AN INVESTIGATION OF TWO CASE HISTORIES
OF CHEMICAL TREATMENT OF
EXPANSIVE SOIL IN DENVER, COLORADO

Report for Masters Degree

by

Miguel Picornell

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of

MASTER OF ENGINEERING

February 1982

Major Subject: Civil Engineering

AN INVESTIGATION OF TWO CASE HISTORIES
OF CHEMICAL TREATMENT OF
EXPANSIVE SOIL IN DENVER, COLORADO

Report for Masters Degree

by

Miguel Picornell

Approved as to style and content by:

____
(Chairman of Committee)

____
(Member)

____
(Member)

____
(Member)

____
(Head of Department)

February 1982

ABSTRACT

The Denver area in Colorado is one of the many such zones in the United States where highly expansive soils are in abundance. As precautionary measures against swelling, several types of chemical stabilization procedures have been used in the Denver area over the last two decades, and one of these treatments uses Fluid 705, manufactured and applied by Soil Technology, Inc.. An experimental evaluation of the effectiveness of Fluid 705 as a chemical treatment agent in the field and in the laboratory is the subject of this report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Con't)

AN INVESTIGATION OF TWO CASE HISTORIES OF CHEMICAL TREATMENT OF EXPANSIVE SOIL IN DENVER, COLORADO

1. INTRODUCTION

The Denver area in Colorado is one of the many such zones in the United States where highly expansive soils are in abundance. Damage related to expansive soils in Denver ranges from minor cracking of interior finishing to large displacements of major structural elements. As precautionary measures against swelling several types of chemical stabilization procedures have been used in the Denver area over the last two decades, and one of these treatments uses Fluid 705, manufactured and applied by Soil Technology, Inc.. Chemical treatment is best applied before the house is built, although in many instances, in Denver, this fluid was used in an attempt to arrest further movement in houses which had already been damaged.

In order to be able to assess the potential of Fluid 705 as a chemical agent for post-construction treatment of expansive soils, an investigation was performed of a site where this treatment process has been found to be successful and another site where this has been unsuccessful. The purpose of the studies described in this report is to further the understanding of the effectiveness of Fluid 705 as a chemical treatment agent for expansive soils. The study involved the following types of investigations:

(a) Experimental study of undisturbed samples from two sites in Denver, where Fluid 705 had been used for post-construction chemical treatment of expansive soils, in which one site is an example of successful treatment, and the other site is an apparent example of unsuccessful treatment.

(b) Treatment of the undisturbed samples from the untreated areas of these two sites, in the laboratory with Fluid 705, and an experimental study of the expansive potential of these soils.

(c) Analyses of the above results to study the effects of Fluid 705 on soils in the field and in the laboratory.

Although more sites would have been desirable in order to obtain a comprehensive view of the effectiveness of the fluid, two residential sites were chosen, one in which the soil treatment with Fluid 705 was successful and one where it was not successful. The results of the laboratory studies and analyses of the two sites are presented in this report.

2. SITE DESCRIPTION

The site where Fluid 705 was successful, is owned by Mr. and Mrs. Kenneth Jacroux and located in the Ken Caryl Ranch Subdivision, 10667 West Chautanga Mounta Road in Littleton, Colorado. The site where Fluid 705 was not successful is owned by Mr. and Mrs. Francis E. Gay and located in the Harrison Park Subdivision, 4629 Ward Way, Morrison, Colorado. These two sites will be referred to as House #10667 and as House #4629 in this report.

The depth to bedrock at both these sites is approximately 10 ft. as shown in Fig. 1. House #10667 is a two-story, full basement single family residence constructed in 1978 and the soils under the basement slab were treated by Soil Technology, Inc. in October 1979. Prior to the soil treatment with Fluid 705, the original contractor for the home, M. J. Brock & Sons, Inc. removed the basement floor slab and installed an interior drainage system, which drains to a sump pump located in the northeast corner ot the basement. Shortly after the slab had been replaced, a rupture occured in the sprinkler system around the exterior of the residence at the southeast corner, causing approximately 1 1/2" of water to pond in the entire basement area. The drain system inside the house must have malfunctioned since very little water reached the sump. The drainage characteristics around the exterior of the house are given in Table 1.

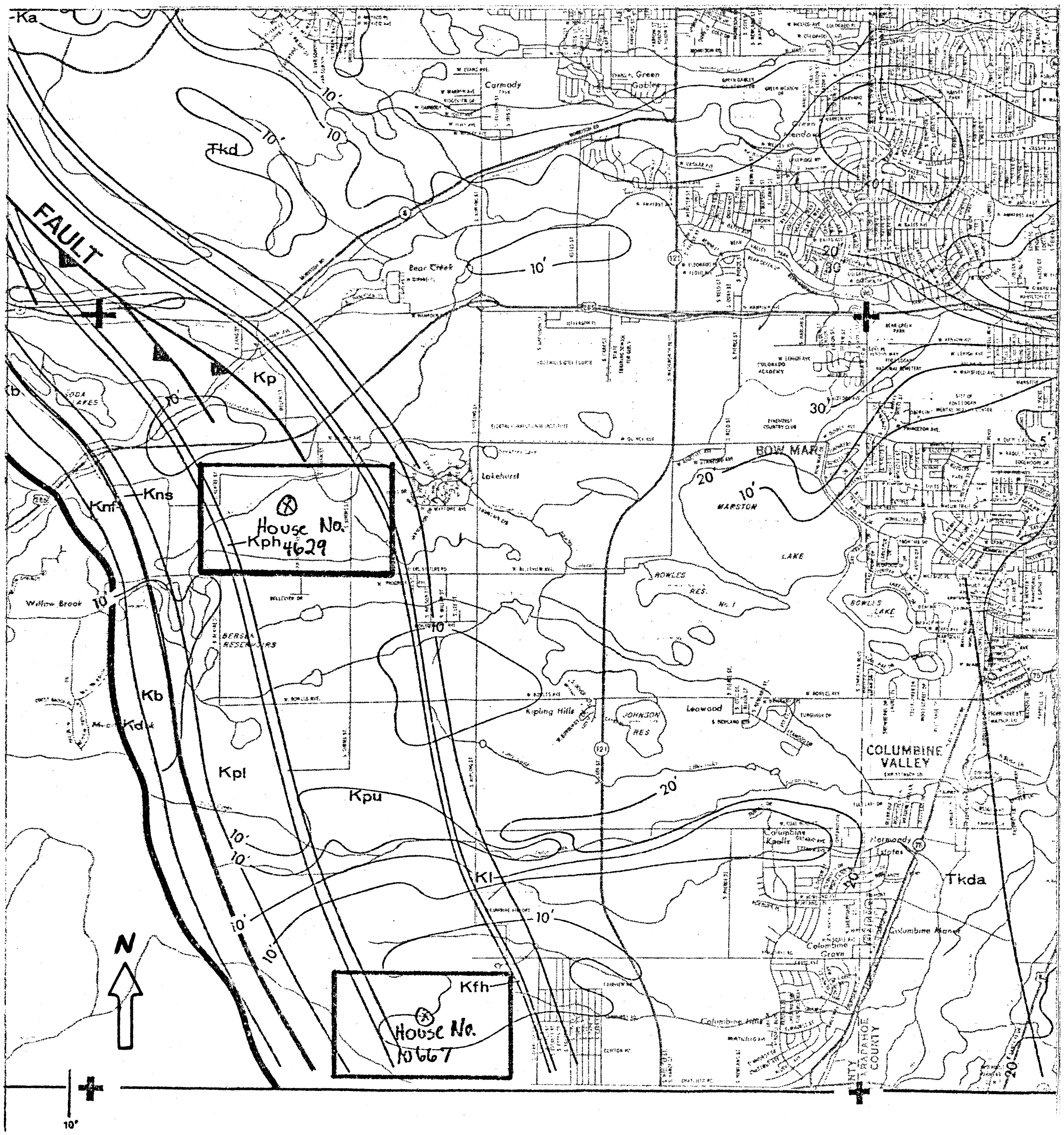
TABLE 1

Drainage Characteristics Around House # 10667

Side	Slope	Type of Cover
South	6" in the first 5'0"	Concrete Sidewalk and landscaping
North	Flat	Patio and Landscaping
East	6" in the first 5'0"	Landscaping and Sod
West	4" in the first 5'0"	Pea gravel and Landscaping

The house # 10667 is equipped with gutters and downspouts, which discharge into downspout extensions measuring approximately 5'0". The lawn surrounding the residence is well-irrigated and in good condition. The residence is equipped with a sprinkler system.

Two test holes were made at this site, one inside the house and one in the yard, and the sampling procedures used are described in the next section of this report. The soils encountered in these two boreholes were very similar and these consist of, 1/2 ft. of top soil and 2 ft. of very stiff moist dark brown clay, underlain by 3½ ft. of firm to medium hard moist gray brown claystone bedrock.



LOCATION MAP

0 1 2 3 miles

SCALE

Reference: Geology Map and Depth to Bedrock, Denver Metropolitan Area, Colorado Geological Survey

Figure 1

House # 4629, is a tri-level, full basement single family residence constructed in February, 1979 and treated with Fluid 705 by Soil Technology, Inc. in September, 1979. The basement concrete floor slab had heaved approximately 5" in the center of the basement, resulting in 1" wide cracks along the north/south center-line of the basement slab area. The drainage characteristics around this house are given in Table 2.

TABLE 2

Drainage Characteristics Around House # 4629

Side	Slope	Type of Cover
North	4" to 15" in the first 5'0"	Plastic and decorative rock
South	6" in the first 5'0"	Unimproved surface
East	8" in the first 5'0"	Concrete patio and landscaping
West	4" in the first 5'0"	Unimproved surface

This house is equipped with gutters and downspouts and all the downspouts discharged onto concrete splashblocks with lengths measuring 3'0".

This lawn is not equipped with a sprinkler system.

3. SOIL SAMPLING PROCEDURES

Similar soil sampling procedures were used at both sites, inside and outside the houses. At the house #10667, 2 test holes were made and 3" dia. Shelby tubes were used for withdrawing samples. In Test hole No. 1, located outside the house, the Shelby tube was pushed into the ground a depth of 24", beginning at an elevation that is level with the bottom of the basement floor slab. The Shelby tube was pushed hydraulically into the soil slowly enough to avoid any significant sample disturbance. No water was intercepted in the borehole during the drilling operation and also 24 hours after the drilling.

Test hole No. 2 was located in the interior of the house near the southeast corner. The distance between Test holes 1 and 2 was 19'6". The soil in the under-slab area was extremely wet. The sump in the northeast corner of the basement was constructed with a depth of 3'0" and 12" of water was visible in the bottom of the pit at the time of sampling. The shelby tubes were driven using a hand held 40 pound hammer.

At the house #4629, two test holes were drilled. Test hole No. 1 was located along the exterior of the house, 9'6" south and 6'6" west of the southeast corner of the house. The ground elevation was located approximately 2'4" below the top of the foundation wall. The shelby tube was pushed 32" into the ground. The depth of the hole from the ground surface was about 8 ft. No water was encountered at the time of drilling, and no water was found in the hole 24 hours after the sampling operations.

Test hole No. 2 was driven inside the house and was located 10'9" west and 1'7" north of the southeast corner of the basement. Two 20" long Shelby tubes were used instead of the standard 35" long tube due to limited head room clearance. The tubes were driven with a 40 pound hammer. No water was found in this test hole.

A shallow interior sump and pump unit was located near the center of the northeast quadrant of the basement. The 16" diameter pit measured 20" in depth and no free-standing water was visible at the time of sampling. However, some water marks were visible in the pit to an approximate depth of 6" and heavy iron staining was also present, indicating the presence of stagnant water during heavy rains. No drainage lines were visible leading into the pit.

4. LABORATORY INVESTIGATION

Several representative samples of soil from both sites were tested in the laboratory. Four types of samples were tested in the laboratory and these are:

(a) undisturbed, untreated samples

(b) undisturbed, field treated samples

(c) undisturbed, laboratory treated samples

(d) reconstituted, laboratory treated samples

A number of routine soil tests and additional physico-chemical tests were performed on the various samples. The results of these tests are discussed in detail in the following sections.

4.1 Grain Size Distribution

Eight samples from the two sites were sieved through #200 sieve and hydrometer analyses were performed. The results from these tests are given in Table 3:

TABLE 3

Grain Size Distribution

House Number	Borehole Number	Sample Location	SAND (%)	SILT (%)	CLAY (%)
10667	1	outside	7.7	63.8	28.5
	1	outside	12.6	44.3	43.1
	2	Inside	11.8	57.2	31.0
	2	Inside	13.8	51.7	34.5
4629	1	Outside	3.2	50.3	46.5
	2a	Inside	6.4	50.6	43.0
	2a	Inside	4.2	44.8	51.0
	2b	Inside	2.3	51.7	46.0

and can be summarized as follows:

	Sand(%)	Silt(%)	Clay(%)
House # 10667	12	54	34
House # 4629	4	49	47

For both sites, the grain size distributions of the treated and untreated samples were quite similar. However, the clay content at the 4629 House site was somewhat higher than that found at the 10667 House site. The soils at both sites are classified as CH-silty clay with some sand.

4.2 Atterberg Limits

Five samples from each of the types:

(a) untreated

(b) field treated with Fluid 705

(c) laboratory treated with Fluid 705

were tested for determining liquid limit, plastic limit and shrinkage limit.

The results of the liquid limit and plastic limit tests are given in Table 4 and in Fig. 2. From these results it is evident that the field treated samples exhibit slightly lower plasticity than the untreated samples. However, because this difference is insignificant, this may be attributed to variability of the properties of the natural untreated soils rather than to the influence of the Fluid 705 used in the treatment.

Two other samples were treated with Fluid 705 in the laboratory for three days by capillarity. A third sample was treated with Fluid 705 in the laboratory for three days by flooding. As expected, the

Plasticity Index of the flooded sample is lower than that of the sample treated by capillarity as given in Table 4. The appearance of the soil also changed due to laboratory treatment.

It is worthy to notice that the apparent increase of plasticity index and liquid limit, shown in Fig. 2, for the treated specimens is due to the removal of the sand fraction by sieving through #200 sieve. It is also interesting to note that all the data points lie along a narrow band parallel to the A-line in Fig. 2 indicating that the mineralogical nature of these samples did not change appreciably due to field or laboratory treatment.

Shrinkage tests were performed on both the untreated samples and the field treated samples, and these results are summarized in Table 5. There appears to be no consistent pattern in the linear shrinkage results but the shrinkage limit of untreated soils is somewhat lower than that of the treated soils.

TABLE 4

Atterberg Limits

Sample Sieved through	House Number	Sample Location	Borehole Number	Liquid Limit (%)	Plasticity Index (%)
#40 sieve	10667	Outside	1	59.7	37.8
		Inside	2	64.1	36.1
	4629	Outside	1	71.9	44.1
		Inside	2a	70.3	42.4
		Inside	2b	73.9	42.0
#200 sieve	4629	Outside*	1	85.3	50.5
		Outside**	1	79.3	42.0
		Outside	2b	80.1	48.7

* The sample was treated in the laboratory by soaking due to capillarity with liquid 705.

** The sample was treated in the laboratory by flooding it with liquid 705.

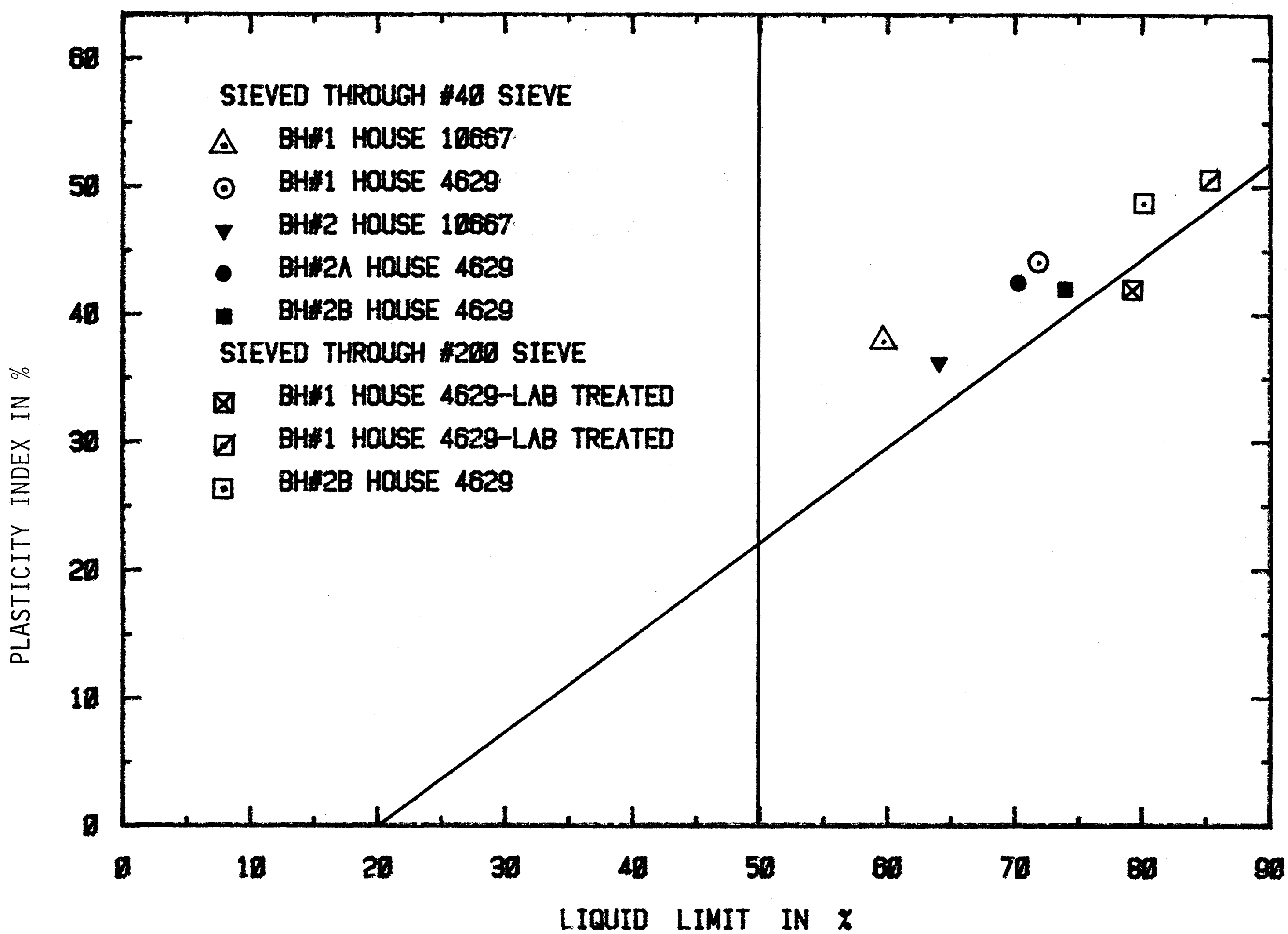


Figure 2

Atterberg Limits

TABLE 5

Shrinkage Characteristics

House Number	location	Borehole Number	Shrinkage Limit (%)	Linear Shrinkage (%)	
10667	outside	1	14.5	17.7	untreated
	inside	2	19.6	18.9	treated
4629	outside	1	14.7	18.9	untreated
	Inside	2 b	19.4	17.3	treated
		2 b	21.6	18.9	

4.3 Water Content

The water content of a number of representative samples from the borings was determined by oven drying at 110^{o}C. These results are given in Table 6. On the average, the water content outside the house was 21% for house # 10667 and 25% for house # 4629. The water content of soils underneath both houses was about 31%. The only exception to this was in the lower portion of the core of bore hole #2 from house # 10667, where the water content was slightly higher. This higher water content corresponds to the observation of freestanding water in the borehole in House # 10667 after sampling.

4.4 Clay Mineralogy

Ten samples from the two sites were tested using x-ray diffractometry for determining the percentages of various clay minerals. Each soil sample selected from the the top and bottom of selected cores was placed in a clean glass container and sealed to avoid contamination. Each glass container with the sample was filled with pH 10, Na_2CO_3 solution to disaggregate the sample. The resulting solution was poured into 100 ml. glass pyrex test tubes and centrifuged for 2.5 minutes at 600 rpm. By this procedure, the coarse-sized fraction (greater than 2 μm) was collected at the bottom of the test tube, while the finer fraction collected at the top. The fine clay fraction was decanted off. A comprehensive treatment of the sample preparation procedures is given in Appendix A.

