion between clay particles [*Jurinak*, 1976]. The physical condition of all soils is not affected equally as the ESP increases. Montmorillonite, however, which is a highly expansive clay, is highly sensitive to the ESP change. Shear strength, permeability and consolidation may all be adversely affected by the high ESP of a montmorillonite clay.

<u>Discussion of Consolidation and Permeability Test Results</u>

General --

The problem was to decide whether or not the average values of the consolidation parameters were statistically different between the three types of treatment. Towards this end an analysis of variance study was done on the C and c_v values for each type of soil. A computer program from the computer science department at Utah State University was utilized. It may be treated as a problem of testing the Null hypothesis that all the mean values for each parameter were equal. Testing for a difference in the C values was relatively simple. If a difference was found in the type of treatment, a least significant difference analysis was performed to determine where the difference occurred. However, the c_v values varied not only with the type of treatment but also with the effective stress. To adequately analyze the c_v values, three differences in c_v were allowed for:

- Difference between treatments
- Difference between effective stresses
- Difference between treatments with a common effective stress.

As with the C values, once a difference in c_v was determined to be significant, a least difference analysis was performed to determine where the difference occurred.

Tooele silt --

For the Null hypothesis to be rejected and the differences to be significantly different at the α level, the calculated F value must exceed the tabular α value. The analysis of variance results, at the 0.10 level, show that there is a significant difference between the average values of C corresponding to the three treatments. Furthermore, the least significant difference test (α = 0.10) indicates that this difference was between treatment 1 (distilled water) and treatment 2 (effluent) as well as between treatment 1 and treatment 3 (leached). Thus, it can be said with a 90 percent degree of confidence that the application of effluent increased the compressibility of the silt. However, since there was no significant difference between the leached values of C and the effluent treated C values, this increase in compressibility was not reversible.

In like manner, the analysis of variance test, at the 0.10 significance level for the c_v values indicates there was a significant difference between treatments as well as a significant difference between treatments with a common stress. The least significant difference test (α = 0.10) shows that there was a significant difference between treatment 2 (effluent) c_v values and the other two treatment values of c_v. An additional least significant difference test (α = 0.10) indicates that this difference is significant only at the 2806 kPa (407 psi) effective stress level. Therefore, it can be said with a 90 percent degree of confidence that at the average effective stress of 2806 kPa (407 psi) there was an increase in the c_v value. Furthermore, since the average c_v values for the effluent were significantly different from the average values of the leached samples, it can also be said with a 90 percent degree of confidence that this increase in c_v from application of the effluent was reversible.

As would be expected, the results also show that the average values of c_v were significantly different between different average effective stresses.

This increase in rate and compressibility of the silt with application of the effluent can probably be attributed to biological conditions rather than chemical changes in the soil. Table 20 shows that the ESP values for the silt were very low. One possible explanation for the increased compressibility would be the formation of slimes on the silt particle surfaces which would reduce the inter-particle friction and thus help make the particles slip past each other. However, the high quality of the effluent may make this an unreasonable hypothesis.

Figure 39 shows that the rate of secondary consolidation for the Tooele silt appears to be independent of both consolidation pressures as well as the type of treatment.

The Tooele silt showed an increase in permeability with application of sewage in Table 18. This does not agree with the results of past researchers but is, however, consistent with the consolidation test results of this study. Since the ESP values for the silt were all so low, this increase in permeability was probably not due to a decrease in the double layer thickness.

Smithfield clay--

The analysis of variance test applied to the Smithfield clay shows that there was no significant difference between any of the mean C values or mean c_v values. The consolidation properties of the Smithfield clay samples were not affected by the effluent. The only significant difference shown was the difference in c_v as the effective stress increased.

Table 20 shows that the clay samples, sample 10C in particular, have high ESP values. Sample 10C was a control sample. It was a dry Smithfield clay that had not been subjected to any treatment. Its high ESP of 54.8

percent indicates that the Smithfield clay samples were in a potentially highly dispersable state prior to treatment and upon remolding (*i.e.*, mixing with distilled water) became highly dispersed. The ESP values for samples 8C and 9C which were leached with distilled water are both well below that of sample 10C. It would seem logical to assume that the ESP values for samples 8C and 9C would have been the same as the ESP for sample 10C and for all the samples prior to treatment. Furthermore, since all the ESP values were approximately the same and all lower than sample 10C, this would indicate that the application of either effluent or distilled water lowers the ESP of the soil from its original high value resulting in a more permeable and less compressible soil. The uniformity of the ESP values was consistent with the uniformity of the C and c_v values.

The secondary consolidation rate for the Smithfield clay showed a definite decrease as the consolidation pressure increased as evidenced by Figure 38. The type of treatment, however, did not appear to have any effect. This observed decrease in rate with an increase in pressure was consistent with findings by *Shiffman, et al.* [1964] on an investigation of a Vicksburg Buckshot clay.

As has been pointed out, the Smithfield clay was initially a potentially highly dispersable clay shown by the ESP value of sample 10C. Upon application of either type treatment, the ESP values for all the samples were reduced and thus made more permeable due to the exchange of sodium ions which resulted in a thinner double layer which creates more free pore water. The permeability coefficient k for both the leached and distilled water treated samples were fairly close as would be expected since the ESP values for the two treatments were the same.

It is possible that the ESP values reported for the different treatments had not reached equilibrium and some or all values might have decreased even more from the original values had they been leached for a longer period of time. This may have resulted in arriving at different equilibrium points for the different treatments.

Permeability tests were not performed on the effluent treated clay samples since it was feared that the distilled water used for the permeability test would alter the chemical state of the treated soil.

Example Problem

The following example problem is included as a means of illustrating how the differences in the consolidation characteristics of the Tooele silt would affect the settlement of an idealized soil profile of Tooele silt such as that shown in Figure 40.

Figure 41 shows the amount of expected settlement plotted against time for the Tooele silt saturated with distilled water and with the wastewater effluent. The computations were based on values of C and c_v obtained from Tables 12 and 15. The ultimate settlement for a soil profile that had been leached with treated sewage would be approximately 68.6 cm (27 in.) with

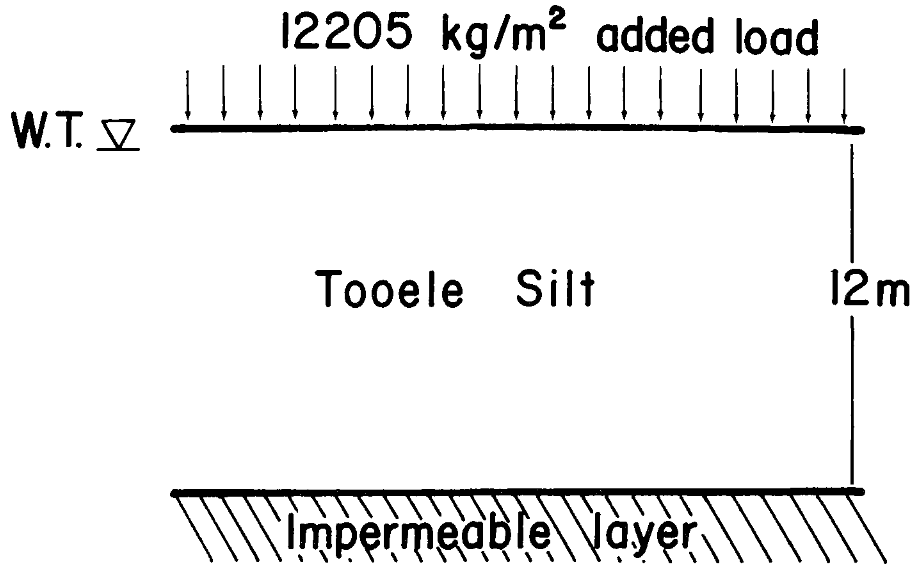


Figure 40. Hypothetical soil profile for example consolidation problem.

90 percent consolidation occurring in 2560 days. The ultimate settlement for a soil profile that had been leached with distilled water would be approximately 50.8 cm (20 in.) with 90 percent consolidation occurring in 3667 days.

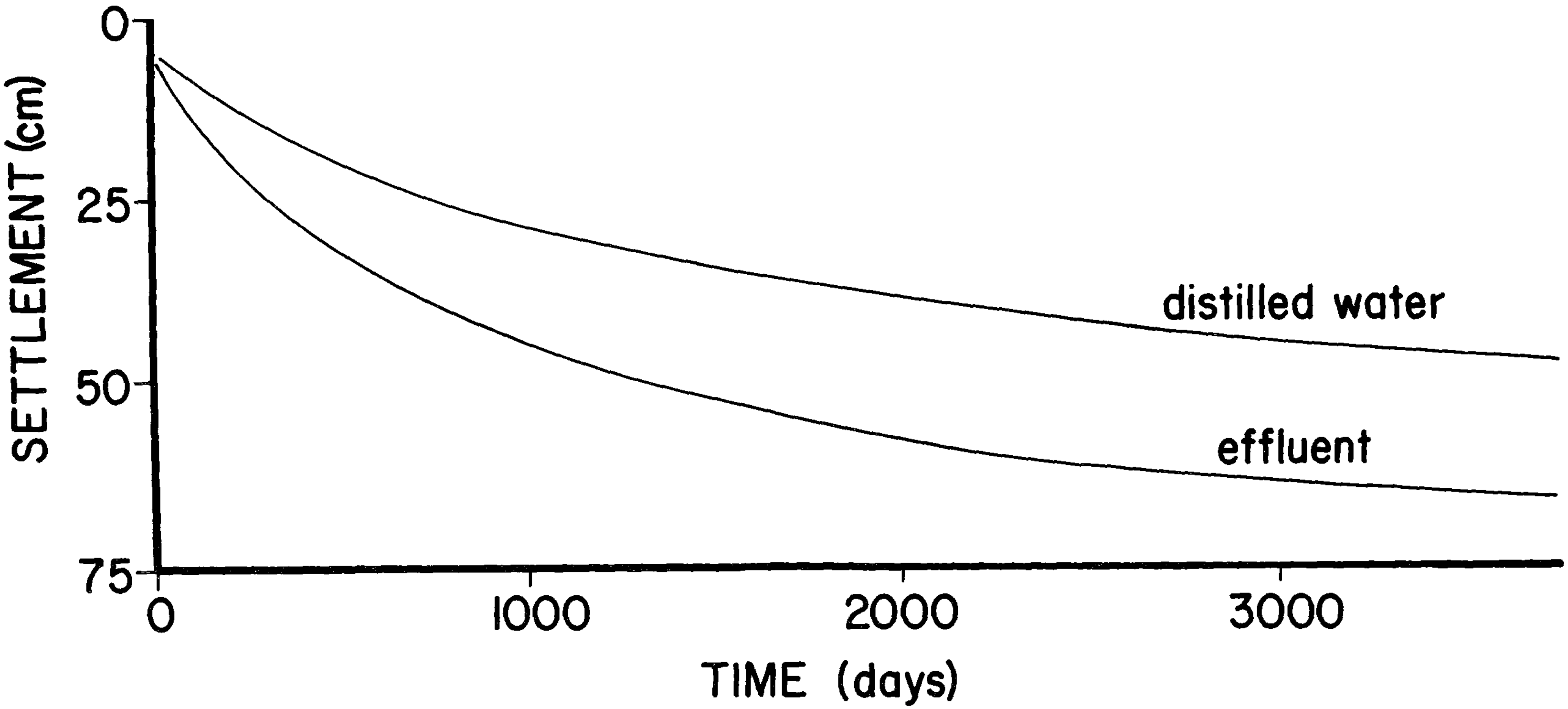


Figure 41. Settlement versus time -- example problem.

REFERENCES

Allison, L. E. 1947. Effect of microorganisms on permeability of soil under prolonged submergence. *Soil Science*, 63:439-450.

Andersland, Orlando B., and P. John Matthew. 1973. Consolidation of high ash papermill sludges. *Journal of the Soil Mechanics and Foundations Division, ASCE*, Proc. Paper 9713. 99(SM5):365-374.