In order to obtain a complete mineralogical analysis, a magnesium chloride (MgCl) treated, and a potassium chloride (KCl) treated specimens were mounted on glass slides. Each specimen was tested on a

TABLE 6

Field Moisture Content

Sample Location	Bore Hole Number	Moisture Content (%)	
		House 10667	House 4629
Outside	1	22.4 21.7 20.1 18.9	24.5 24.6 25.6 26.3 26.3
Inside	2	26.7 34.7 30.8	
Inside	2a		30.1 31.6 32.4
Inside	2b		30.3 27.5

Norelco X-ray diffractometer using a Monochromatic K_α radiation from a copper target (CuK_α). All of the diffractograms were produced by using a standard energy setting for the Cu tube (35 KV and 15 mA) with a time constant of 2, a chart speed of 30% hour, a scale of 500, and a scan of

1^o/minute. Each specimen was run at 25^{o}C (constant controlled room temperature). The KCl-treated samples were heated to 300^{o}C and 550^{o}C and two additional runs were made on the diffractometer.

The ten samples from the two sites were treated with Fluid 705 in the laboratory by soaking them for 72 hours in the fluid. The same procedures described above were used again in the X-ray diffractometer analyses. The diffractogram allows one to identify the types of clay minerals present in the soil and to estimate the percentage of each of them. The results of these tests are summarized in Table 7. The fractions of clay minerals, Montmorillonite, Vermiculite, Kaolinite, Illite, and Chlorite are expressed in percent in Table 7 for the 10 samples before and after treatment in the laboratory with Fluid 705. There is no significant difference in the percentages of Montmorillonite/Vermiculite mix present in the samples before and after treatment, except in the case of samples 200B and 300A both of which were taken from soil at house site # 4629. In sample 200B, the percent of montmorillonite decreased and that of illite increased whereas in sample 300A the percent of montmorillonite increased while the percentage of kaolinite and illite decreased. Because these two peculiar cases indicate countering trends in the percent of montmorillonite, they are considered to be inconclusive. This is especially so since in all of the rest of the tests, the percentages of minerals remain unchanged within the limits of accuracy of the measurement technique. Therefore, it is concluded that the Fluid 705 has no effect on the clay mineralogy based on these test results.

TABLE 7

Clay Mineralogy

House Number	Sample Number	Untreated					Treated with Fluid 705				
			M/V	K	I	C		M/V	K	I	C
4629	100A		70	10	20	0		65	15	20	0
4629	100B		70	10	20	0		70	10	20	0
4629	200A		75	10	15	0		70	10	20	0
4629	200B		55	20	25	10		20	30	40	0
4629	300A		25	30	30	15		55	15	20	10
4629	300B		60	15	25	0		60	15	25	0
10667	400A		55	20	25	0		60	20	20	0
10667	400B		50	20	30	0		65	15	20	0
10667	500A		70	5	25	0		80	5	15	0
10667	500B		60	5	25	0		60	5	15	0

M/V Montmorillonite/Vermiculite mix

K Kaolinite

I Illite

C Chlorite

All the data are expressed in %.

4.5 Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of the surface area per unit weight of the minerals that are available to adsorb cations such as sodium, potassium, calcium, and so on. It was measured by Harris Laboratories, Inc. an independent testing laboratory in Lincoln, Nebraska. Normally, the more active clays have smaller, thinner particles with larger surface area per unit weight and will have a higher cation exchange capacity as a result. Treatment of the soil should tend to aggregate the clay particles, lowering the surface area per unit weight and also lowering the cation exchange capacity.

Harris Laboratories determined the CEC by saturation, according to the procedure of H. D. Chapman, "Methods of Soil Analysis" Part 2. Edited by C. A. Black, American Society of Agronomy, Inc. 1965, pp. 891-901. Eight samples were tested without laboratory treatment with Fluid 705 results of these determinations on 8 samples are shown in Table 8.

There is not any consistent pattern, in all of the determinations, that would indicate a lower CEC in the treated soils inside the houses. In fact, Table 8 shows that the highest CEC values were <u>inside</u> each house where presumably the soil has been treated by Fluid 705. The larger CEC values may simply be due to the natural variability of the soils.

4.6 Exchangeable Sodium Percentage

The exchangeable sodium percentage (ESP) indicates the amount of salt such as NaCl that is in the pore fluid of the soil. A clay that has been deposited in a marine environment will have a higher exchangeable sodium percentage and will tend to be more active and more erodable than one that has the same type and percent of clay but a lower ESP. Higher ESP soils will tend to crack more frequently or to develop larger cracks in the soil mass, providing more ready means of access to fluids entering the soil mass. It should be easier to inject fluids into a soil mass with a higher ESP.

Harris Laboratories determined the ESP values by the procedure laid down in:

Exchangeable Cation Analysis of Saline & Alkali Soils,
C. A. Bower, R. F. Reitemeier and M. Fireman
Soil Science, Volume 73, No. 4, April 1952.

It consisted in the extraction of the pore fluid from a soil sample with ammonium acetate and measuring the sodium concentration in the extract. A second subsample of the same soil was mixed with water to the saturation percentage. At that water percentage, the pore fluid was extracted. The sodium concentrations and total hardness (calcium plus magnesium) in this extract was then determined. The difference between the two sodium concentrations has been considered as the amount of sodium saturating the Base Exchange. The ratio of this difference to the cation exchange capacity was thus computed as the Exchangeable Sodium Percentage (ESP).

The patterns of ESP that can be found in Table 8 are as follows:

(a) the ESP outside of house # 10667 is higher than that outside of house # 4629. This indicates that the soil mass should be more fractured at house # 10667 and more receptive of injected fluids.

TABLE 8

Cation Exchange Capacity and Sodium Saturation

House Number	Sample Location	Borehole Number	Cation Exchange Capacity (meq/100 gr)	Total Sodium (meq/100 gr)	Dissolvable Sodium (meq/100 gr)	EXCHANGEABLE SODIUM	
						meq/100 gr	PERCENTAGE
10667	Outside	1	8.7	8.61	4.88	3.73	42.9
	Inside	2	10.3	11.30	7.00	4.30	41.7
	Inside	2	31.3	7.74	1.94	5.80	18.5
4629	Outside	1	8.4	5.91	3.32	2.59	30.8
	Outside	1	12.2	2.52	0.74	1.78	14.6
	Inside	2a	9.4	8.61	5.30	3.31	35.2
	Inside	2a	20.6	8.78	5.10	3.68	17.9
	Inside	2b	7.4	8.61	5.03	3.58	48.4

(b) The ESP outside of house # 10667 is higher than the average ESP inside the house, possibly indicating that the treatment lowered the exchangeable sodium at that house. On the other hand, this may be due to the natural variability of the soil.

(c) The average ESP inside both houses is nearly the same.

Although it is not shown conclusively in these data, the ESP at house # 10667 may be higher, on the average, than that at house # 4629.

The results of the tests on the saturated soil paste are given in Table 9. Determinations were made of the water content at saturation, pH, electrical conductivity, and the concentrations of sodium, calcium, and magnesium cations.

One striking difference is noted in Table 9 and that is the difference in water content at saturation. Despite the soil at house # 10667 having a smaller percentage of clay size particles than at house # 4629 (34% to 47%, respectively), it took more water to saturate it.

There are no consistent patterns of cation concentrations in Table 9, except that there appears to be a higher concentration of cations outside of house # 10667 than inside, whereas the pattern is reversed for house # 4629.

The differences in pH and electrical conductivity are discussed below.

4.7 Electrical Conductivity

Electrical conductivity measurements were made on eight samples, three from house # 10667 and five from house # 4629. The results are given in Table 9. It is interesting to note that the electrical conductivity of the field treated soil is lower than that of the untreated

TABLE 9

Physico-Chemical Characteristics of Saturation Extract

House Number	Sample Location	Borehole Number	SATURATION, PERCENTAGE	pH at Saturation	ELECTRICAL CONDUCTIVITY at Saturation (mmhos/cm.)	SODIUM (meq/100 gr)	CALCIUM (meq/100 gr)	MAGNESIUM (meq/100 gr)	TOTAL HARDNESS (ca + Mg) (meq/100 gr)
10667	outside	1	180.7	7.8	4.10	4.88	1.97	1.92	3.89
	inside	2	200.0	8.3	3.65	7.00	1.67	1.46	3.13
	inside	2	161.9	8.5	1.39	1.94	0.20	0.15	0.35
4629	Outside	1	151.0	7.9	3.45	3.32	1.81	1.59	3.40
	Outside	1	114.5	7.9	1.32	0.74	0.42	0.30	0.72
	Inside	2a	139.4	7.8	4.65	5.30	2.11	1.69	3.80
	Inside	2a	145.7	7.8	5.00	5.10	2.12	1.72	3.84
	Inside	2b	193.3	7.8	3.30	5.03	2.01	1.28	3.29

soil at house # 10667, whereas the electrical conductivity of the field treated soil is higher than that of the untreated soil at house # 4629. This is the same pattern as exhibited by the cation concentrations, which is to be expected since conductivity always increases with higher cation concentrations. If the Fluid 705 had any effect on the soils at these two sites, these effects are of contradictory nature based on the laboratory results in Table 9. Because of this apparent contradiction, it may be that the differences between the behavior of field treated and untreated soils at these two sites are primarily due to natural variability in the soil properties.

4.8 pH Value

pH Value determinations were made on several samples and the results are given in Table 9. The pH values of the samples from house # 4629, are consistent at 7.8 and indicate that they are slightly basic. The Fluid 705 appears to have no appreciable effect on the pH value of the soil at this site. The pH value of the field treated soil from house # 10667 has an average value of 8.4, whereas the pH value of the untreated soil from this site is 7.8. There is some difference in pH between treated and untreated soil, because Fluid 705 is very basic with a pH of about 13+ and it appears that the fluid may have had some influence on the soil beneath house # 10667. This is consistent with some of our other findings, namely that house # 10667 has less clay and a higher ESP and thus is more likely to be cracked and fissured so as to permit the entry of the fluid into the soil mass more readily.

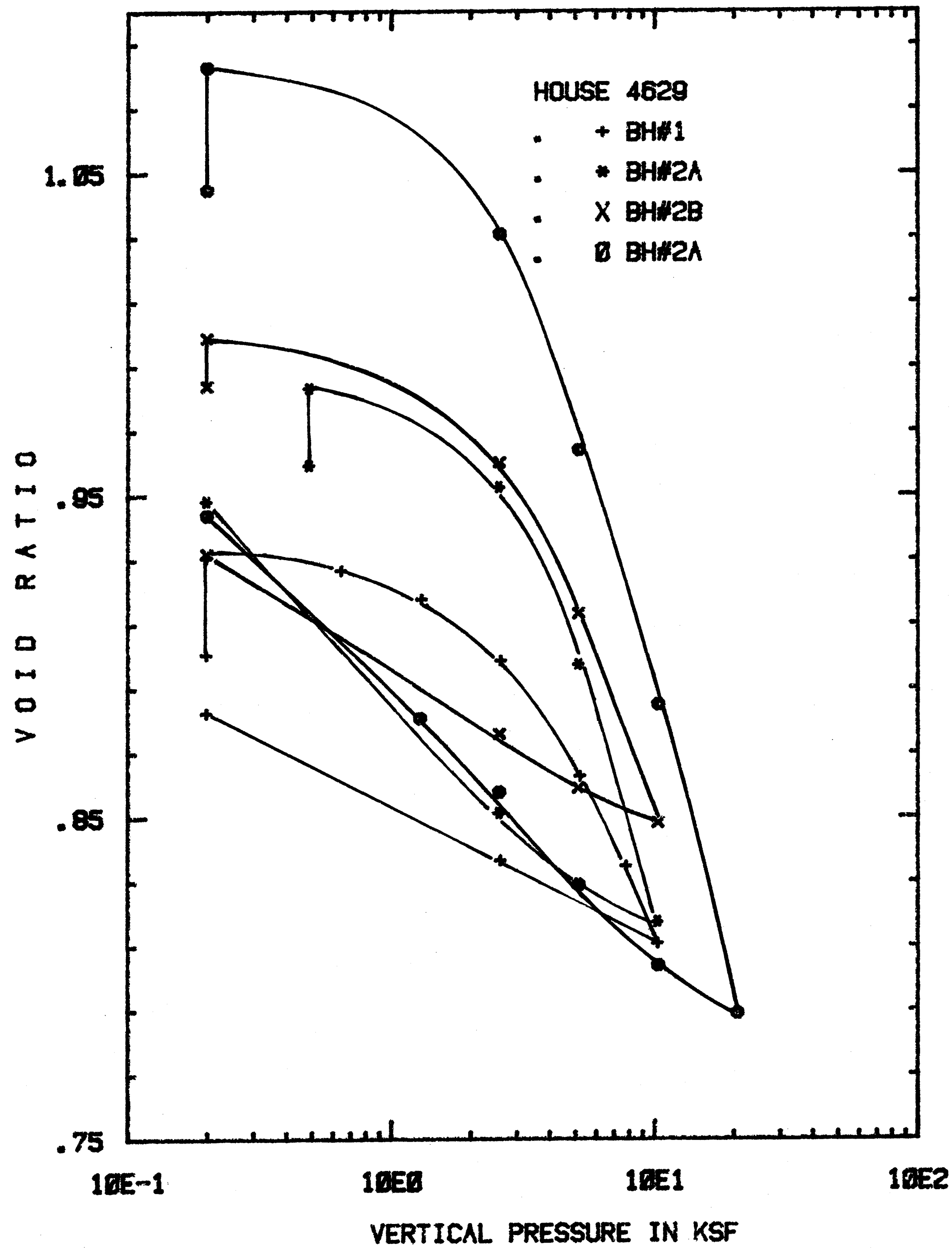
4.9 Swelling Tests

Eleven free swell tests and expansion pressure tests were conducted on samples from the two sites. The moisture content, dry density, degree of saturation of the samples were determined before and after the tests and the results are given in Table 10. The free swell tests were performed under a light restraining consolidation pressure that would simulate the field conditions at both sites. The samples were trimmed in a consolidometer ring and free swell movements were monitored using a dial gauge under a consolidation pressure of 0.20 ksf. After the reading had levelled, additional loads were applied to the sample in the consolidometer until the thickness of the sample returned to the initial value. The pressure required in each case to compress the sample back to its original thickness, without any swell, was defined as the expansion pressure. The test results on free swell and expansion pressure for a number of samples from both houses are shown in Figs. 3 and 4. The natural water content, free swell under 0.2 ksf pressure, and expansion pressure for six undisturbed samples are shown in Table 11. It is to be noted that one of these free swell tests (House # 4629, Borehole 2a) was performed under 0.49 ksf pressure. The free swell inside the house #10667 is 1.0% and the expansion pressure is 0.9 ksf. The free swell outside house # 10667 is 2.1% and the expansion pressure is 2.8 ksf, which is higher than that recorded inside the house. The same is true for the house # 4629. The free swell inside this house has an average of 1.3% compared to 1.6% outside the house. It should be noted that the natural moisture content inside both houses is higher than that outside. Hence the differences in free swell and expansion pressure can be attributed to

TABLE 10

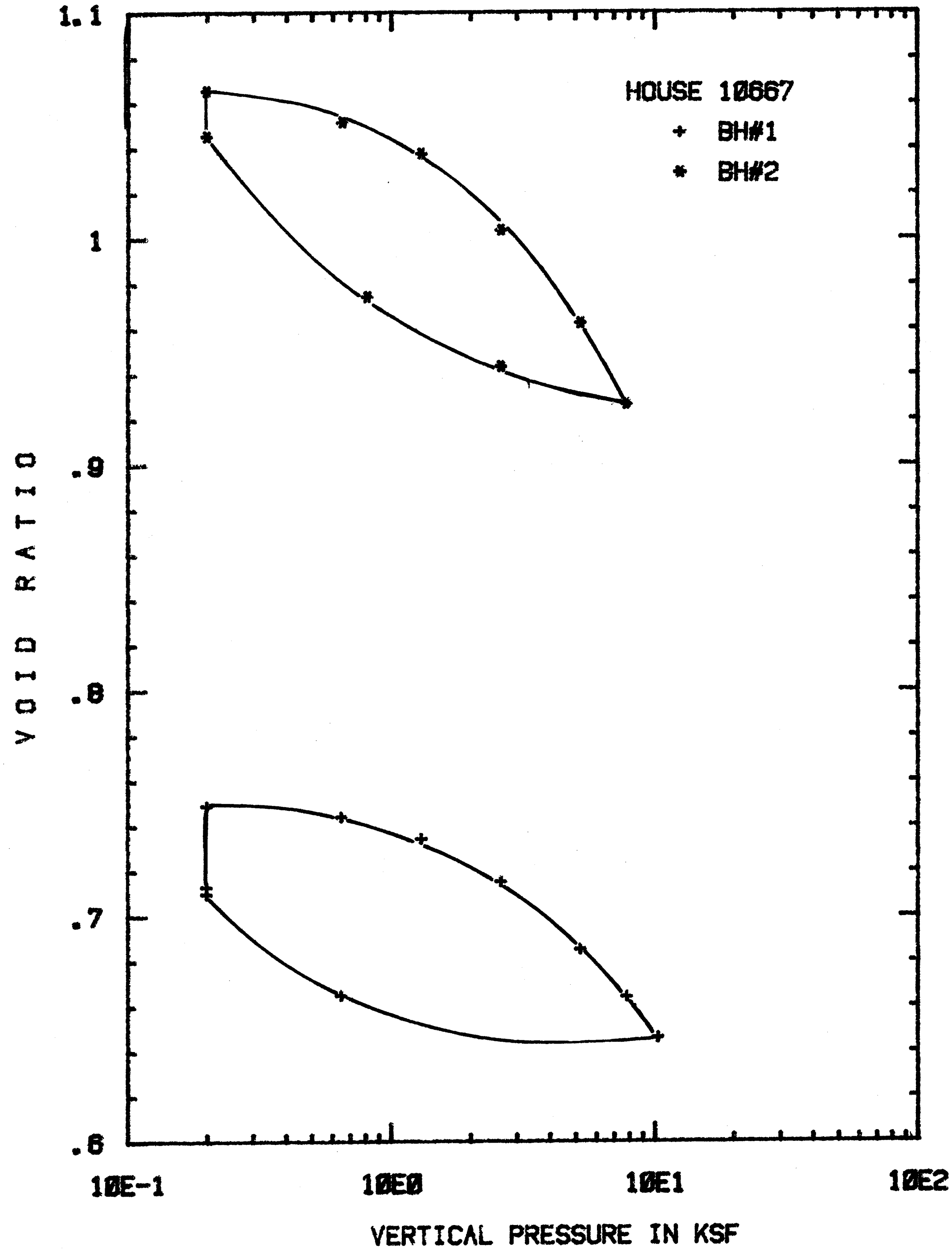
Degrees of Saturation and Dry Unit Weights of Swell Test Specimens

House Number	Borehole Number	SPECIFIC GRAVITY G_s	BEFORE TEST MOISTURE CONTENT (%)	BEFORE TEST DRY DENSITY (gr/cc)	BEFORE TEST DEGREE of SATURATION	AFTER TEST MOISTURE CONTENT (%)	AFTER TEST DRY DENSITY (gr/cc)	AFTER TEST DEGREE of SATURATION
10667	1	2.86	20.1	1.67	81	22.9	1.67	92.
	1	----	18.9	1.67	76	----	----	----
	2	2.81	30.8	1.37	83	29.6	1.42	85.
	2	----	5.8	1.21	12	35.5	1.41	99.
	2	----	5.4	1.56	17	23.9	1.64	91.
4629	1	2.84	26.1	1.50	84	30.1	1.51	97.
	1	----	25.6	1.51	82	----	----	----
	1	----	6.2	1.61	23	24.2	1.66	90.
	2a	2.87	32.4	1.40	89	29.3	1.48	89.
	2a	2.89	31.6	1.46	93	31.6	1.48	96.
	2b	2.86	27.5	1.44	80	31.4	1.48	96.



Comparison of Swell Tests - House 4629 - Undisturbed Specimens

Figure 3



Comparison of Swell Tests - House 10667 - Undisturbed Specimens

Figure 4

TABLE 11

Swelling Characteristics of Undisturbed Samples

House Number	Sample Location	Borehole Number	Natural Moisture Content (%)	Free Swell under 0.2 ksf (%)	Expansion Pressure (ksf)
10667	outside	1	20.06	2.1	2.8
	Inside	2	30.80	1.0	0.9
4629	Outside	1	26.13	1.6	2.5
	Inside	2a	32.40	1.9	2.0
	Inside	2a	31.60	1.25 (*)	2.0
	Inside	2b	27.50	0.7	1.0

* This free swell test was performed under 0.49 ksf pressure.

the variation in natural moisture content. Therefore, the results are consistent with previous experience at other sites with expansive soils, where larger magnitudes of swell have been recorded with lower natural moisture contents.