APHA, AWWA, WPCF. 1975. *Standard Methods for the Examination of Water and Wastewater*. 14th Ed. Washington, D.C. 1193 p.

Aziz, M. M., A. Alvin Bishop, and I. S. Dunn. 1966. Influence of exchangeable ions on the stability of drain banks. *Transactions of the American Society of Agricultural Engineers*. 9(6):788-792.

Buisman, A. S. K. 1936. Results of long duration settlement tests. *Proceedings of 1st International Conference on Soil Mechanics and Foundation Engineering*. 1:103-106.

Day, A. D., J. L. Stroehlein and T. C. Tucker. 1972. Effects of treatment plant effluent on soil properties. *Journal of Water Pollution Control Federation*. 44(3):372-375.

de Vries, J. 1972. Soil filtration of wastewater effluent and the mechanism of pore clogging. *Journal of Water Pollution Control Federation*. 44(4):565-573.

Dunn, I. S., and L. R. Anderson. 1976. *Viscous resistance during consolidation*. Unpublished Report on a University Research Project, Department of Civil and Environmental Engineering, Utah State University.

Dunn, I. S., L. R. Anderson, and F. W. Kiefer. 1979. *Fundamentals of Geotechnical Analysis*. In press. John Wiley and Sons.

Jurinak, J. J. 1976. Soil science, 619 lecture notes. Utah State University

Lambe, T. William. 1958. The structure of compacted clay. *Journal of the Soil Mechanics and Foundations Division, ASCE*, Proc. Paper 1654. 84 (SM2):1-34.

Lance, J. C., and F. D. Whisler. 1972. Nitrogen balance in soil columns and intermittently flooded with secondary sewage effluent. *Journal of Environmental Quality*. 1(2):180-186.

Mesri, G., and R. E. Olson. 1971. Consolidation characteristics of montmorillonite. *Geotechnique*, 21(4):341-352.

Mitchell, James K. 1976. *Fundamentals of soil behavior*. John Wiley and Sons, Inc., New York. 422 p.

Olson, R. E., and G. Mesri. 1970. Mechanisms controlling the compressibility of clay. *Journal of the Soil Mechanics and Foundation Division, ASCE*, Proc. Paper 7649. 96(SM6):1863-1878.

Rice, Robert C. 1974. Soil clogging during infiltration of secondary effluent. *Journal of Water Pollution Control Federation*. 46(4):708-716.

Schiffman, R. L., C. C. Ladd, and A. T-F. Chen. 1964. *The secondary consolidation of clay*. International Union of Theoretical and Applied Mechanics, Symposium of Rheology and Soil Mechanics.

Shainberg, I., and A. Caiserman. 1971. Studies on Na/Ca montmorillonite systems 2. The hydraulic conductivity. *Soil Science*. 3(5):276-281.

Taylor, D. W. 1948. *Fundamentals of soil mechanics*. John Wiley and Sonc, Inc., New York. 700 p.

U. S. Government. 1973. Federal secondary treatment standards. Federal Register. 38(159):22298. U. S. Government Printing Office, Washington, D.C.

APPENDIX A

STRAIN VERSUS EFFECTIVE PRESSURE

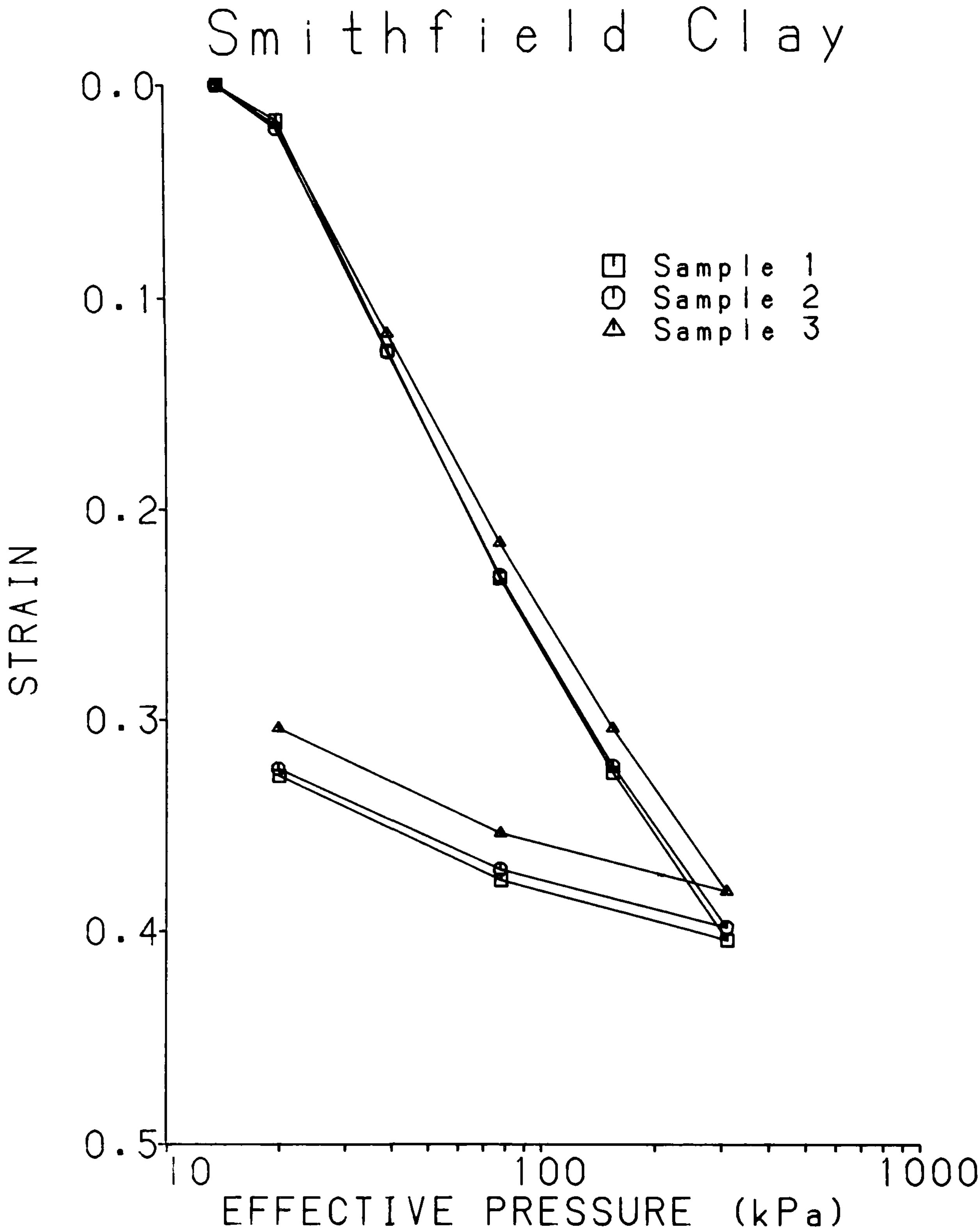


Figure A-1. Smithfield clay, strain versus effective pressure, effluent.