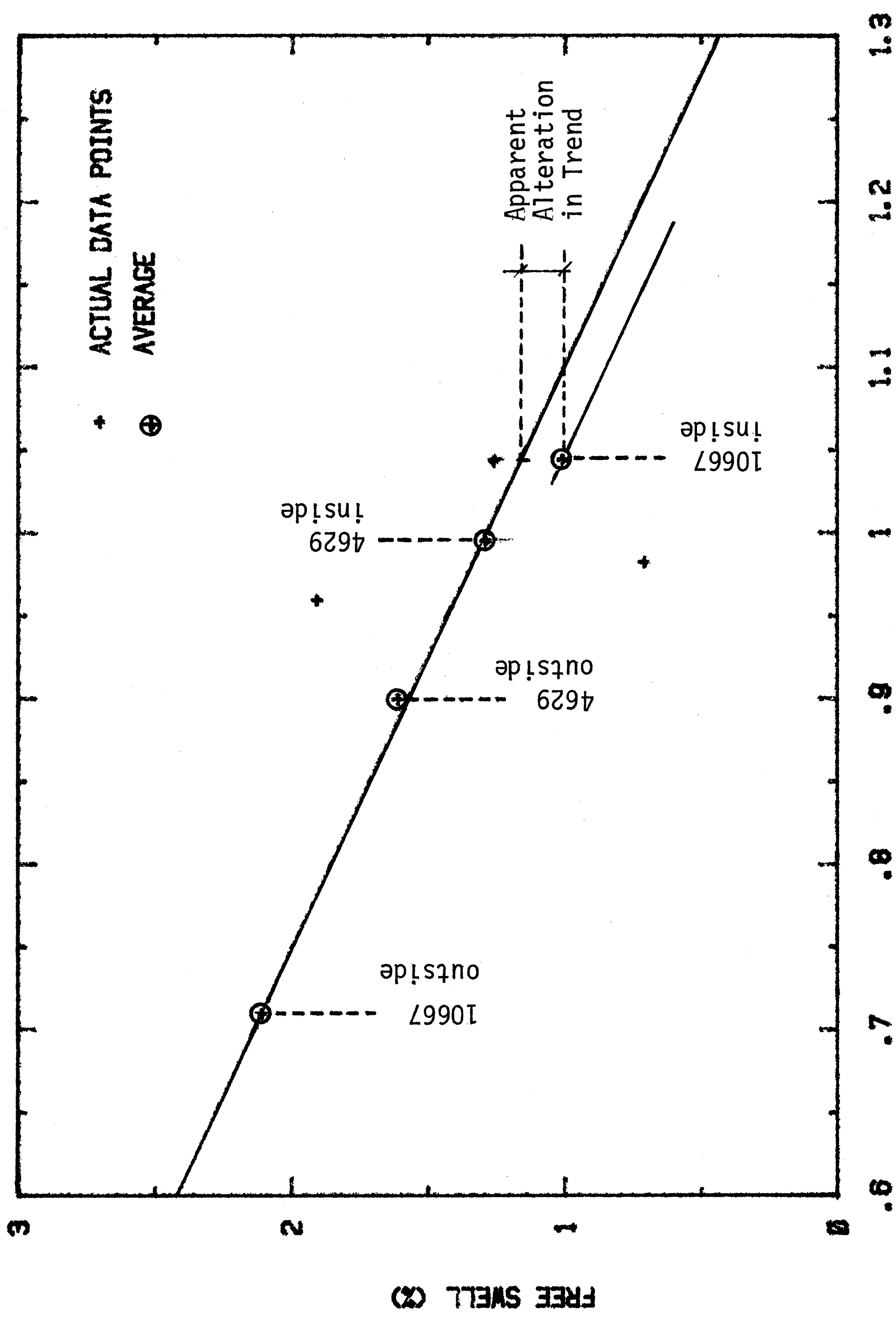
In order to determine the relative effect of the treatment inside houses # 10667 and 4629, graphs were made of the free swell and the expansion pressure versus the initial void ratio of the soil. These two graphs are shown in Figures 5 and 6.

On both graphs, a straight line was drawn between the two points representing untreated soil to obtain a trend line for untreated soils. Lines parallel to this were drawn through the two points representing the soil treated in the field. Any deviation of the second line from the first is an indication of the amount of alteration in the soil property that was effected by field treatment of the soil. The scatter of the three data points representing the treated soil at house # 4629 gives some indication of the natural variability of the soil on a site. An average of these was used to represent the treated soil.

The two graphs with trend lines constructed on them show the following:

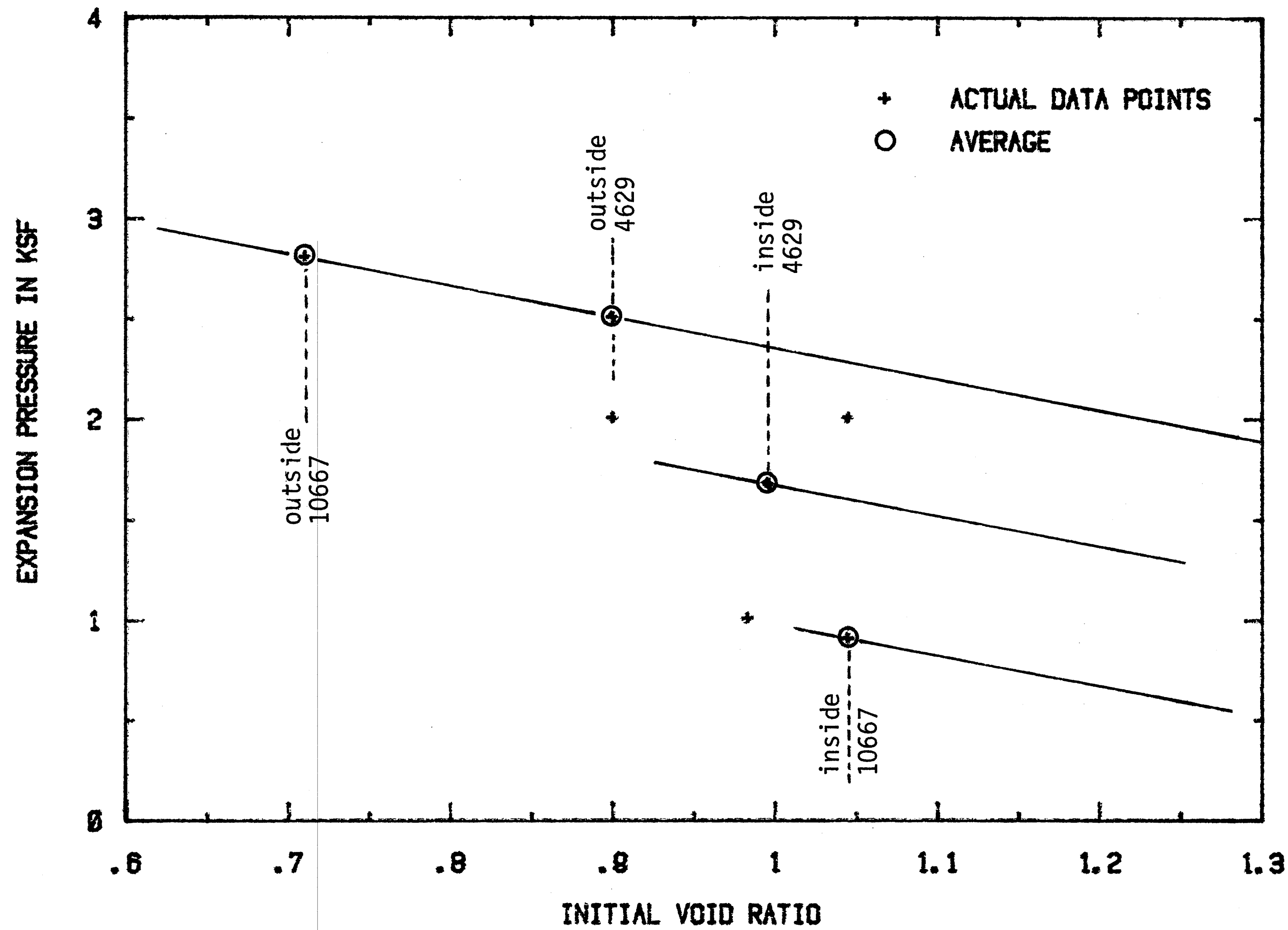
(a) free swell was not altered by treatment at house # 4629. Instead, the reduction in free swell is what would be expected with an untreated soil that had its void ratio increased by flooding with water.

(b) Free Swell <u>was</u> altered by treatment at house # 10667 more than would be expected by increasing the void ratio by flooding with water.



Free Swell vs Void Ratio for the Two Sites

Figure 5



Expansion Pressure vs Void Ratio for the Two Sites

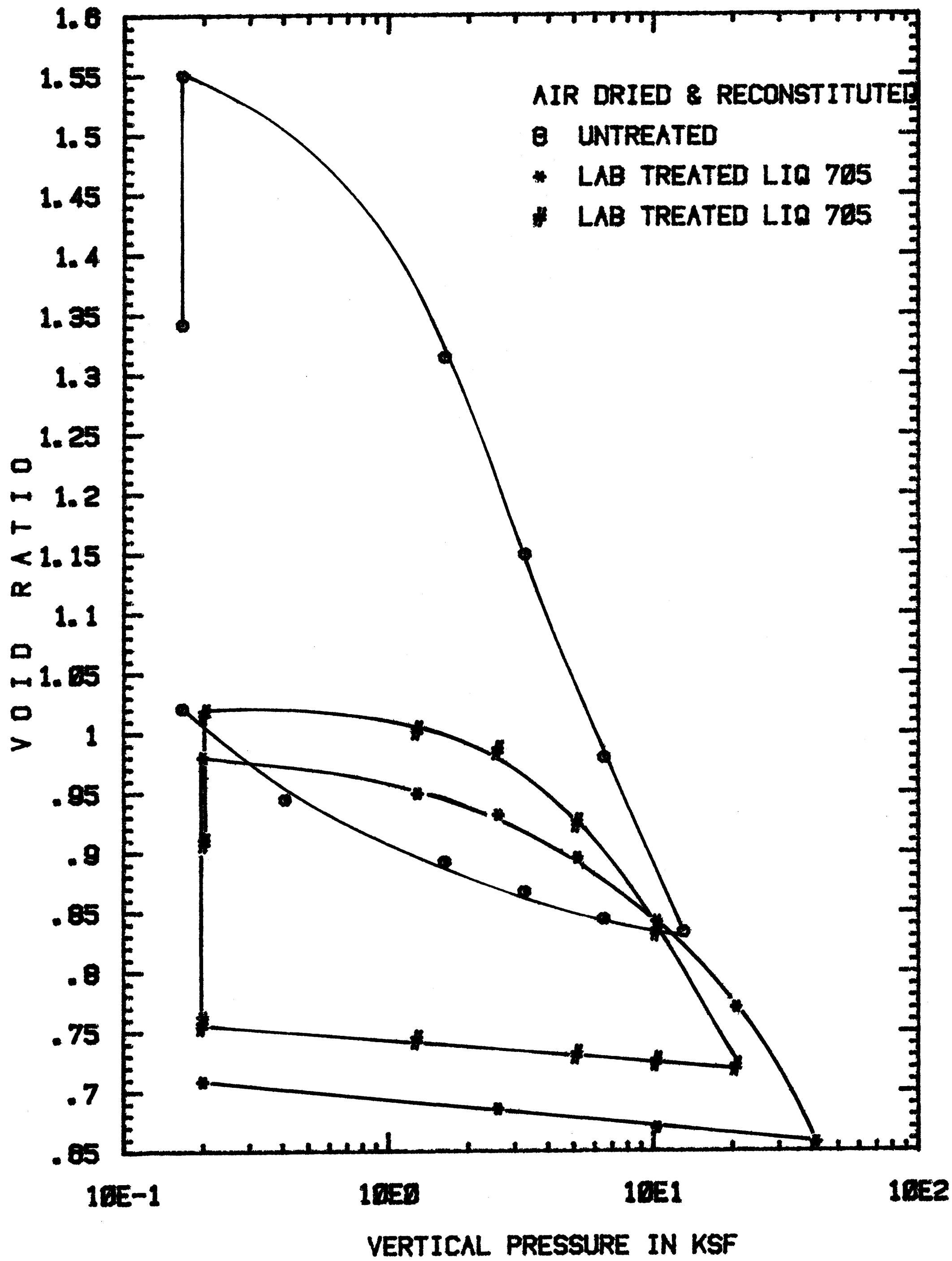
Figure 6

(c) Expansion pressure was altered at both sites but there was about twice the change at house # 10667 as at house # 4629.

It should be noted that the free swell behavior is much closer to the condition in the field beneath a basement than is the expansion pressure. The weight of a slab such as a basement slab is no more than 0.05 to 0.10 ksf, which is closer to the pressure condition in the free swell case than is the expansion pressure.

Two other undisturbed samples were treated with Fluid 705 by capillary action in the laboratory after which free swell-expansion pressure tests were performed. These samples were treated for three days and trimmed in a consolidometer ring. The free swell registered upon flooding with distilled water was almost zero. Furthermore, three other airdried, reconstituted samples were treated with Fluid 705 in the laboratory and the free swell-expansion pressure tests were conducted. The results of these tests are shown in Fig. 7 and summarized in Table 12. The airdried, reconstituted samples were treated in the consolidometer ring and the Fluid 705 was used to flood the sample. It is significant that the free swell recorded during flooding with Fluid 705 was on the order of the free swell registered with the addition of distilled water. In summarizing the samples did not swell farther on the addition of water after they had been treated in the laboratory with Fluid 705 by capillarity, whereas free swells of 6.1 to 12.3% were registered during lab treatment of the airdried, reconstituted samples by flooding with Fluid 705.

The significance of these facts is that whenever a fluid enters a soil which is already 85 to 97 percent saturated, the volume of the soil will increase, regardless of what the fluid is. Flooding a sample of soil with



Comparison of Swell Tests - Air Dried and Reconstituted Specimens

Figure 7

TABLE 12

Swelling Characteristics of Laboratory Treated Samples

Sample Type	House Number	Borehole Number	Initial Moisture Content (%)	Free Swell Under 0.2 ksf (%)	Expansion Pressure (ksf)
Undisturbed, Treated with Fluid 705 by capillarity	10667	1	18.9	0.0	0.0
Undisturbed, Treated with Fluid 705 by capillarity	4629	1	25.6	0.0	0.0
Airdried, reconstituted	10667	2	5.8	8.9 (*)	1.5
Airdried, reconstituted	10667	2	5.4	6.1 (*)	6.4
Airdried, reconstituted	4629	1	6.2	12.3 (*)	20.0

(*) Swelling caused by entry of Fluid 705 into sample.

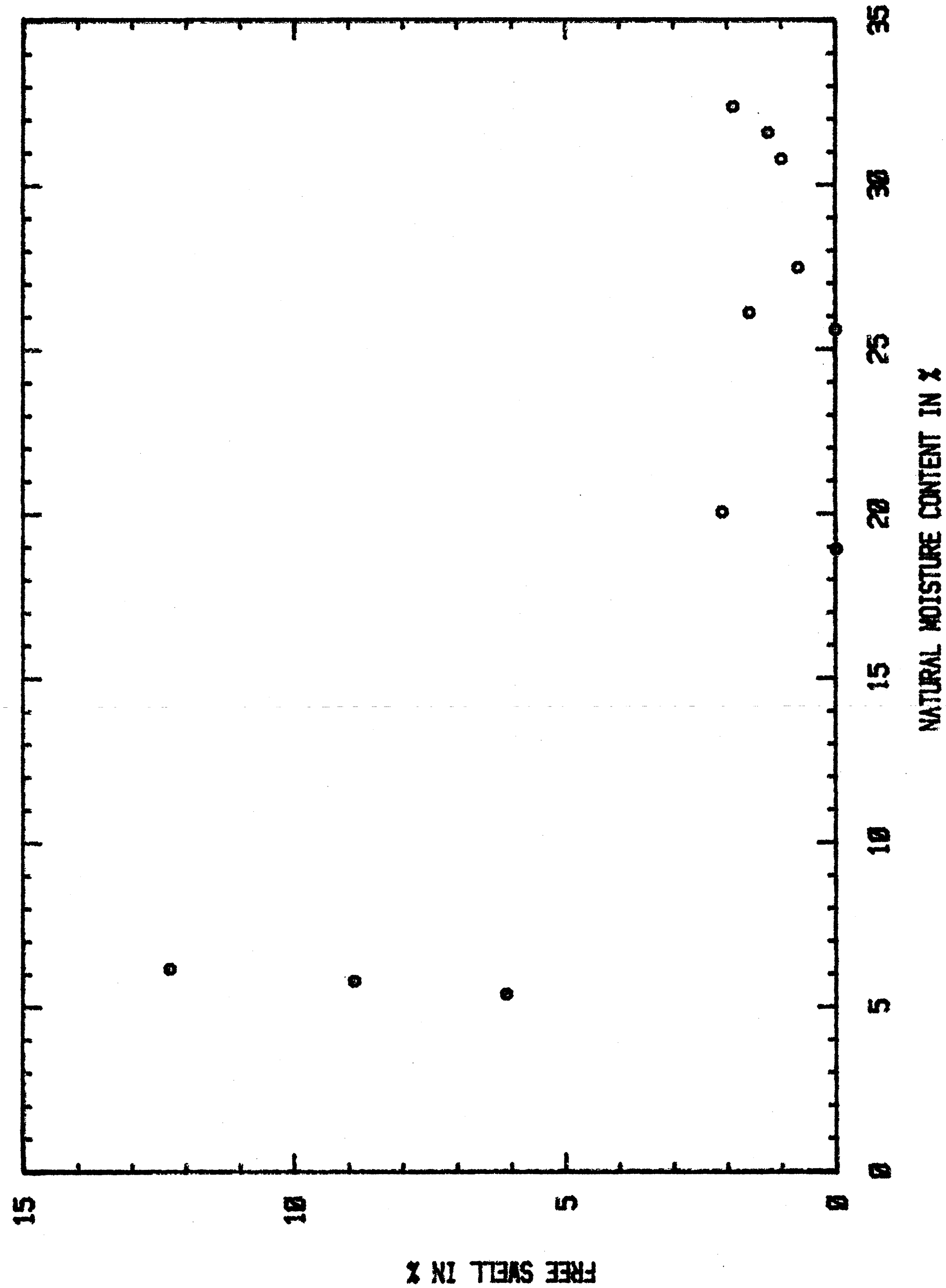
Fluid 705 will cause the soil to swell just as will flooding the sample with water. While such flooding is occurring, the void ratio of the soil increases and a reduction in free swell and expansion pressure occurs naturally. It may be that one of the benefits of using Fluid 705 or any fluid for that matter is to pre-swell the soil and thus to reduce its potential for swelling still farther.

As a further illustration of this, Fig. 8 shows a clear trend of decreasing free swell with increasing natural water content in undisturbed samples. The lower free swell values for soils sampled inside the houses are due to the considerably higher moisture content of the soils inside the buildings. There are several possible sources of this higher water content including the Fluid 705 that was injected beneath the house foundation, or possibly subsurface water that cannot escape from beneath the building, or perhaps water from a malfunctioning perimeter drain, or a combination of these possibilities.

4.10 Permeability

Falling head permeability tests were performed on the free swell-expansion pressure samples between applications of consolidation pressure. Tests were run on undisturbed samples and laboratory treated samples. Some of these latter samples were treated in the laboratory by capillary action and others were airdried, reconstituted samples that were treated by flooding. The results from these tests are shown in Tables 13 and 14 and in Figs. 9 and 10.

The permeability values of the undisturbed samples are in the ranges of 4.9×10^{-9} to 1.9×10^{-7} cm/sec for house # 10667 and 3.4×10^{-7} to 2.4×10^{-5} cm/sec for house # 4629. The field treated samples indicate



Free Swell vs Initial Moisture Content

Figure 8

TABLE 13

Permeability of Undisturbed Samples

House Number	Sample Location	Borehole Number	Average Piezometric Head (cm)	Vertical Pressure (ksf)	Void ratio	Coefficient of Permeability (cm/sec)
10667	outside	1	80	2.62	0.714	1.85×10^{-7}
			79	10.34	0.645	4.87×10^{-9}
	inside	2	72	2.62	1.003	2.84×10^{-5}
			75	7.86	0.926	2.77×10^{-7}
4629	outside	1	70	1.31	0.917	2.35×10^{-5}
			77	10.34	0.810	3.36×10^{-7}
	inside	2a	81	5.16	0.897	5.92×10^{-9}
			83	10.32	0.817	5.43×10^{-9}
	inside	2a	88	20.69	0.789	9.71×10^{-9}
	inside	2b	81	5.16	0.913	1.09×10^{-7}
			81	10.34	0.848	1.59×10^{-8}

TABLE 14

Permeability of Laboratory Treated Samples

Sample Type	House Number	Borehole Number	Average Piezometric Head (cm)	Vertical Pressure (ksf)	Void Ratio	Coefficient of Permeability (cm/sec)
Air-dried, Reconstituted, Untreated Soil Sample	10667	2	65	0.17	1.550	3.89×10^{-7}
			68	1.64	1.314	7.22×10^{-8}
			64	3.28	1.149	2.40×10^{-8}
			76	6.55	0.979	6.54×10^{-9}
			76	13.11	0.833	1.78×10^{-9}
Air-dried, Reconstituted, Treated with Fluid 705 in Oedometer	10667	2	74	10.34	0.833	2.80×10^{-8}
			80	20.70	0.720	1.15×10^{-8}
Air-dried, Reconstituted, Treated with Fluid 705 in Oedometer	4624	1	77	10.34	0.841	1.31×10^{-8}
			75	20.70	0.769	7.85×10^{-9}
			84	41.39	0.656	1.93×10^{-9}

TABLE 14 (Continued)

Sample Type	House Number	Borehole Number	Average Piezometric Head (cm)	Vertical Pressure (ksf)	Void Ratio	Coefficient of Permeability (cm/sec)
Undisturbed, Treated with Fluid 705 by Capillarity	10667	1	72	5.17	0.671	9.33×10^{-7}
			76	10.35	0.645	1.66×10^{-7}
			68	20.70	0.609	3.74×10^{-8}
			67	41.39	0.567	1.25×10^{-8}
Undisturbed, Treated with Fluid 705 by Capillary	4629	1	73	5.17	0.828	1.55×10^{-8}
			80	10.35	0.776	3.31×10^{-9}

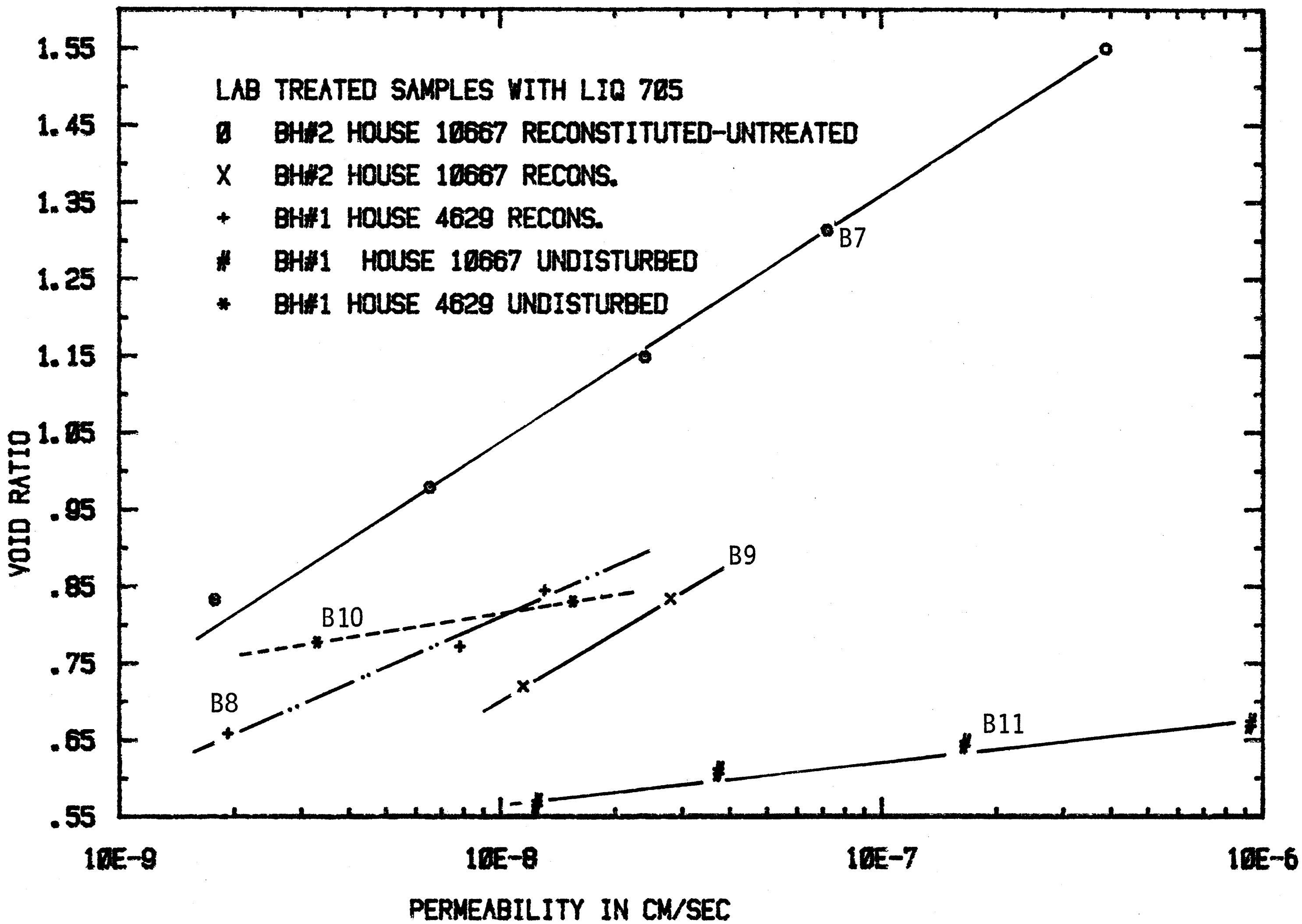


Figure 9

Note: B8 corresponds to the test shown in Figure B8 of the Appendix B and data on Table 14.

Permeability vs Void Ratio-Laboratory Treated Samples

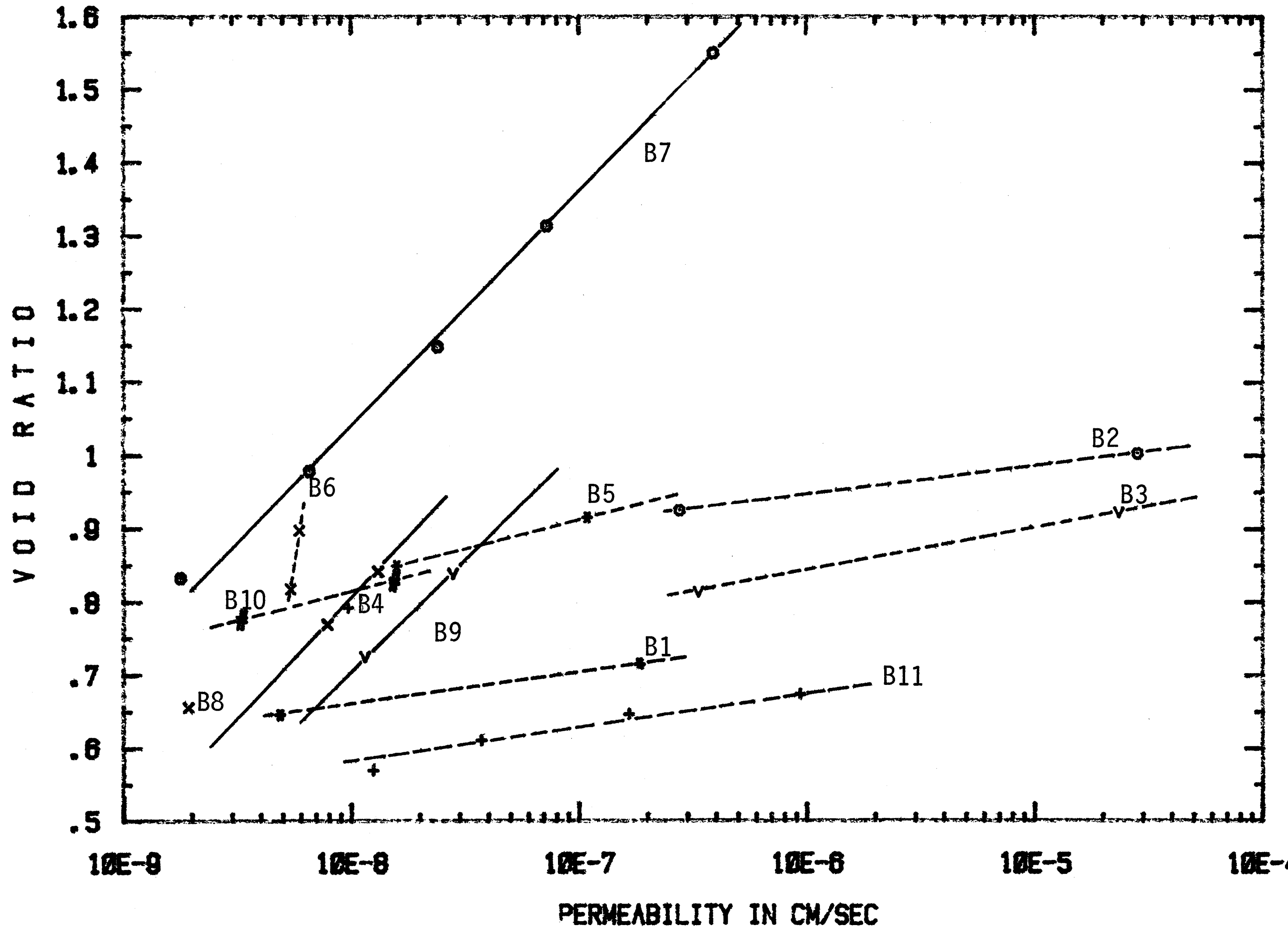


Figure 10

Note: B5 - Corresponds to the Test shown on Figure B5 of Appendix B and data on Tables 13 & 14.

Permeability vs Void Ratio

permeability values in the ranges of 2.8 x 10^{-7} to 2.8 x 10^{-5} cm/sec for house # 10667 and 5.4 x 10^{-9} to 1.1 x 10^{-7} cm/sec for house # 4629 therefore, the permeability of the soil inside the house # 10667 is about two orders of magnitude higher than that measured outside the house. But, it should be noted that the void ratios of the samples from inside this house are also considerably higher than the void ratios of the samples from outside the house. This is consistent with our findings on the initial void ratios, free swell, and expansion pressures earlier in Section 4.9 of this report. The opposite trend is seen in the permeability at the other site, where the treatment with Fluid 705 was unsuccessful. There is little or no appreciable difference in void ratio of the soils present inside and outside the house # 4629. However, the values of permeability measured in the laboratory on representative samples indicate two orders of magnitude higher permeability for soils <u>outside</u> the house. The results from the laboratory treated samples indicate the effect on permeability of saturation with Fluid 705. Based on the results given in Table 14, it can be concluded that for samples with comparable void ratios, the permeability of the reconstituted soil that was untreated in the laboratory is about 2 x 10^{-9} cm/sec and that of the laboratory treated reconstituted soil is about 2 x 10^{-8} cm/sec. Although there is one order of magnitude difference in the permeability both values are very low. In these laboratory conditions, maximum opportunity to affect the permeability was afforded to Fluid 705, both by capillary saturation and by soaking the samples for 72 hours. In the field, no such ideal conditions would be present. Thus, a change of permeability by a factor of 10 at these low levels of permeability cannot be expected to permit a substantially greater flow of Fluid 705 or of water into the center of the individual clods and peds of the soil.

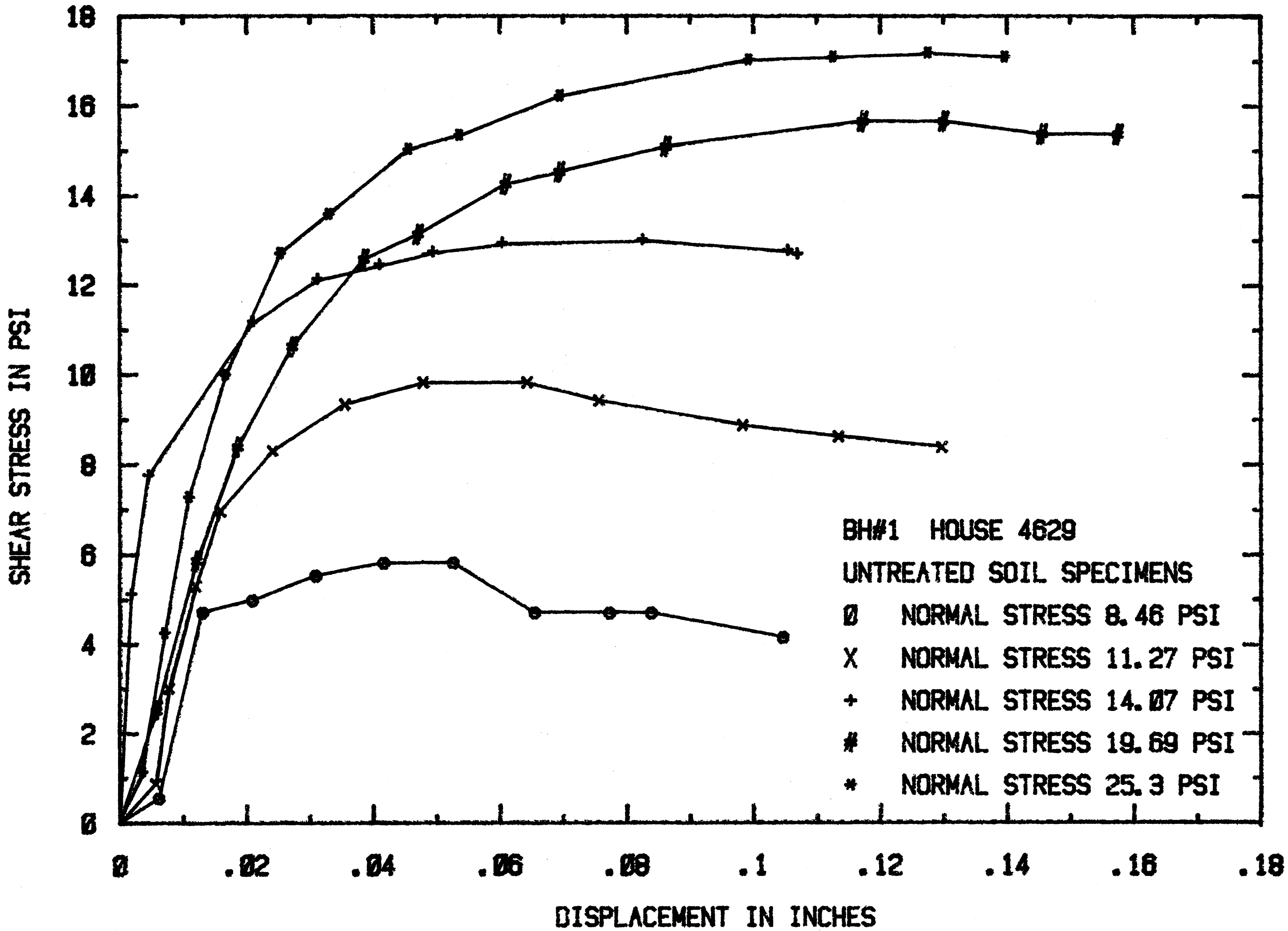
The lower permeabilities measured in the undisturbed samples were due, at least in part, to the presence of seams of sand or gravel, the natural fissure pattern in the soil, and to the irregularities in trimming the sample to fit the interior of the consolidation ring.

It is believed that the presence of a natural crack pattern in the soil mass in the field will promote a more rapid diffusion of Fluid 705, or water, or any other fluid throughout the soil mass and more effective treatment may be expected in those soils with more cracks more closely spaced together. This belief is consistent with our previous findings concerning the exchangeable sodium percentage in Section 4.5 of this report.

4.11 Drained Shear Strength

Nine samples were trimmed by pushing a ring with a cutting edge into the sample cores. Five of these samples were tested in this undisturbed state and the rest were soaked in Fluid 705 by capillary action for three days. Each sample was placed in direct shear box and consolidated under various normal stresses under fully drained conditions. After primary consolidation was complete, the samples were sheared at a rate of 0.0002 inches/min. The shear stress-displacement curves for the undisturbed samples are shown in Fig. 11, and the curves for the samples treated with Fluid 705 are shown in Fig. 12. All of the tests were run on samples from House # 4629, where the field treatment was unsuccessful. Due to the poor quality of the samples due to excessive disturbance when pushing the ring and the presence of large fissures, the samples from House # 10667 were not tested. A comparison between the

Figure 11



Comparison of Strain vs Stress Curves - Untreated Soil Specimens

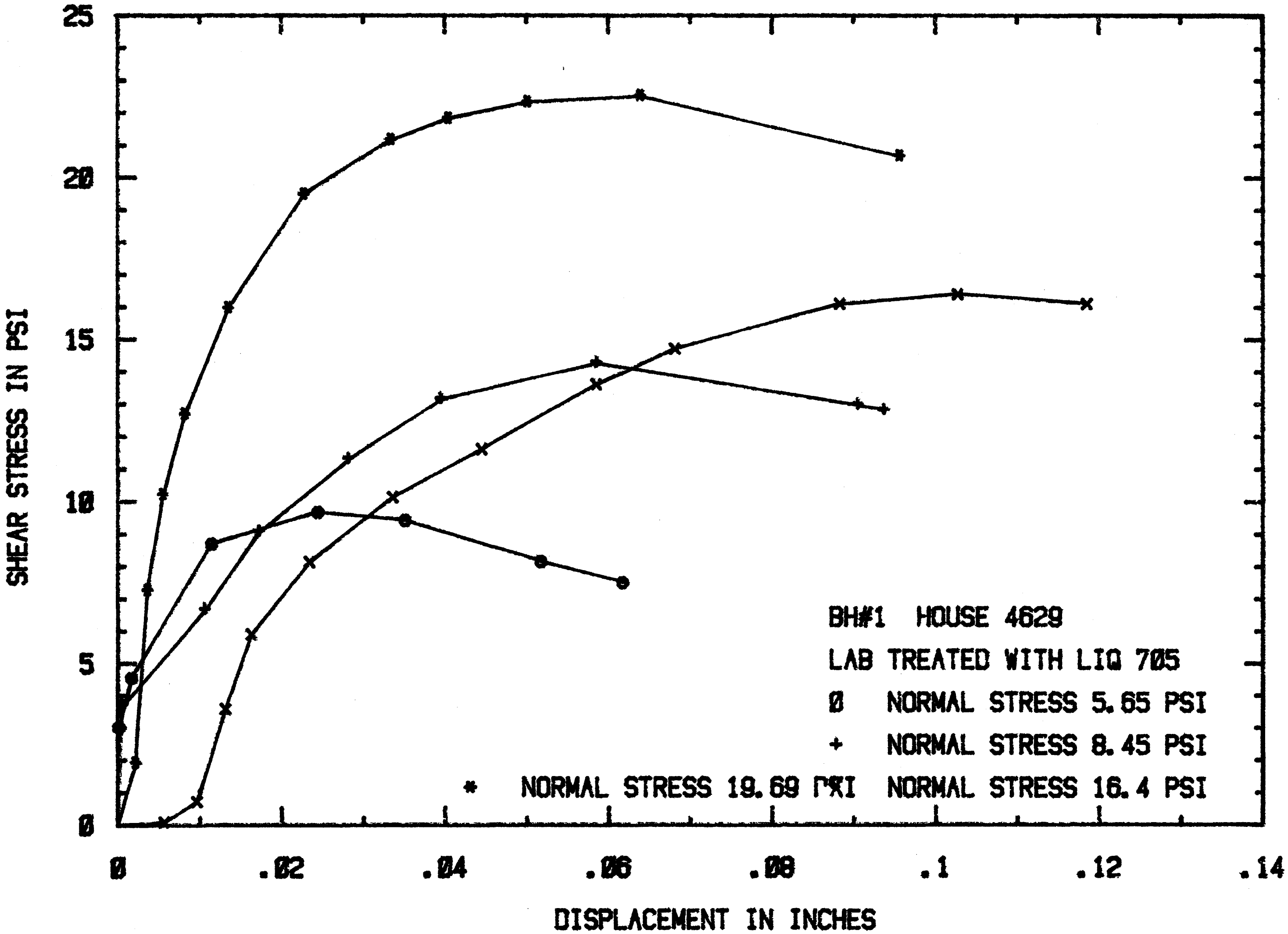


Figure 12

Comparison of Strain vs Stress Curves - Treated Soil Specimens.

stress-strain curves of the laboratory treated and the untreated samples is shown in Fig. 13 and summarized in Table 15. It is clear from this figure that the drained shear strength of the sample increases by about 40%, by laboratory treatment with Fluid 705. Fig. 14 shows a comparison of the Mohr-Coulomb envelopes for the laboratory treated and untreated soils from house # 4629. The chemical treatment of this soil with Fluid 705 has an appreciable effect on the drained shear strength. The cohesion intercept increases from 2.2 psi to 6.0 psi, and the angle of internal friction increases from 32^{o} to 39^{o}.