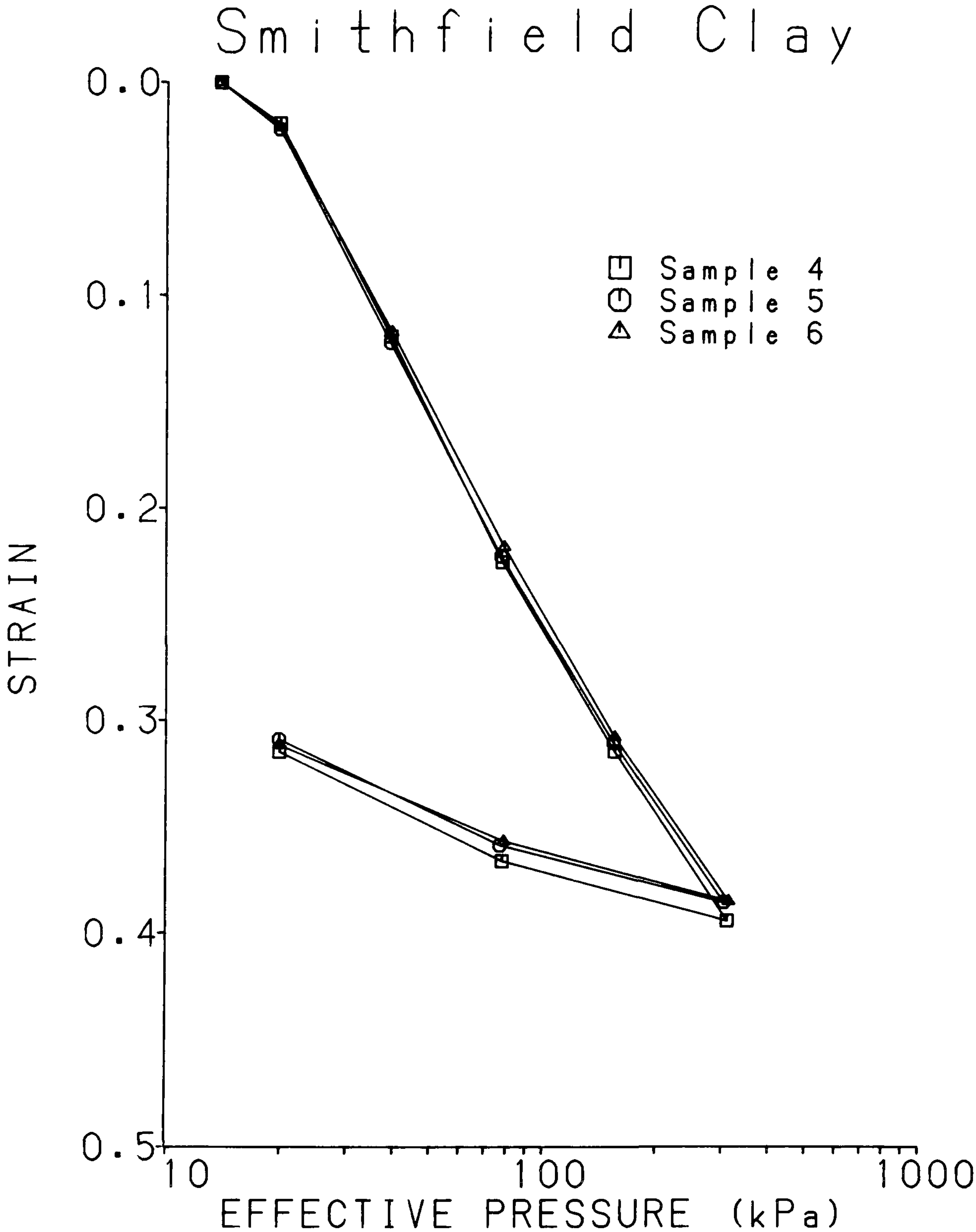


Figure A-2. Smithfield clay, strain versus effective pressure, leached.