5. CONCLUSIONS AND RECOMMENDATIONS

A very thorough series of tests was made on soils from two sites, one of which, house No. 10667, was successfully treated with Fluid 705 and the other of which, house # 4629, was not successful since further damage occurred subsequent to treatment. Both treatments were made subsequent to construction. An attempt was made to select two houses that were formed in the same geological formation so that the soils would be relatively similar. Soil samples were taken inside and outside each house so that some contrast could be made between the untreated soil outside the house and the field treated soil inside the house.

The treatment that can be effected in the field is limited by the amount of cracking, fissuring, and sand and gravel lenses that exist in the natural soil mass and the permeability of the clods and peds. Because of this, a soil that is highly fissured or has large seams of gravel to carry Fluid 705 can be expected to be treated more effectively in the field than one that is not so fractured or so criss-crossed with gravel seams. This appears to be one of the principal differences

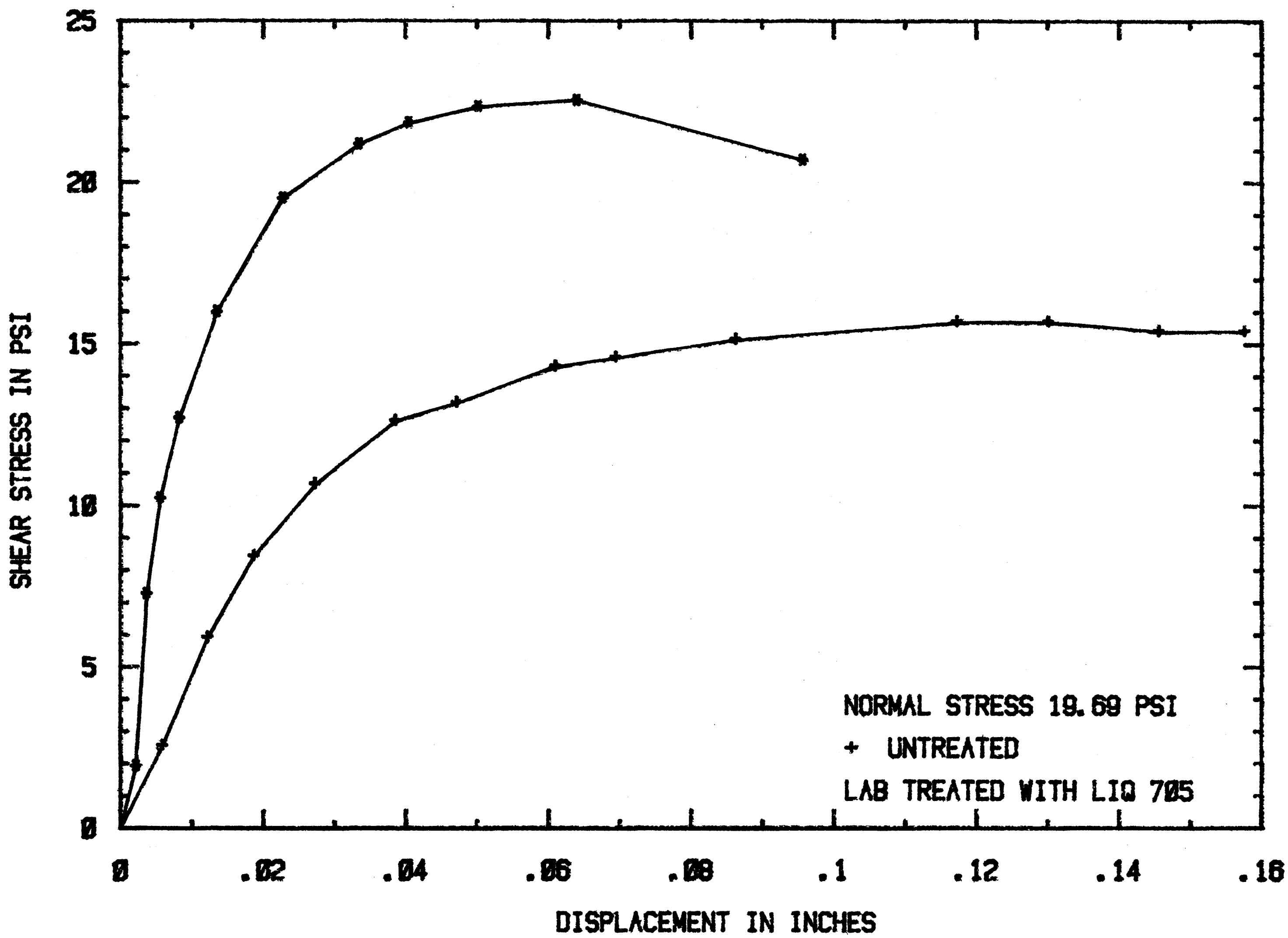


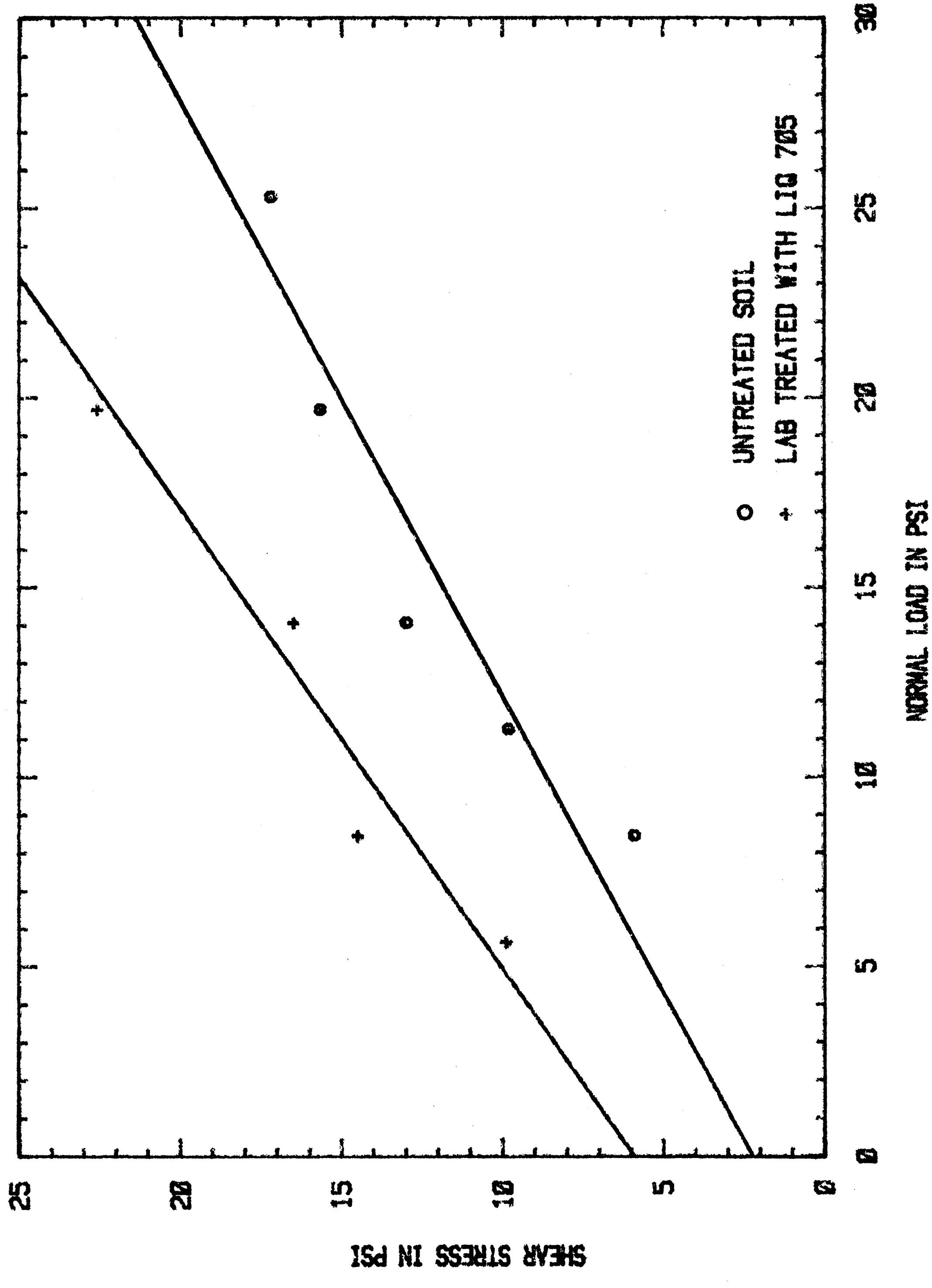
Figure 13

Comparison Stress vs Strain Curves Between Treated & Untreated Specimens

TABLE 15

Summary of Results from Direct Shear Tests on Samples from House #4629

	Normal Stress (psi)	Shear Strength (psi)	Displacement at Failure (inch)
Untreated Soil	8.46	5.89	0.055
	11.27	9.81	0.048
	14.07	12.97	0.083
	19.69	15.65	0.125
	25.30	17.20	0.128
Treated Soil	5.65	9.80	0.029
	8.45	14.40	0.072
	14.07	16.40	0.103
	19.69	22.50	0.064



Drained Shear Strength

Figure 14

between house # 10667 and house # 4629.

The other differences that we noted in our tests were due primarily to this fact. However, we did not wish to let the issue lie there.

Supposing that a particular clod of soil were surrounded by sufficient quantities of Fluid 705 to saturate it, which is rarely the case, we wanted to see how much of a change of soil properties could be effected soaking a sample of the soil in the fluid.

We treated some of the undisturbed samples in the lab by allowing the soil to become saturated with the fluid by capillary action. Some of the other samples were treated in the laboratory by soaking the soil for 72 hours in the fluid.

We airdried, ground up and remixed samples of soil from the two sites and ran tests of these re-constituted soils both in an untreated condition and in conditions of treatment by capillarity and flooding.

All of these variations were undertaken to see how much of a change can be effected by a thorough soaking treatment with the fluid. There were some striking changes in the measured properties of the soil. In the following paragraphs, the major differences we noted are summarized.

5.1 Field Differences

The soil at house # 4629 had more clay than the soil at house # 10667. The soil samples from house # 10667 showed many cracks and seams of gravel much more so than the samples from house # 4629. The soil at house # 4629 was more active than at house # 10667 having higher liquid limits and plasticity indexes. The water content was the same (31%) under both houses although the soil was drier outside of house # 10667 (21%) than outside of house # 4629 (25%). The higher water content under both houses is undoubtedly due, in part at least, to the post-construction injection of Fluid 705. However, because the soil beneath house # 10667 was more fractured and had more gravel seams, it was more receptive of the fluid. Its natural void ratio (0.71) is less than that at house # 4629 (0.88) but its post-treatment void ratio was higher (1.04) than at house # 4629 (1.00 average). Its free swell and swell pressure were altered more than at house # 4629. The pH under house # 10667 was higher (8.4) than outside the house (7.8) indicating that the high pH Fluid 705 had penetrated into the samples we took. However, no such evidence of change of pH was found at house # 4629 (7.8 - 7.9).

It is obvious from this recount of the results of our tests that Fluid 705 did have a positive effect on the soil at house # 10667 where the treatment was regarded as successful. On the other hand, the positive effects on the soil at house # 4629 were not as great, apparently because not as much of the fluid penetrated into the soil.

It is also apparent that successful treatment requires the soil mass to be fractured with frequent cracks and highly permeable gravel seams so that the fluid can surround and diffuse into the clods and peds of the less permeable clay soil. This condition was apparent at house # 10667 but not at house # 4629.

The mineralogy of the clay fraction of the soils on the two sites was virtually the same but the exchangeable sodium percentage of the soil at house # 10667 appeared to be greater than that at house # 4629. The permeabilities of the undisturbed samples presented a perplexing picture. The permeabilities of the undisturbed soil samples from beneath house # 10667 were around 100 times larger than those outside, whereas the permeabilities of undisturbed samples from beneath house # 4629 were around 100 times smaller than those outside. This peculiarity is one of the reasons we decided to run more tests on reconstituted soil from both houses to see whether such changes in permeability are reasonable in soil that have been carefully prepared in the laboratory.

5.2 Laboratory Differences

Laboratory treatment of reconstituted soil samples was much more thorough than can be achieved in the field. The permeability of the reconstituted soil was increased by a factor of 10 due to treatment by Fluid 705, indicating that the trend noted in the field samples taken from house # 10667 is in the proper direction. It is apparent that Fluid 705 will increase the permeability of a clay if the soil is treated properly with the fluid. As noted above, this may not be possible in the field unless there is a connected series of cracks, fissures, and highly permeable seams of granular soil that will permit the injected fluid to disperse throughout the soil mass.

The shear strength of the reconstituted lab samples was increased by about 40% by capillary treatment with Fluid 705.

Laboratory swelling tests on undisturbed and reconstituted soil samples showed that once Fluid 705 has been allowed to saturate and expand a soil, further expansion due to the entry of water into the soil is nil. However, tests on dry reconstituted soil showed that the soil will expand a large amount (6-12%) and will develop sizeable expansion pressures (1.5 - 20.0 ksf) when Fluid 705 enters the soil. So at least one effect of injecting Fluid 705 into a soil mass is to pre-swell it so that the potential for further swelling is reduced.

No significant difference was noted in the mineralogy of the soil from either site between samples measured before and after a 72-hour soaking with Fluid 705. A small alteration in the Atterberg limits was detected after soaking with the fluid.

The mechanism involved in the change of properties caused by the treatment with Fluid 705 has not been identified with certainty. However, most of the results obtained appear to indicate that the application of the fluid merely causes some "cementation" of the soil matrix.

The proprietor's original suggestion that the fluid causes mineralogical changes in the expansive clay minerals can certainly be disregarded. Montmorillonites are formed from basic rocks and require a basic environment for preservation; their known weathering products, chlorites and kaolinites, both form at pHs below 6 or lower; furthermore, at ambient pressure and temperature, any chemical changes would occur at extremely slow rates, requiring years for any significant change to take place. Nevertheless, the Fluid 705 is basic, the sample used in the laboratory test had a pH of 8.5; therefore, the fluid will not create an environment to degrade the expansive clays. These considerations were confirmed by the results of the mineralogical analysis and by the minimal changes of plasticity index induced by the treatment with liquid 705.

The alternative mechanism of cation exchange can also be disregarded as the cause of the observed changes. The only metal cations relatively abundant in Fluid 705 were sodium (3.9 molar) and potassium (1.8 molar). Neither one of these could be responsible of a diffuse double-layer depression since both are monovalent cations; as a consequence, these will not ause flocculation or aggregation of the clay matrix. There is, however, the unknown interaction of the organic matter in Fluid 705 with the clay matrix. Therefore, this process cannot be ruled out with certainty.

Excluding the clay-organic interaction, it appears that "cementation" is the only possible mechanism left out. This interpretation is also supported by the changes observed upon treatment with the Fluid 705. The increase in shear strength occurred mainly as a change in cohesion of the material, as could be expected from a "cementation" of the soil matrix; the treated soil was more brittle, reaching failure at lower strain levels, also a typical effect of "cementation." From visual inspection, it was apparent, besides a change in color, that the soil had been "cemented;" it appeared more homogeneous and strengthened. This was specially apparent where breaking down treated soil clods in the preparation of the soil for the Atterberg Limit test. Furthermore, the much lower elastic recoveries upon unloading in the consolidation cell, also appear to indicate, that to a certain extent the stresses were trapped and full recovery was not allowed by some "cementation" of the matrix.

All above considerations point out to "cementation" as the responsible mechanism of the observed behaviour. However, there is not enough information available on the chemical composition of Fluid 705 to permit a definition of a chemical process by which this "cementation" takes place. Two possible alternatives include the formation and precipitation of carbonates with the soluble cations in the soil solution, such as calcium, magnesium, sodium, etc; the second possibility, probably more remote, would include the increase of solubility of aluminates caused by the increase in pH and their combination with silica and calcium to form tricalcium aluminates or similar cementing products.

5.3 Conclusions

House # 10667 was sucessfully treated with Fluid 705 and House # 4629 was not. The fluid has properties which alter the physical and chemical characteristics of the soil to reduce its swelling potential and to increase its strength, pH, and permeability. However, in order for these effects to be produced, concentrated quantities of the fluid must be dispersed throughout the soil mass, surrounding and permeating the individual blocks, clods, and peds of the soil. This process is greatly assisted by the presence of cracks, fissures, and highly permeable seams of non-clay granular soils such as gravel and clean sand. Because the permeability of the clayey soil remains low even through it may be raised by a factor of 10 by treatment, it would be unwise to think that the fluid permeates more than about an inch a year into intact soil (i.e. soil without cracks).

In seeking a site in which Fluid 705 can be used successfully it is considered essential to locate soil with a well developed system of cracks and gravel or clean sand seams laced throughout the soil mass. This can be determined by taking undisturbed core samples and investigating the individual samples as they are extruded from the sampling tube.

Injection of the fluid causes the soil mass to swell a large amount. If we are to believe the initial void ratios outside and inside of house # 10667, the change of void ratio was from 0.71 to 1.04, an increase of volume strain of (1.04 - 0.71)/1.71 or 19 percent! After the fluid has been injected, and provided that it has been able to permeate into the small clay blocks, clods, and peds there will probably be little additional swelling due to the entry of water into the soil. Because of this large swelling upon injection of the fluid, it is wise to remove the basement slab completely before performing the injection, as in practice that is normally done anyway to provide access for the injection tools.

Many other conclusions of a more detailed nature may be made on the basis of the data collected in this project. Many of these have been mentioned or alluded to in those sections of this report which deal with each specific test that was made.

In summary, Fluid 705 will work to stabilize expansive soil but is highly dependent upon the cracked and seamed nature of the soil mass on site for its successful application.

APPENDIX A

X-RAY DIFFRACTION SAMPLE PREPARATION PROCEDURES

M Saturation Procedure

1. Disperse in pH 10 Na_2CO_3 solution. If the sample and solution will not disaggregate by simple hand shaking, place the sample and solution in the ball mill (Rm.3) for 5-10 minutes.

2. Pour the mixture into test tubes that are all the same size. All the test tubes must be the same weight. The centrifuge will not work correctly unless the test tubes are equal weight. When placing the test tubes within the centrifuge holders, make sure the rubber stoppers in each holder are there because the centrifuge will be unbalanced if they are not.

3. Centrifuge for 2.5 minutes @ 600 rpm. This must be precisely accurate and do not use the brake to stop the centrifuge, let it stop by itself.

4. Decant of the clays and save the coarse fraction to use for SEM work if needed.

5. Add 1N MgCl and balance all the tubes to equal weights.

6. Centrifuge for 5 minutes @ 1500 rpm.

7. Decant liquid off shlowly so that one does not pour the clays off because sometimes the clays are not completely centrifuged to the bottom of the test tube and will pour off with the liquid.

8. Agitate on the vortex for 30 seconds. This allows the clays to completely and evenly absorb the Mg^{2+} ions.

9. Add 1N MgCl and balance all tubes to equal weights.

10. Centrifuge for 5 minutes @ 1500 rpm, decant.

11. Repeat steps 9 and 10 two more times. Total MgCl saturations = 3.

12. Add 50% ethanol and balance all tubes to equal weights.

13. Agitate on vortex for 30 seconds.

14. Centrifuge for 5 minutes @ 1500 rpm, decant.

15. Add acetone (90% in H_2O) and balance all tubes to equal weights.

16. Agitate on vortex for 30 seconds.

17. Centrifuge for 5 minutes @ 1500 rpm, decant. At this point, the supernate should be clear.

18. Add 10% glycerol in ethanol. This is a crucial step. If there is lots of clay remaining in the test tube, then add 4 to 6 drops; if there is a very small amount of clay remaining in the test tube, then add 1 to 2 drops at the most.

19. Agitate on vortex for 30 seconds.

20. Add distilled H_2O, drop by drop, with intermitant agitation after every drop on the vortex until a slurry is produced. Too much H_2O will cause one to have a watery smear that is virtually useless.

21. Let smear dry under watch glass to prevent contamination from dust particles and destruction of the slides.

    Run once at 25^oC.