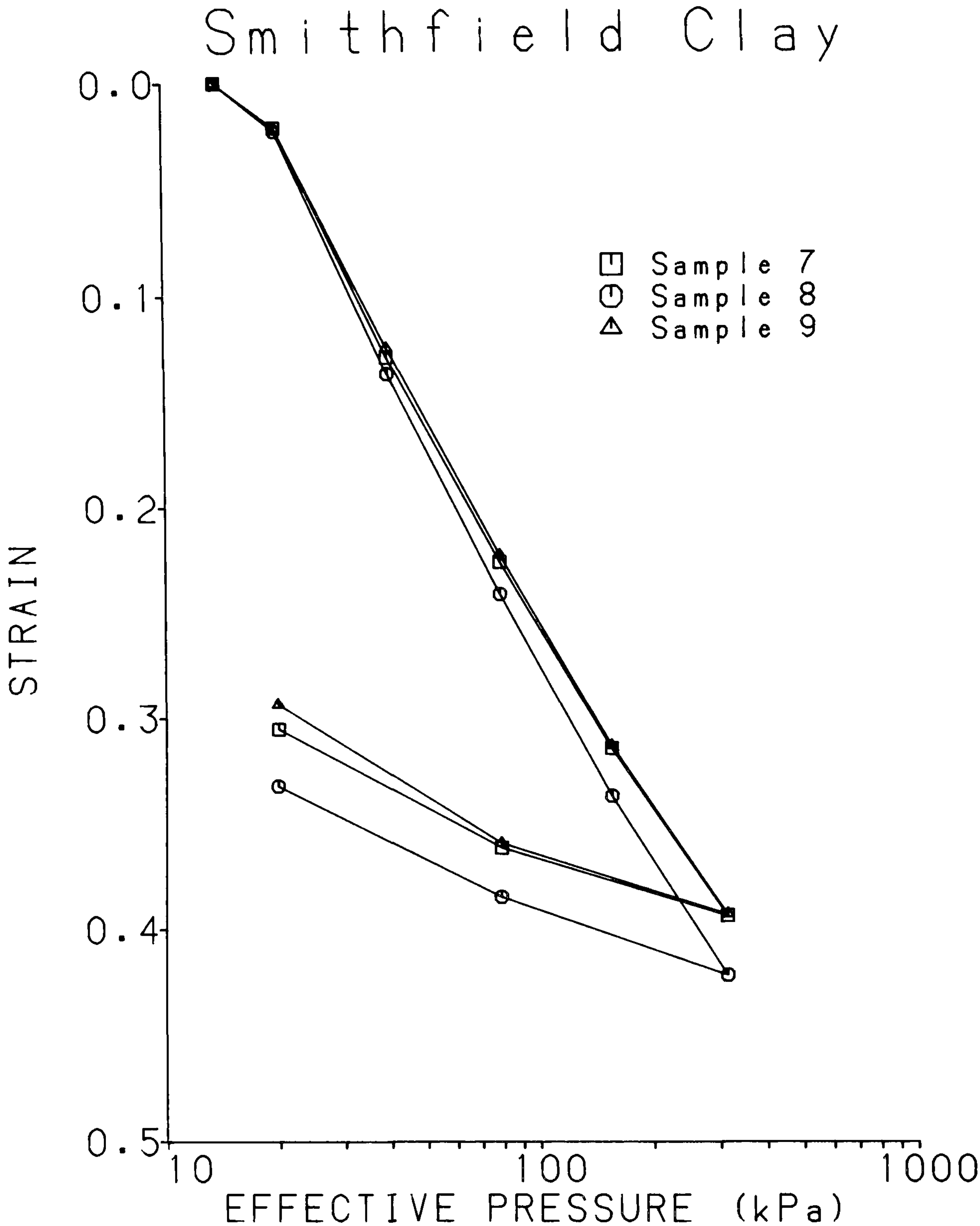


Figure A-3. Smithfield clay, strain versus effective pressure, distilled water.

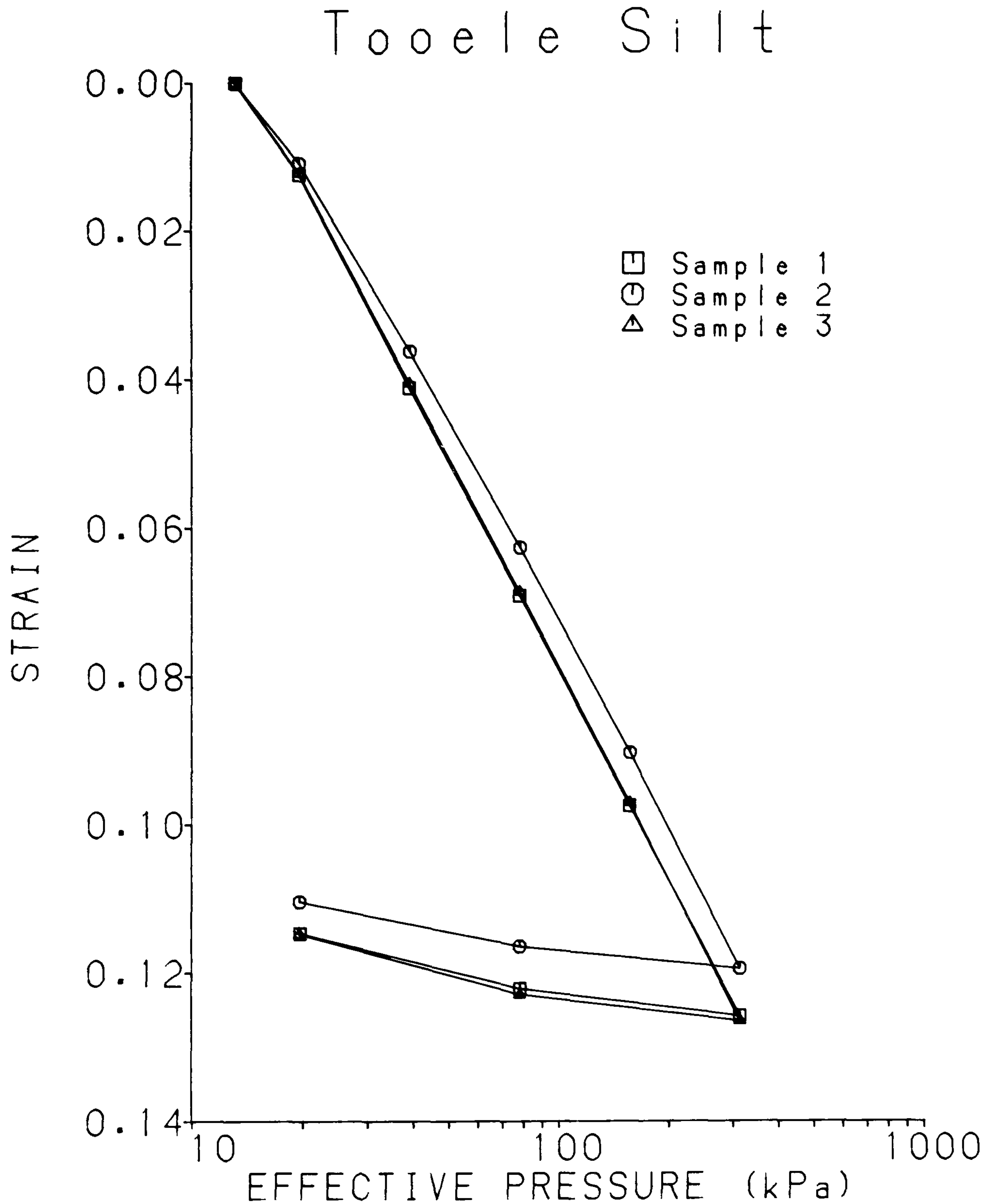


Figure A-4. Tooele silt, strain versus effective pressure, effluent.

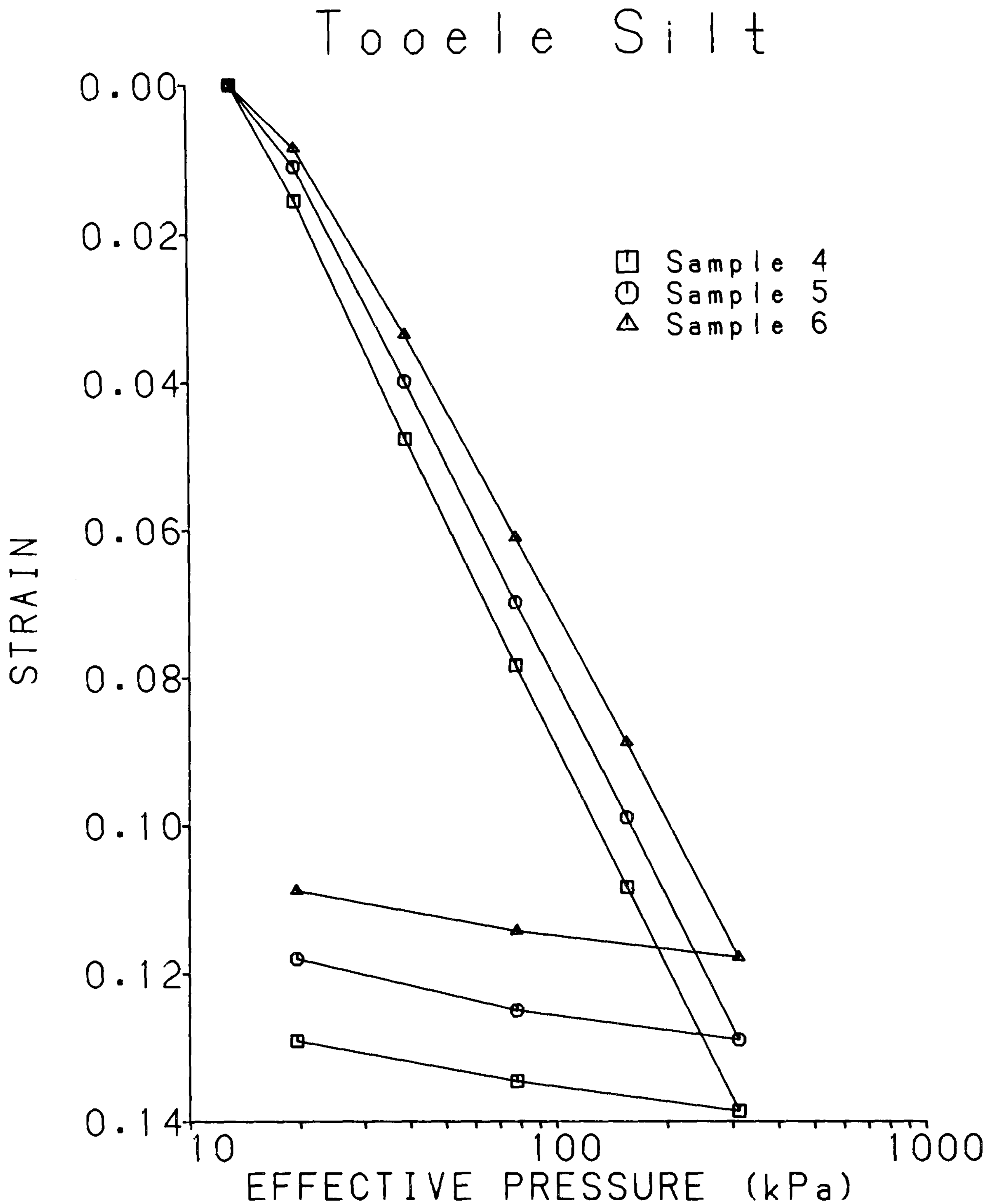


Figure A-5. Tooele silt, strain versus effective pressure, leached.