K Saturation Procedure

1. Disperse in pH 10 $Na_2 CO_3$.

2. Centrifuge 2.5 minutes @ 600 rpm to separate clays. Again, this must be accurate.

3. Decant clays.

4. Agitate on vortex.

5. Add KCl solution and balance all tubes to equal weights.

6. Centrifuge for 5 minutes @ 1500 rpm, decant.

7. Repeat steps 4, 5, and 6 three more times. Total KCl saturations = 4.

8. Decant after last run, agitate on vortex, then add distilled H_2O and balance all tubes to equal weights.

9. Centrifuge for 5 minutes @ 1500 rpm, decant.

10. Agitate on vortex, then add <u>50%</u> ethanol and balance all tubes to equal weights.

11. Centrifuge for 5 minutes @ 1500 rpm, decant.

12. Agitate on vortex, then add <u>95%</u> ethanol and balance all tubes to equal weights.

13. Centrifuge for 5 minutes @ 1500 rpm, decant.

14. Add distilled H_2O, drop by drop, until it slurrys. Be careful, too H_2O will yield a watery smear that is virtually useless.

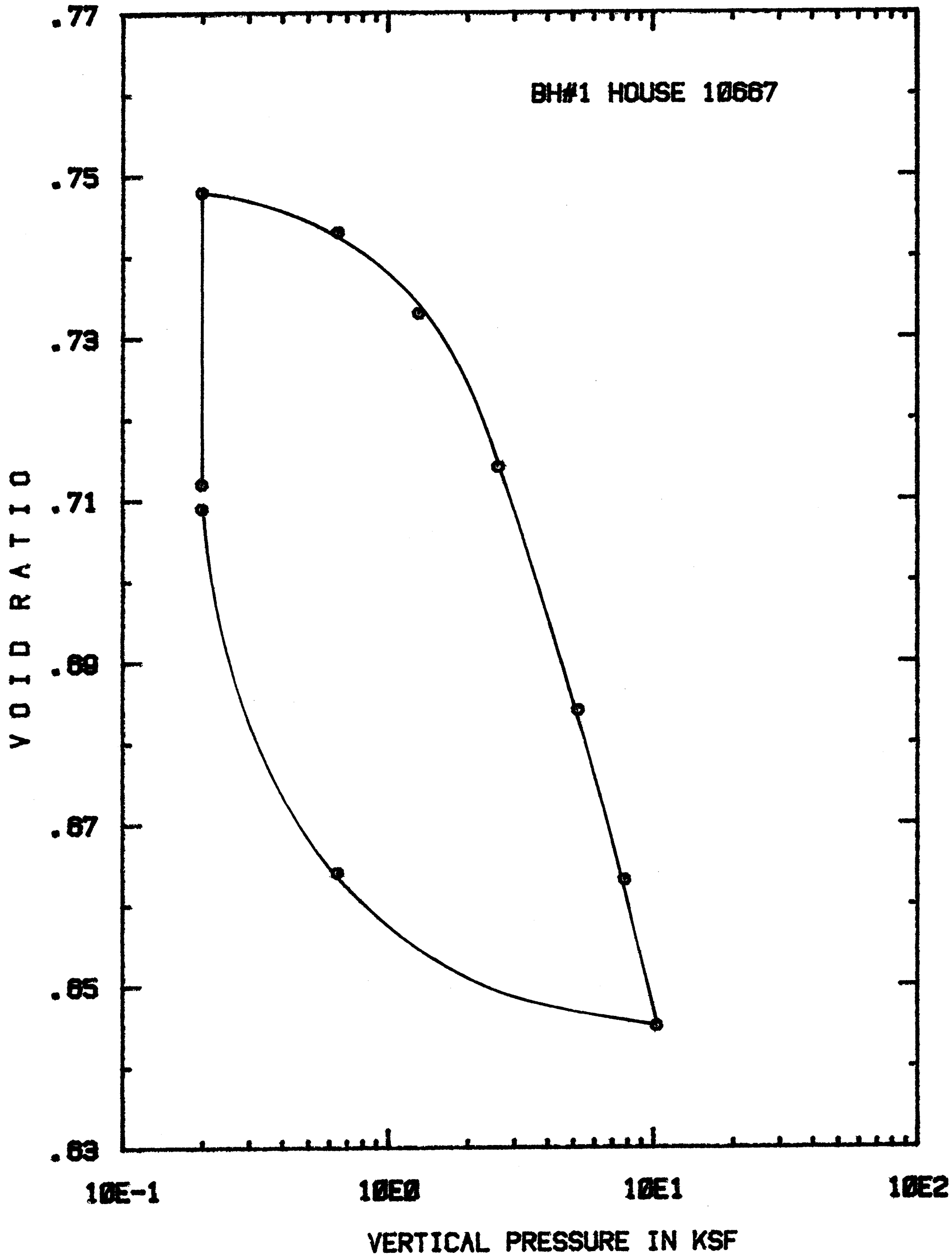
Run once @ $25^{o}C$.

Heat for 2 hours @ $300^{o}C$ and rerun after cooling.

Heat for 2 hours @ $550^{o}C$ and rerun after cooling.

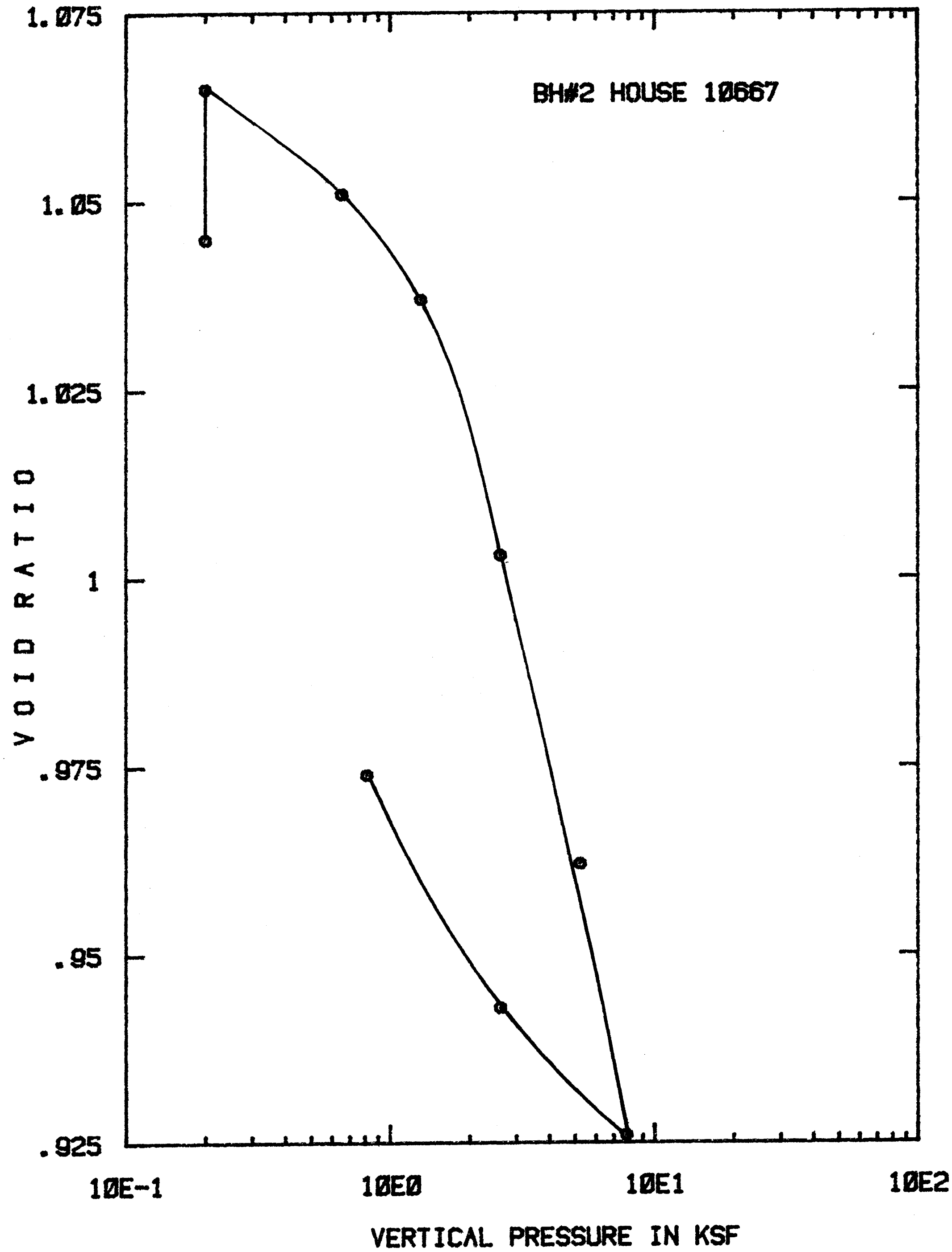
APPENDIX B

ADDITIONAL LABORATORY RESULTS



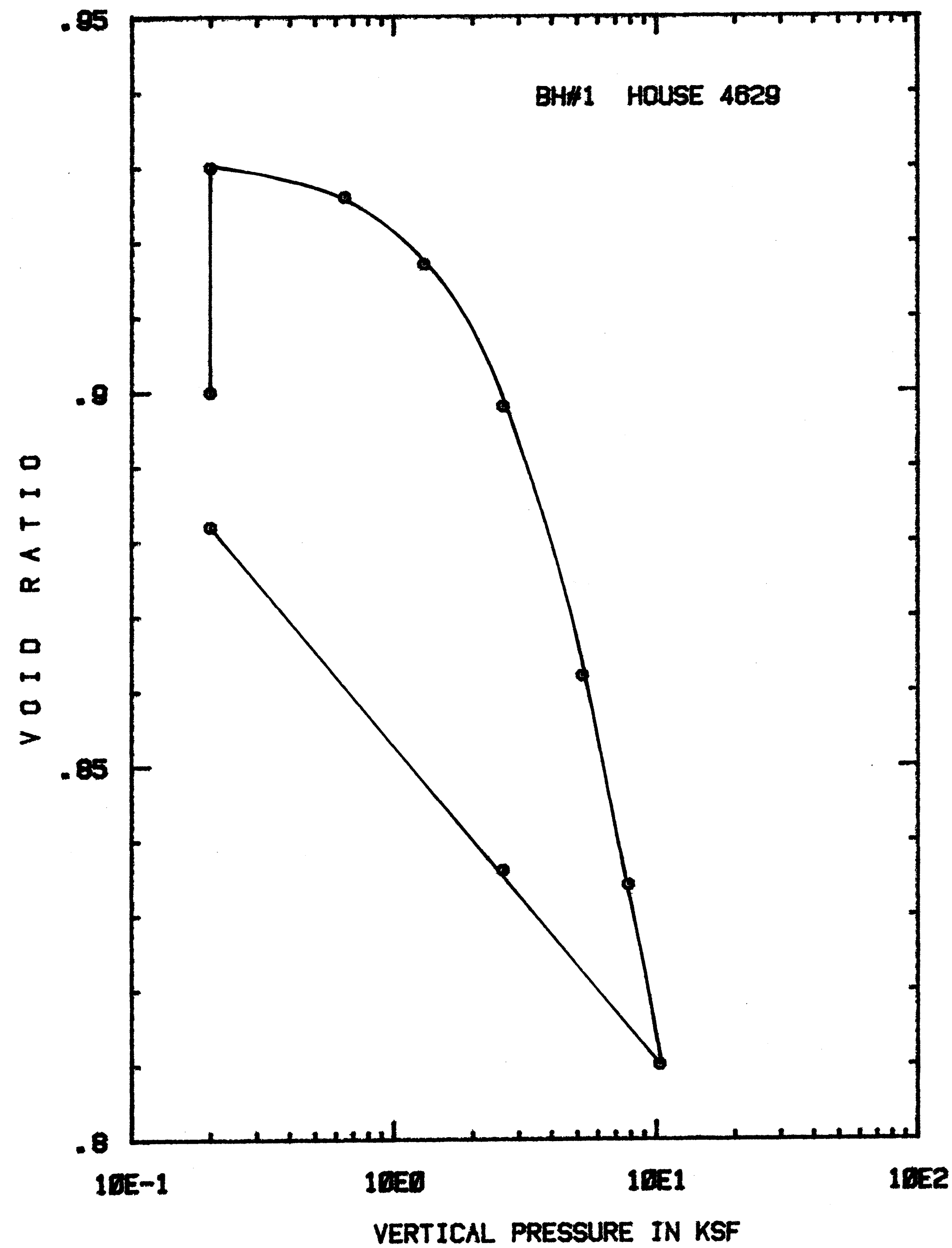
Consolidation Test - Undisturbed Sample Outside the House

Figure B1



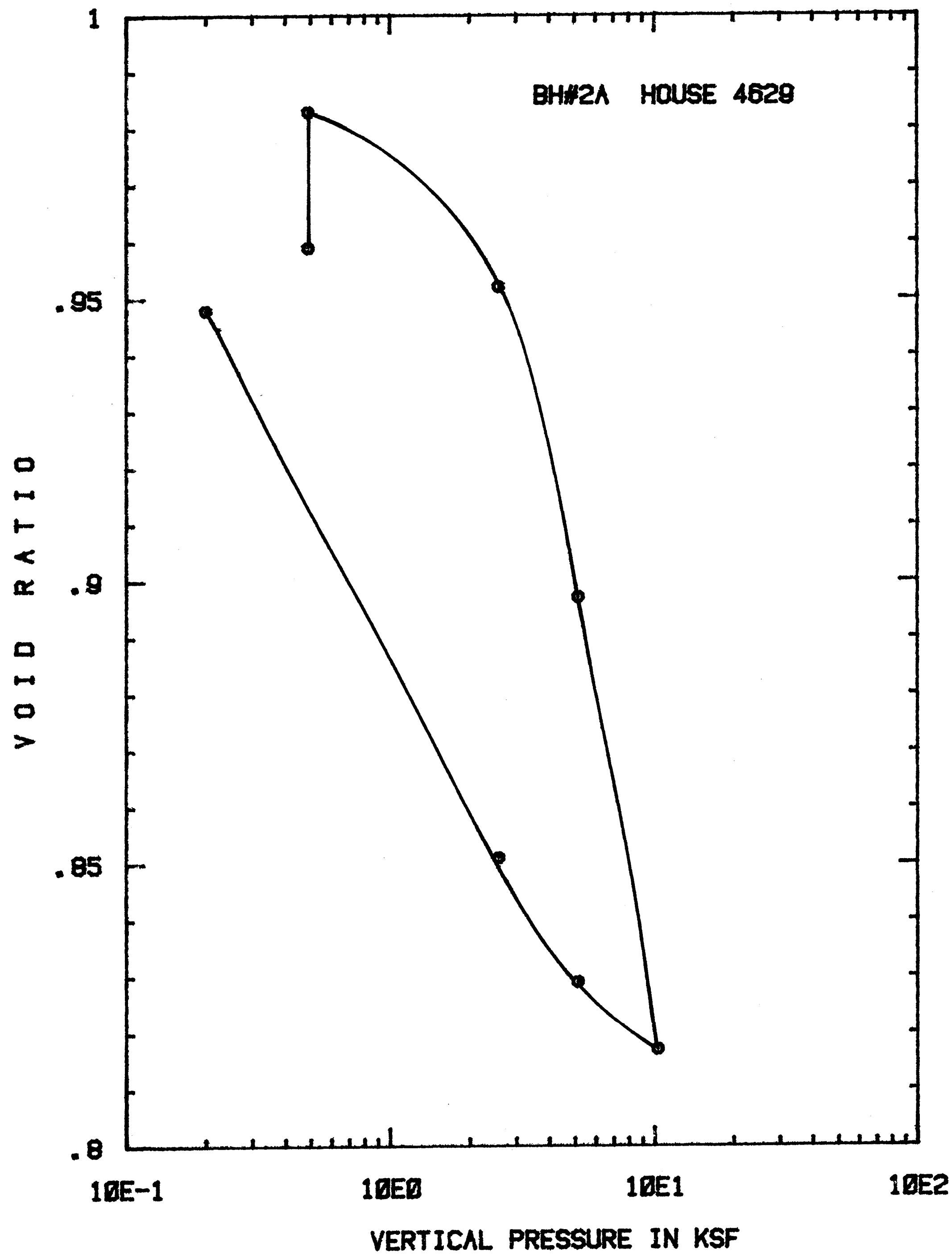
Consolidation Test - Undisturbed Sample Inside the House

Figure B2



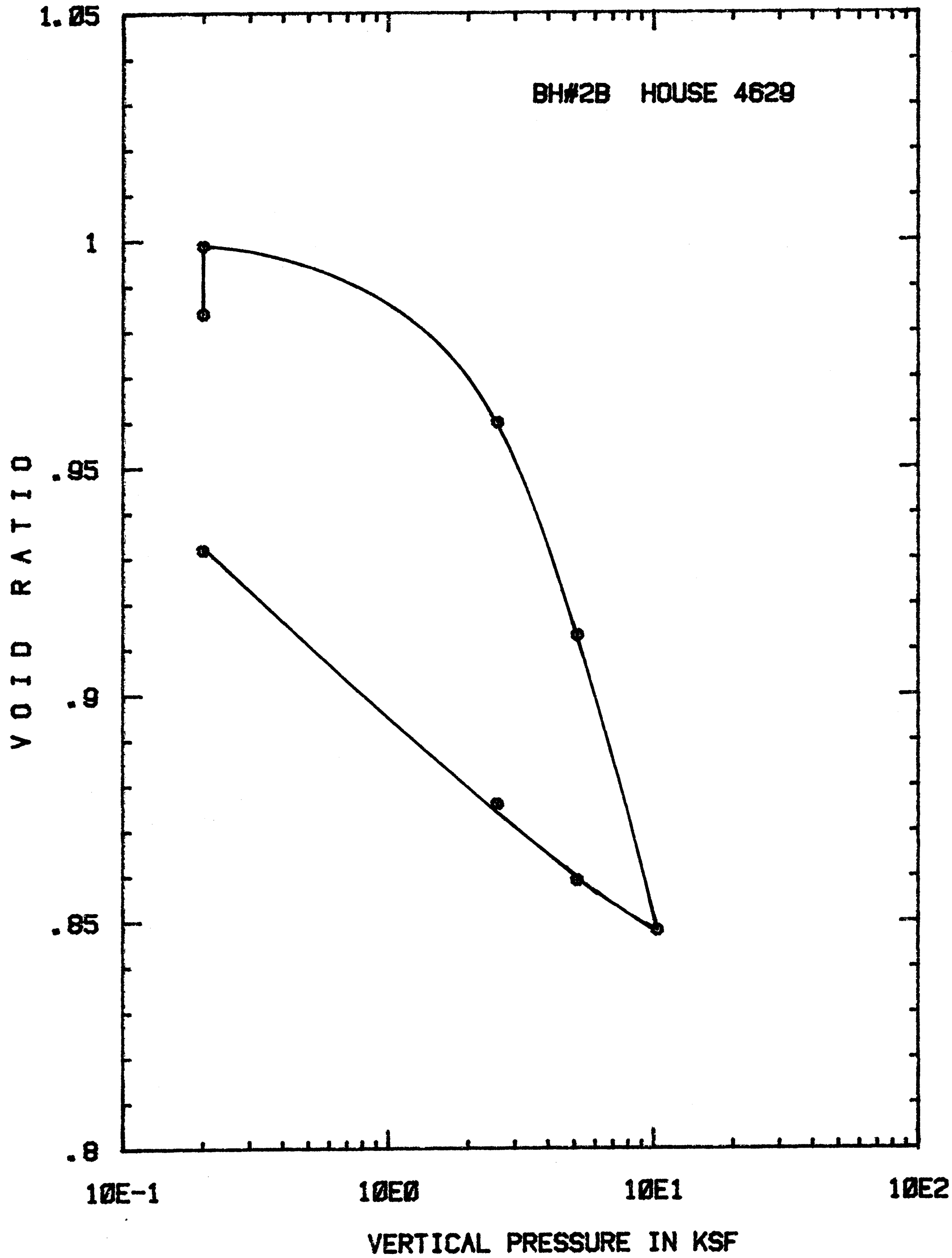
Consolidation Test - Undisturbed Sample Outside the House