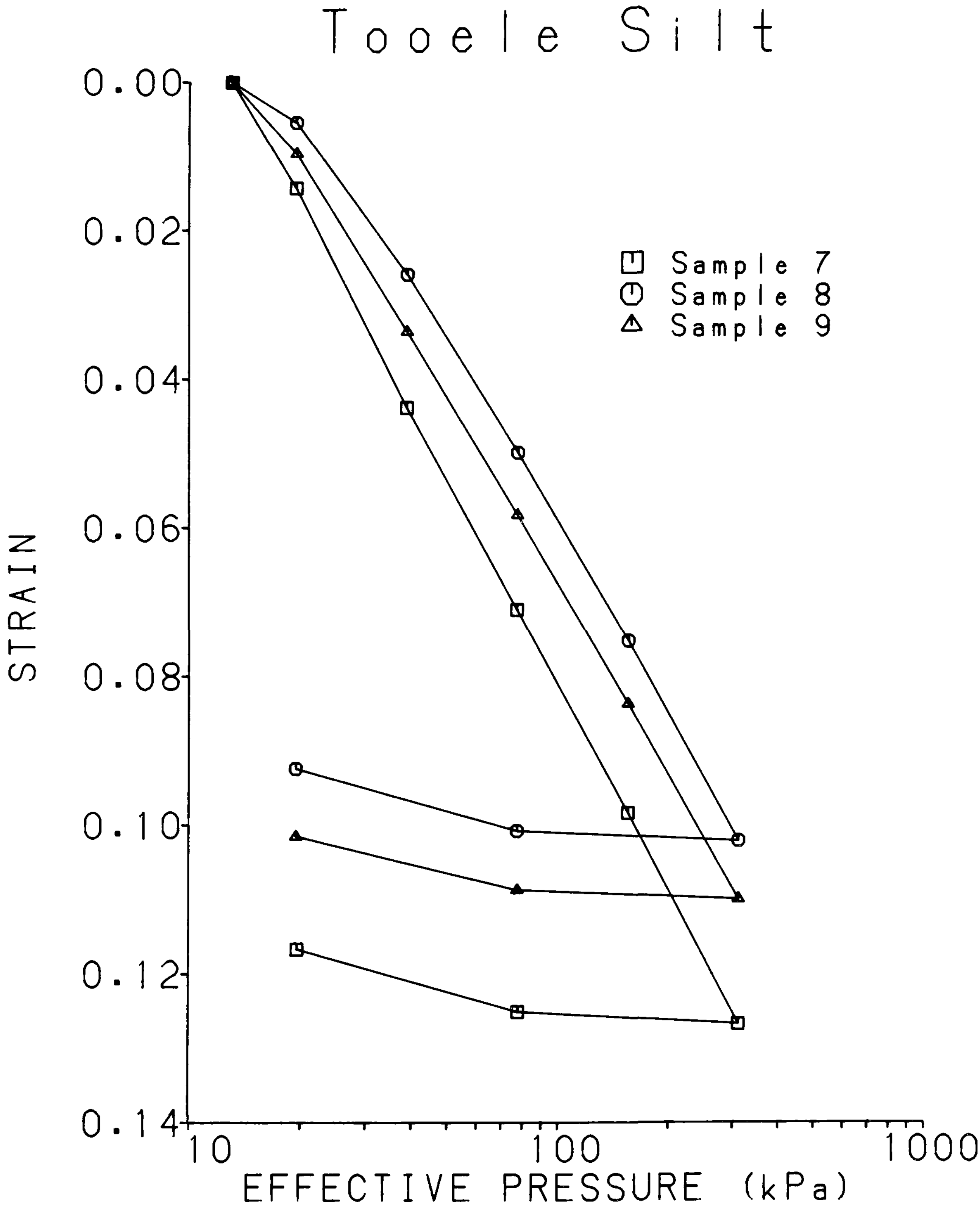


Figure A-6. Tooele silt, strain versus effective pressure, distilled water.

APPENDIX B

c_v VERSUS EFFECTIVE PRESSURE FOR THE SMITHFIELD CLAY AND TOOELE SILT SAMPLES

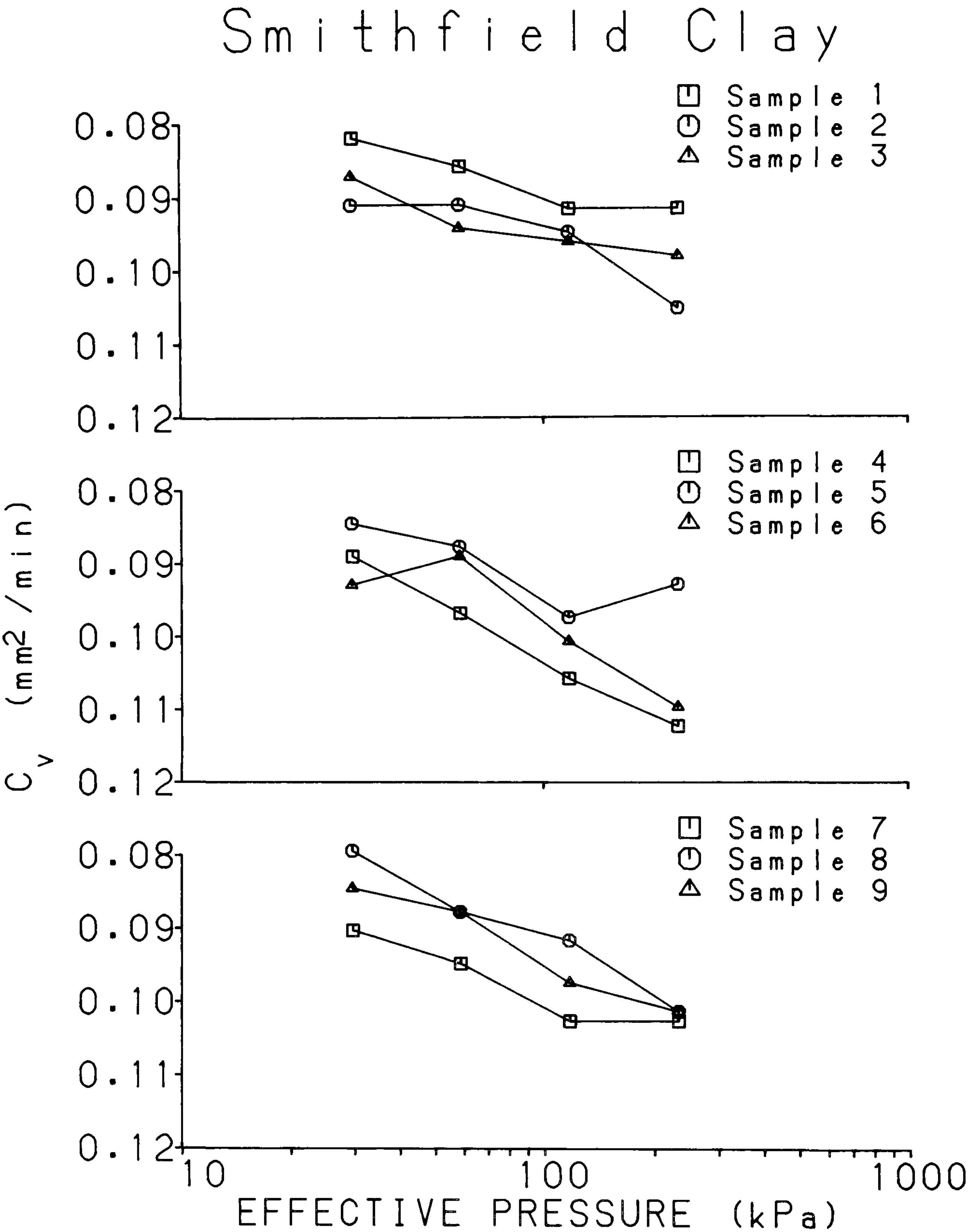


Figure B-1. Smithfield clay, c_v versus effective pressure.