Figure B3



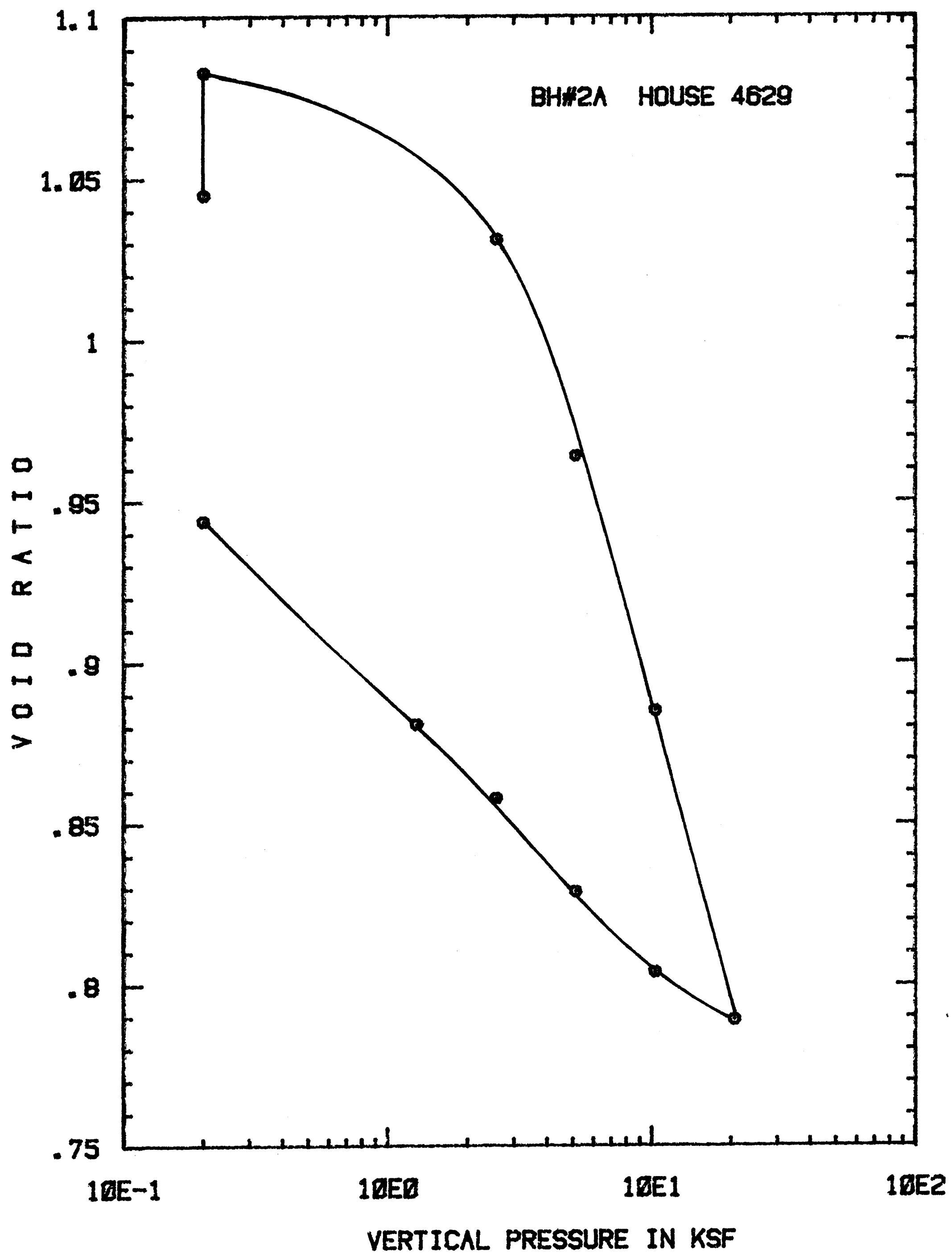
Consolidation Test - Undisturbed Sample Inside the House

Figure B4



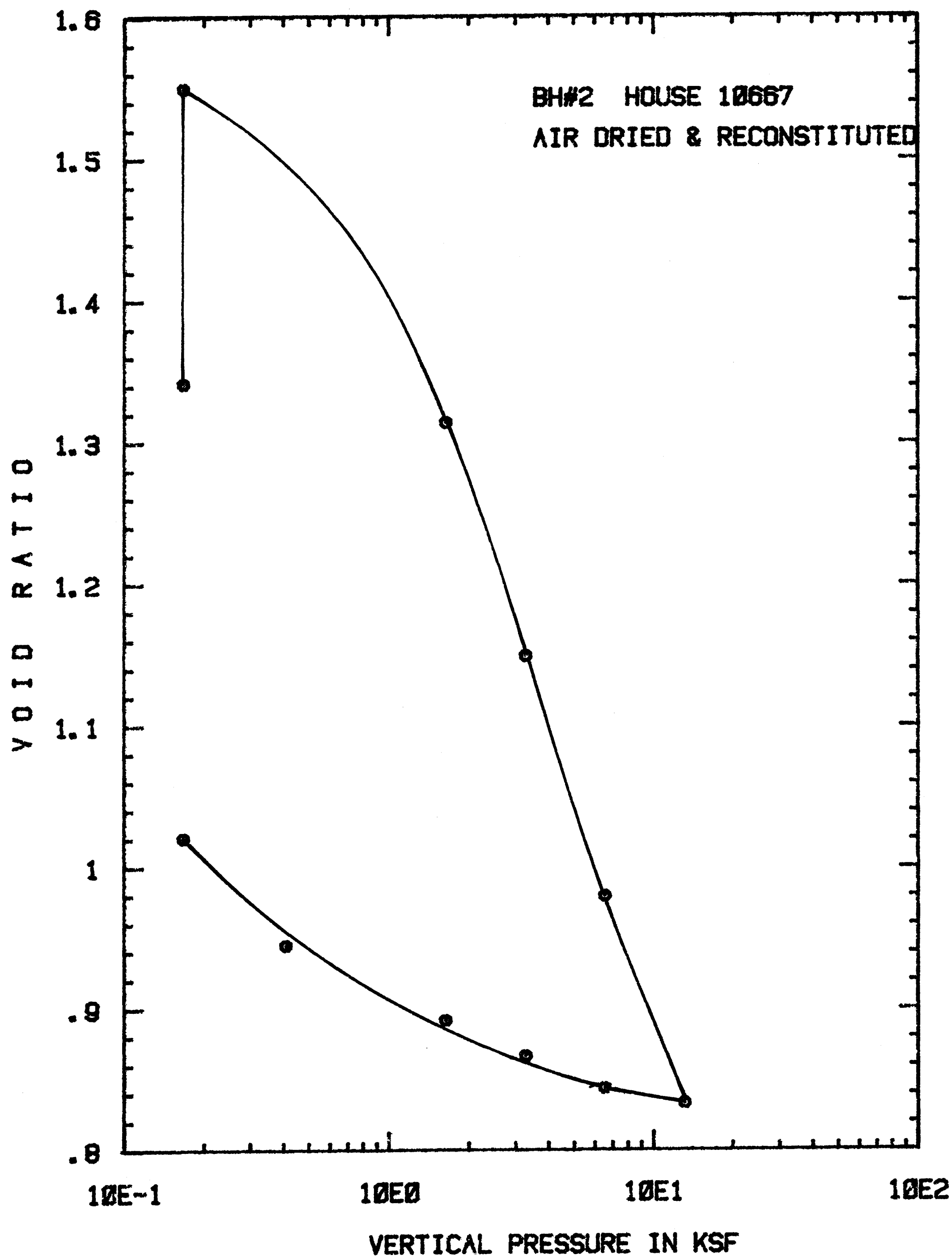
Consolidation Test - Undisturbed Sample Inside the House

Figure B5



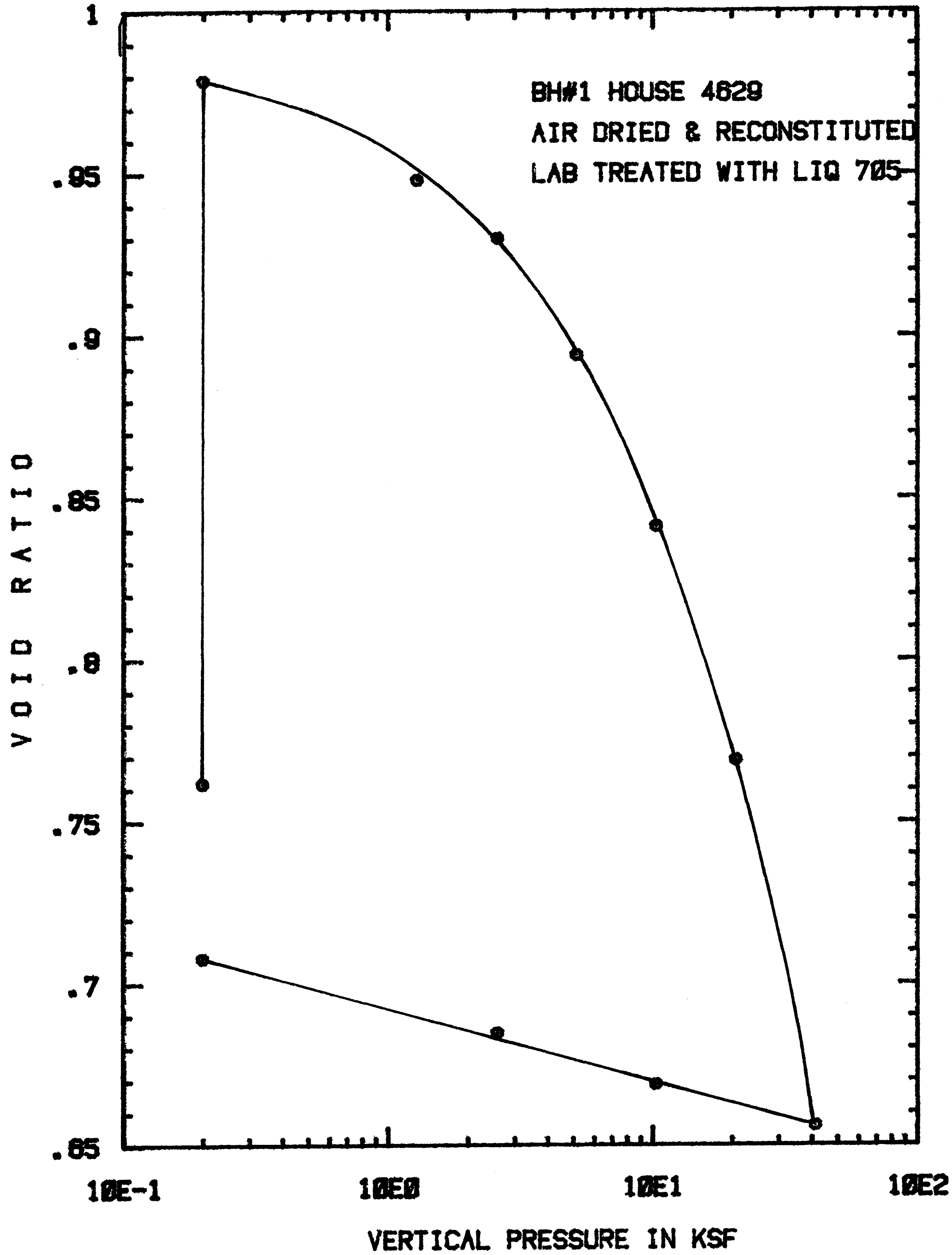
Consolidation Test - Undisturbed Sample Inside the House