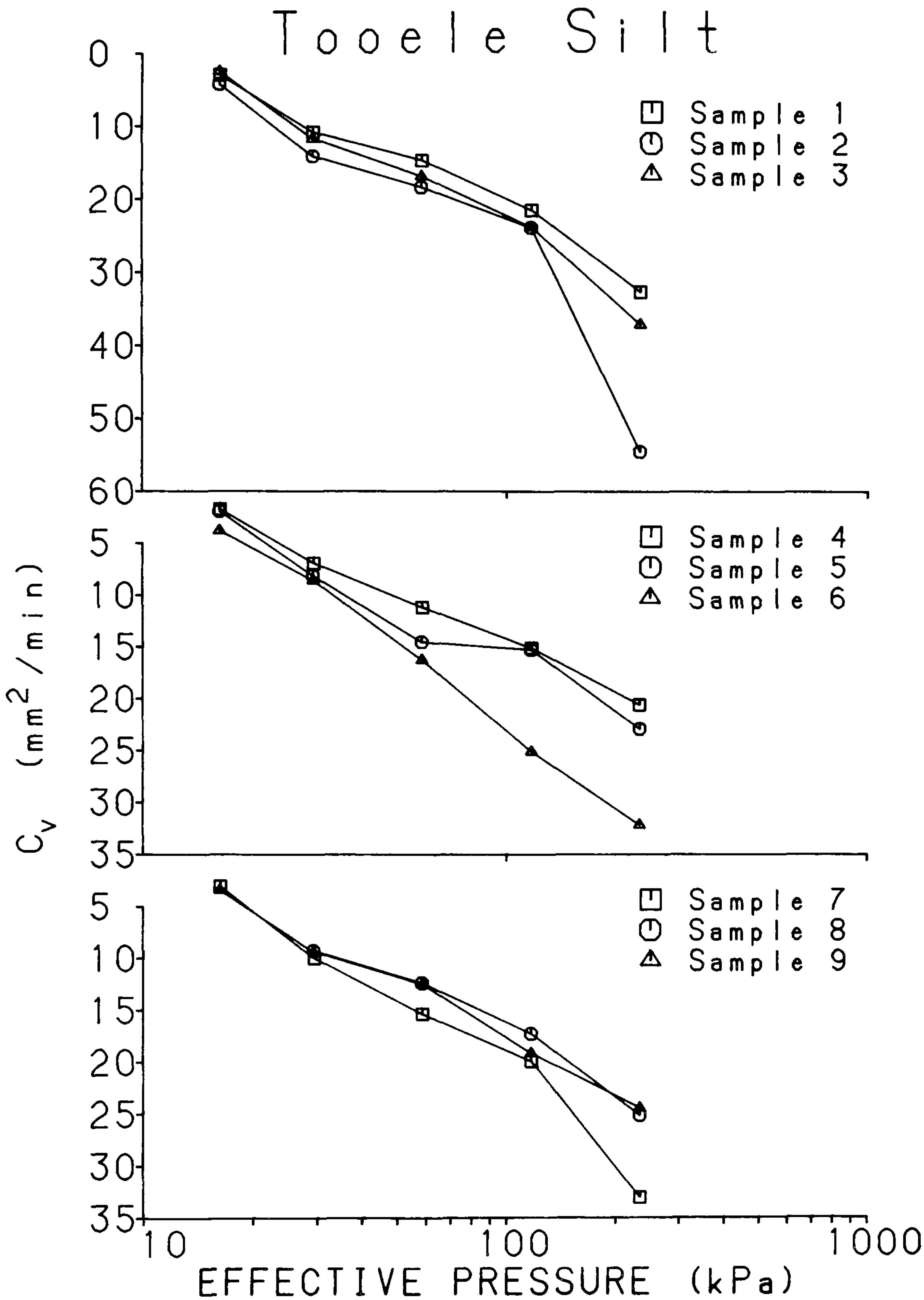


Figure B-2. Tooele silt, c_v versus log of effective pressure.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-171b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE LONG-TERM EFFECTS OF LAND APPLICATION OF DOMESTIC WASTEWATER: Tooele, Utah, Slow Rate Site Vol. II: Engineering Soil Properties		5. REPORT DATE **August 1979 issuing date** 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Anderson, Loren R., J. H. Reynolds, R. W. Miller, W. F. Campbell, D. G. Beck, and J. A. Caliendo		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Utah Water Research Laboratory Utah State University Logan, Utah 84322		10. PROGRAM ELEMENT NO. 1BC822 11. CONTRACT/GRANT NO. 68-03-2360
12. SPONSORING AGENCY NAME AND ADDRESS Robert S. Kerr Environmental Research Lab - Ada, OK Office of Research and Development U. S. Environmental Protection Agency Ada, Oklahoma 74820		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/15
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

A high quality secondary sewage effluent was applied to three soil types and its effects on the shear strength, consolidation properties, and permeability of the soils was studied. The three soil types were a poorly graded sand, a clayey silt, and a highly plastic clay. Each soil was divided into nine samples. Six samples were leached with secondary sewage effluent and three with distilled water. Three of the effluent samples were then re-leached with distilled water in order to investigate the possibility of any reversible phenomenon.

After a suitable amount of leachate has passed through the samples, direct shear tests, standard consolidation tests, and falling head permeability tests were performed. The shear strengths of the sand and silt were not appreciably affected by the application of wastewater. The shear strength of the clay was slightly increased by the wastewater effluent. The compressibility, rate of consolidation, and permeability of the silt increased with application of the effluent whereas the clay samples were not affected by the application. Except for the rate of consolidation at high stress levels, application of distilled water to treated samples did not reverse changes in the above properties.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Soil properties Land use Sewage treatment	Tooele, Utah Soil types Land application Sewage effluent Soil mechanisms Soil engineering	50D 48E 68D 91A 91G

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 90
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

U S GOVERNMENT PRINTING OFFICE 1979 -657-060/5370