Figure B6



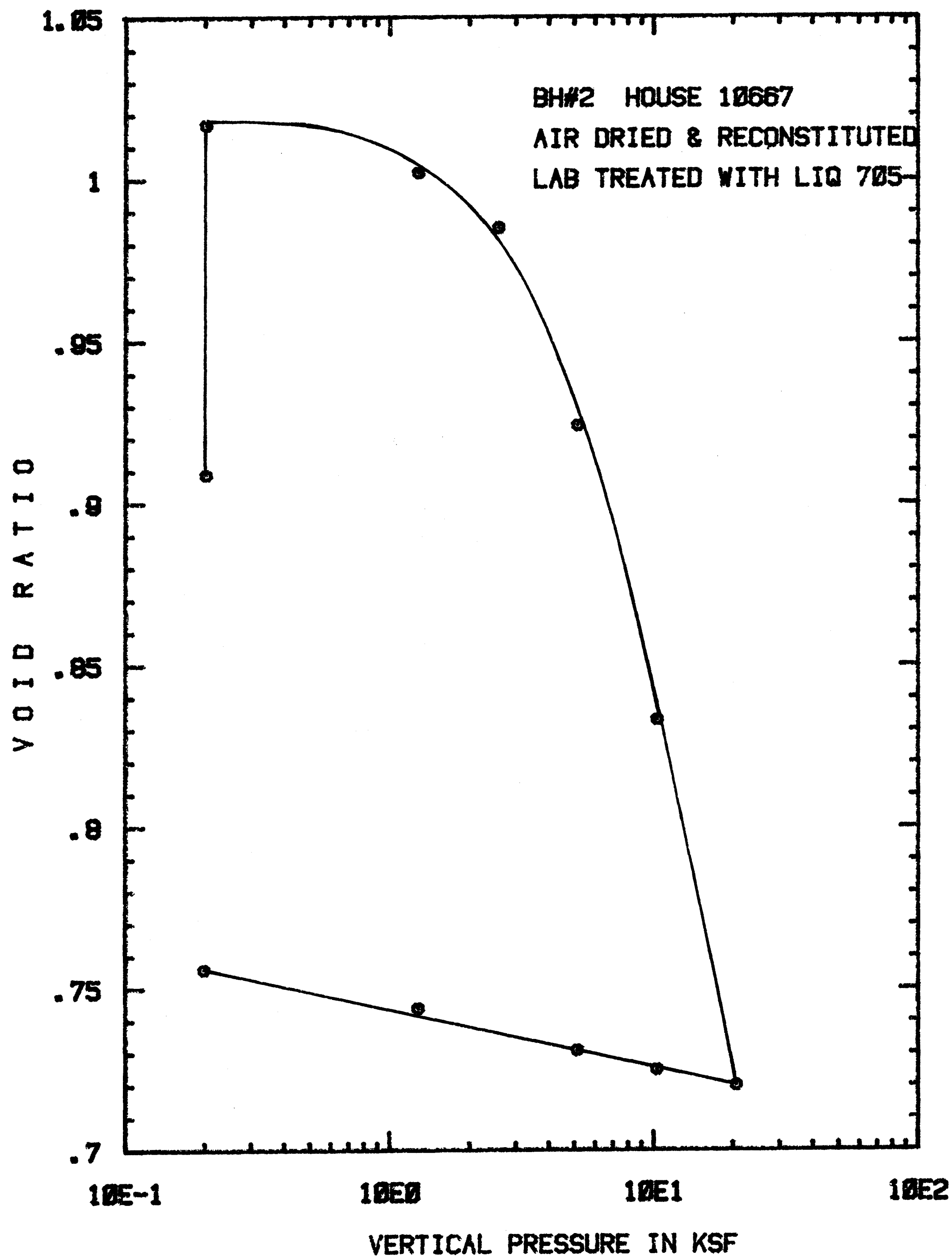
Consolidation Test

Figure B7



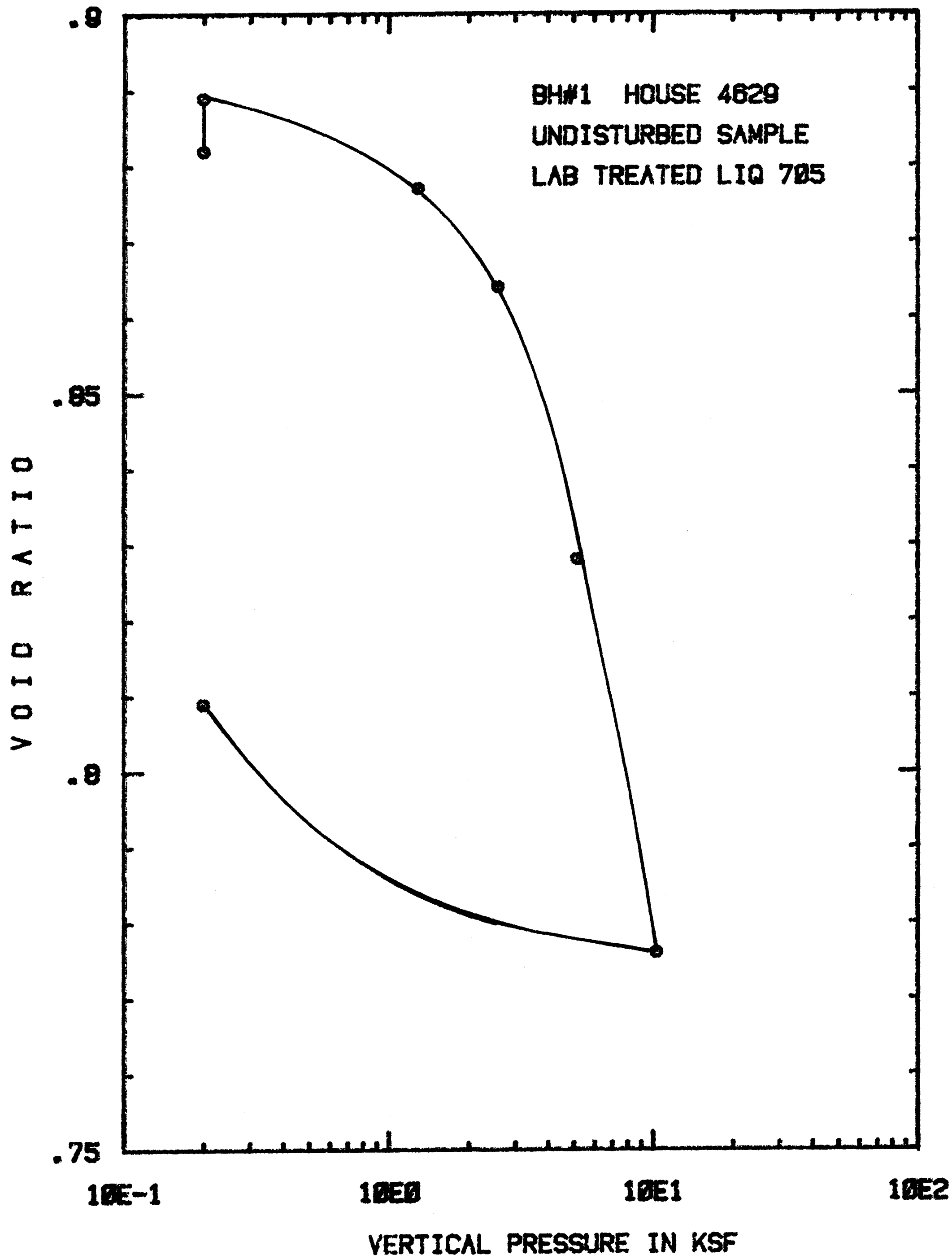
Consolidation Test

Figure B8



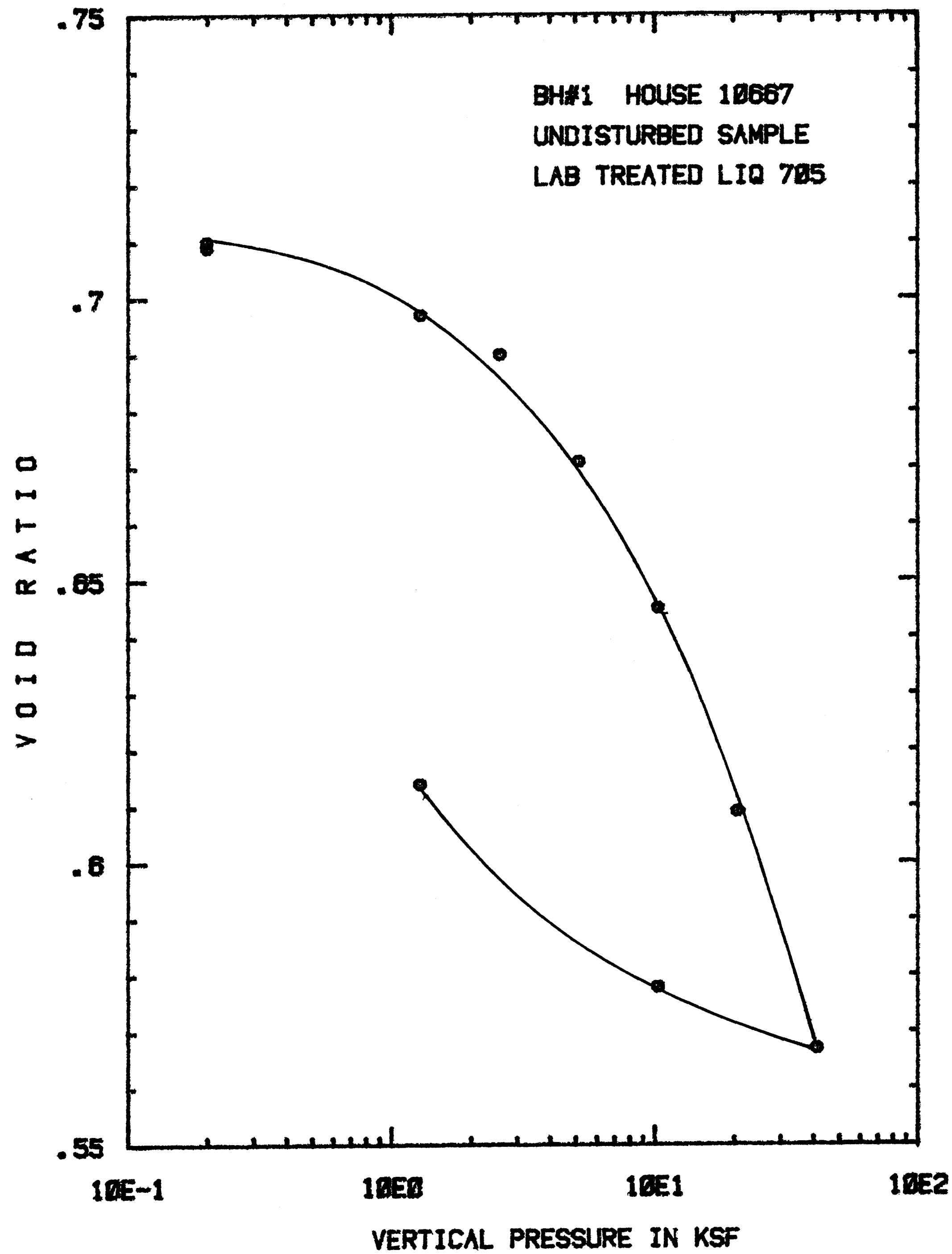
Consolidation Test

Figure B9



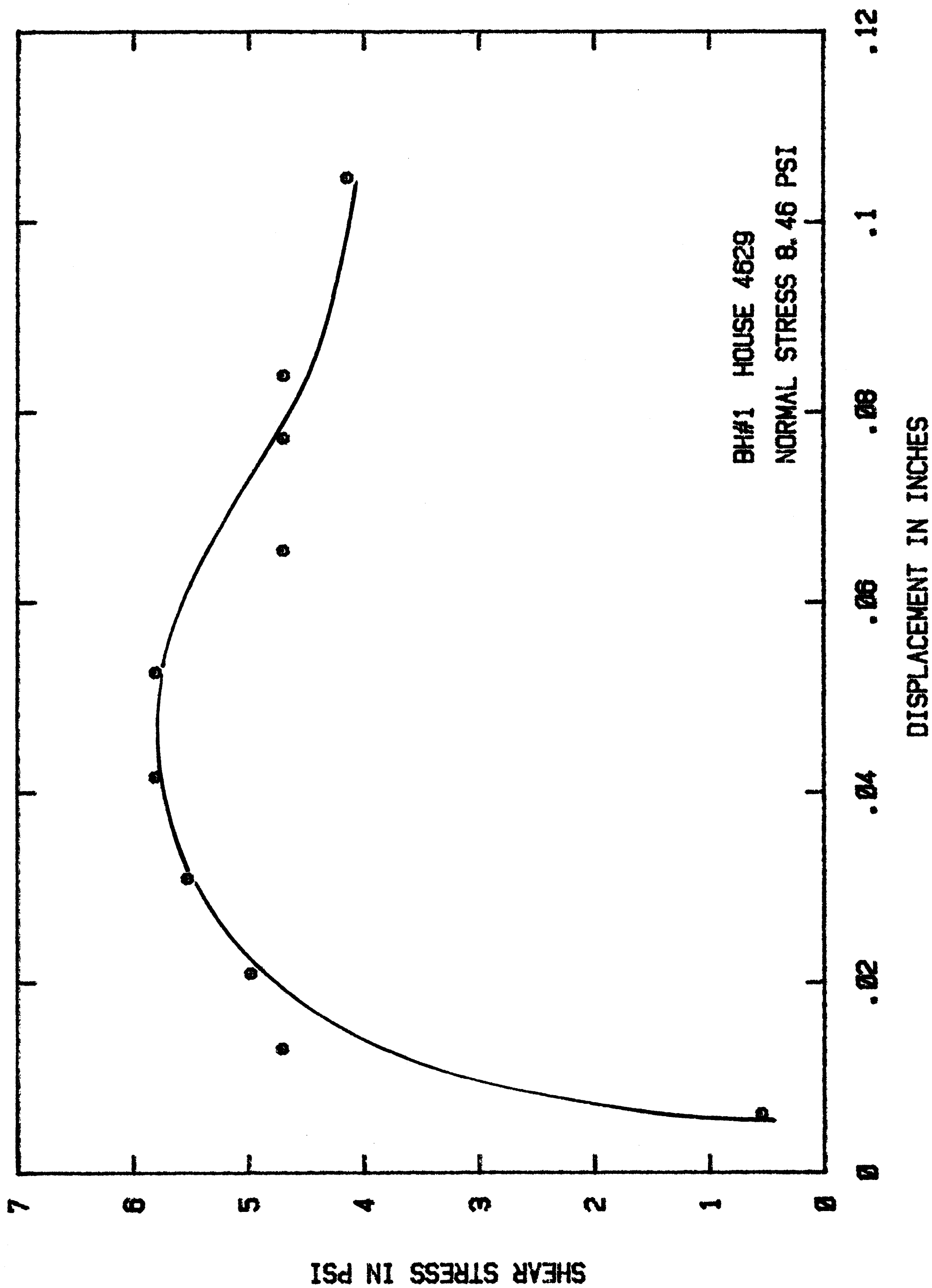
Consolidation Test

Figure B10



Consolidation Test

Figure B11



Drained Direct Shear Test

Figure B12

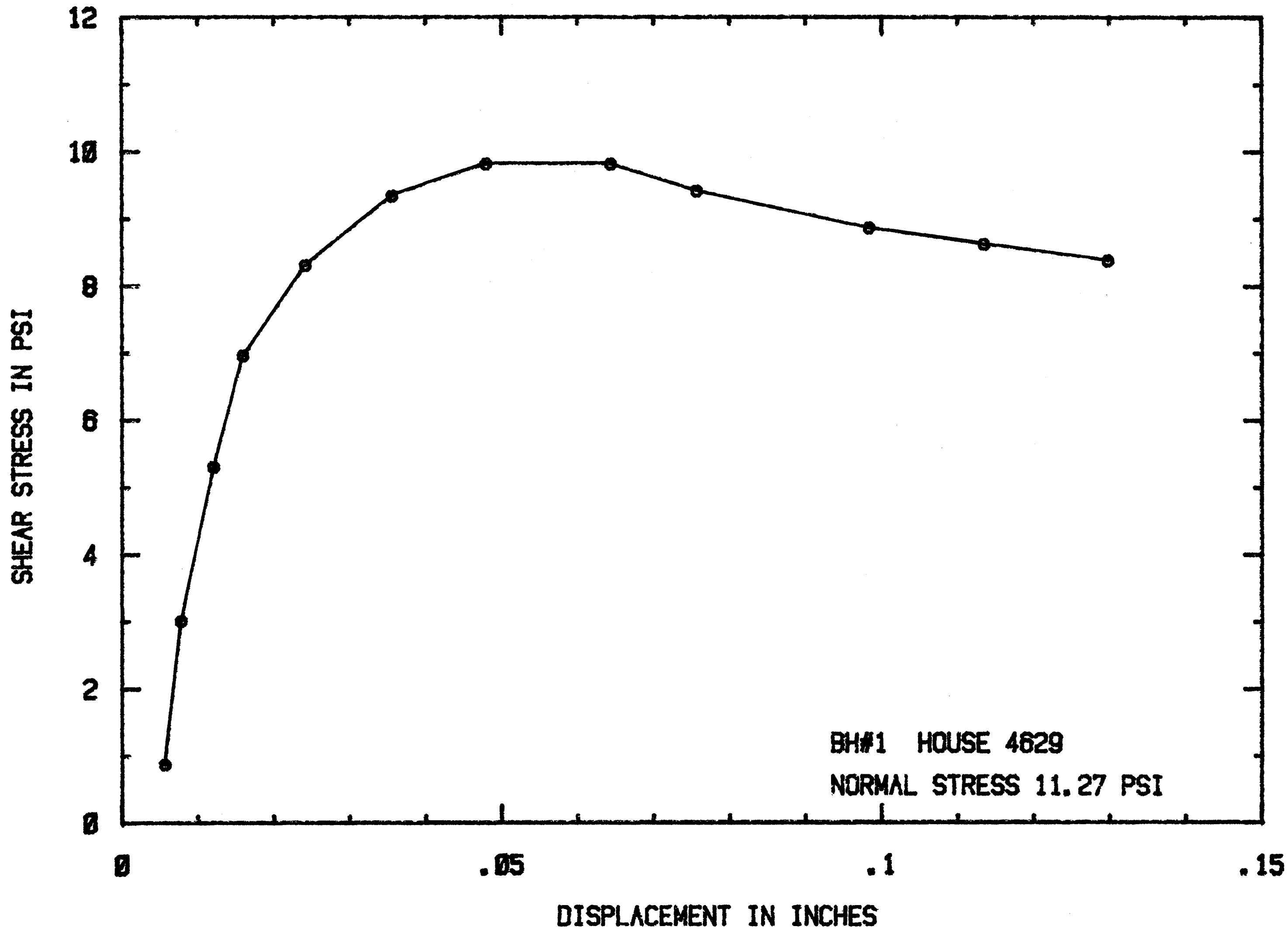
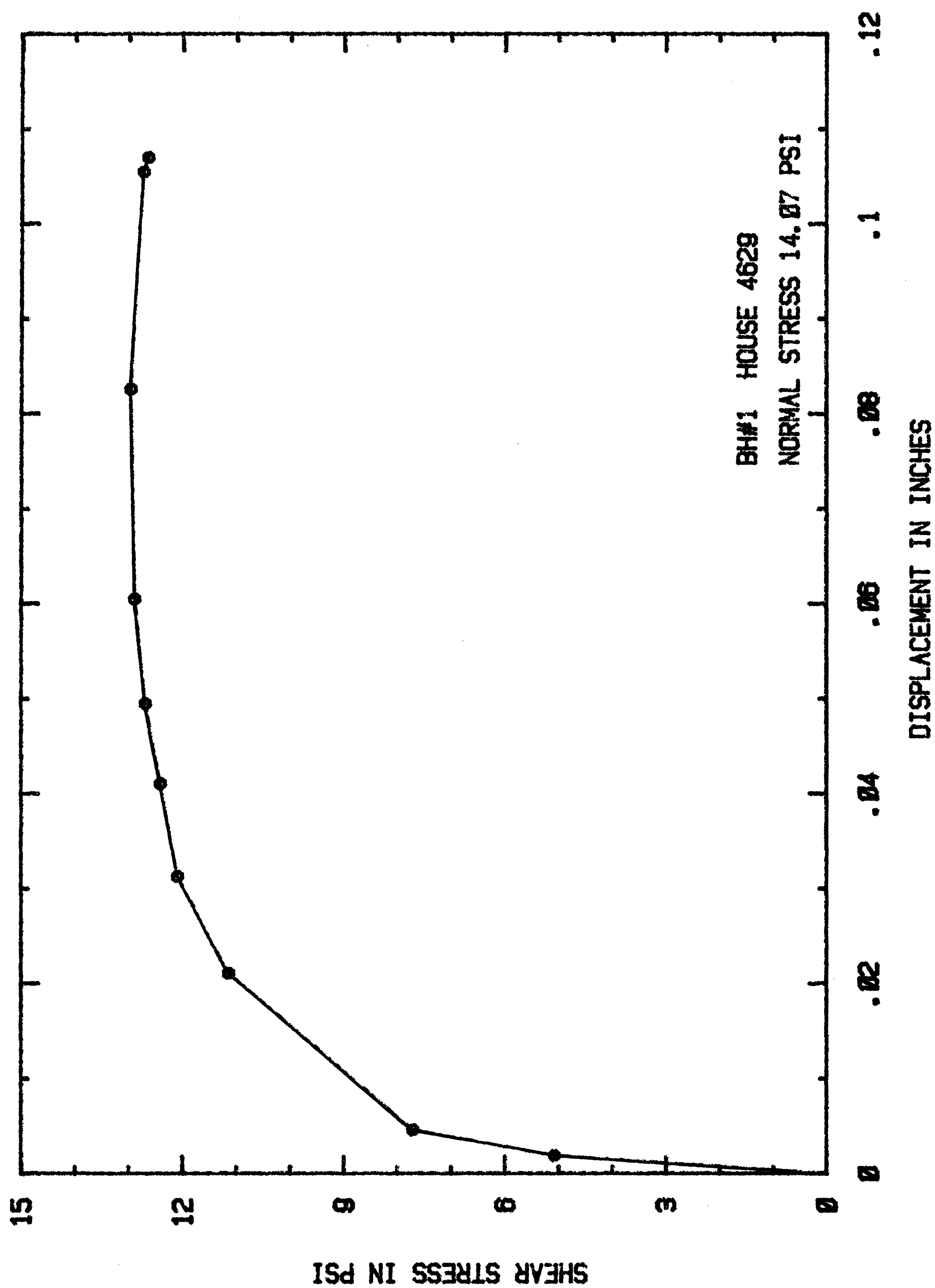


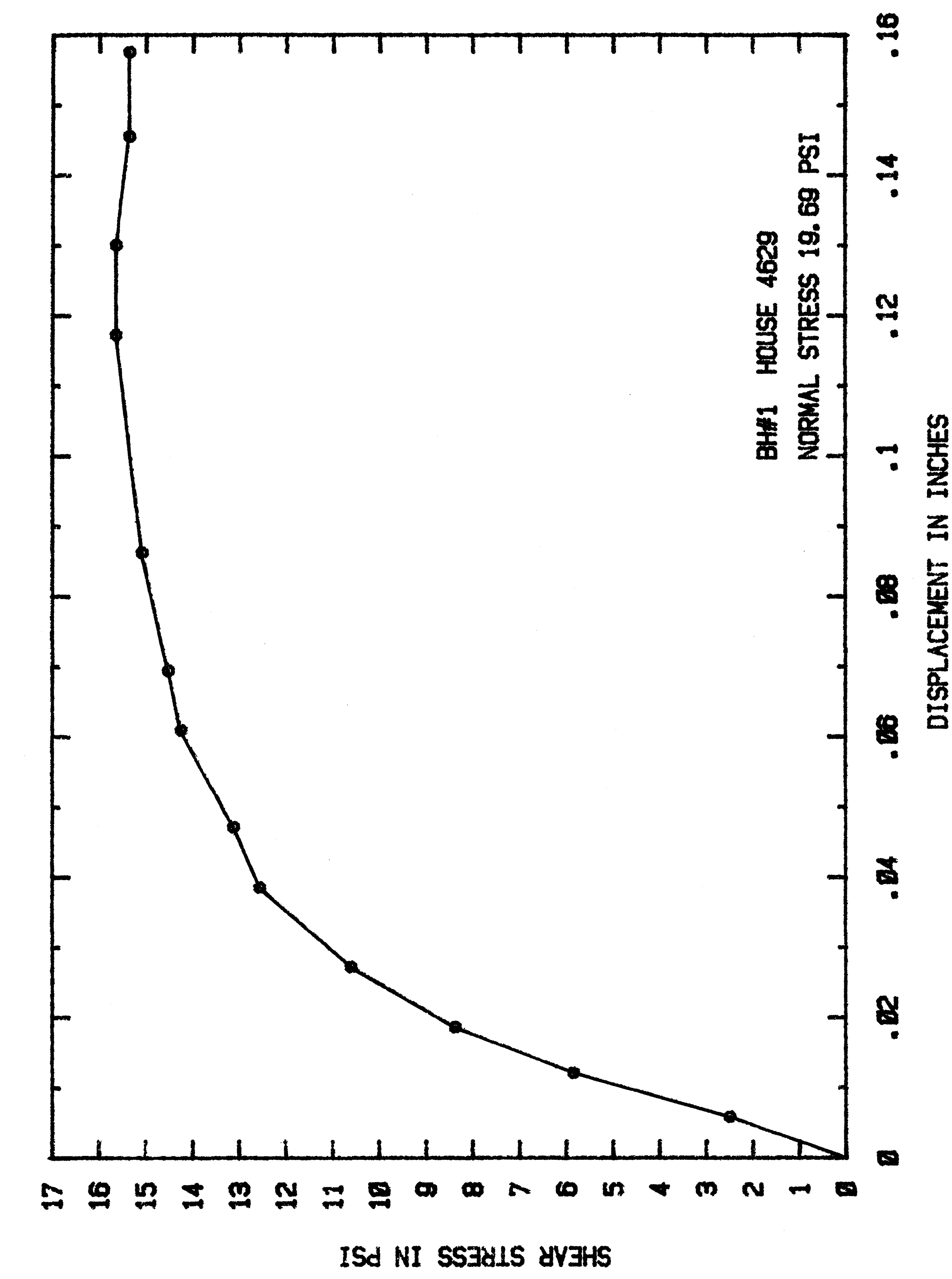
Figure B13

Drained Direct Shear Test



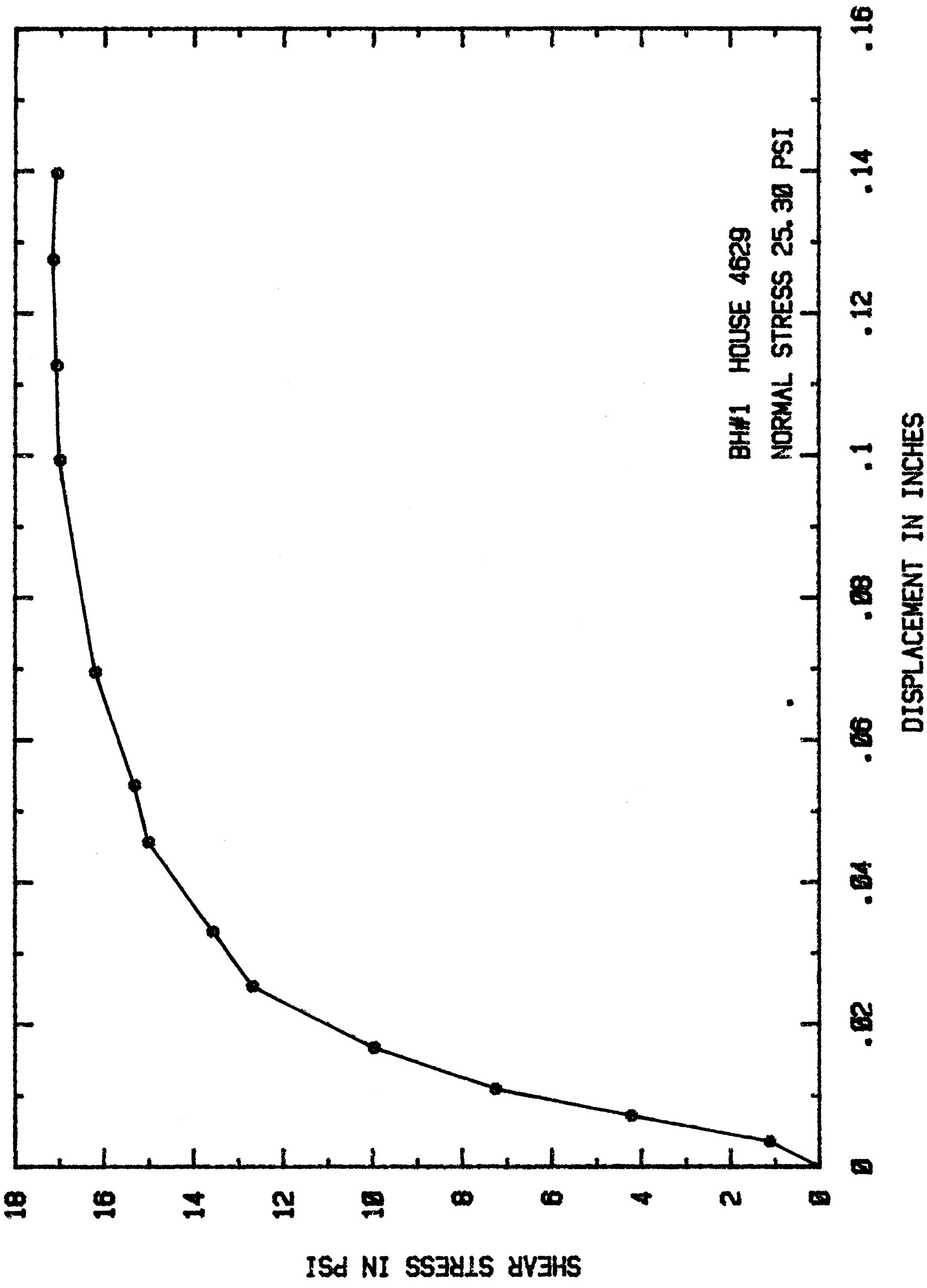
Drained Direct Shear Test

Figure B14



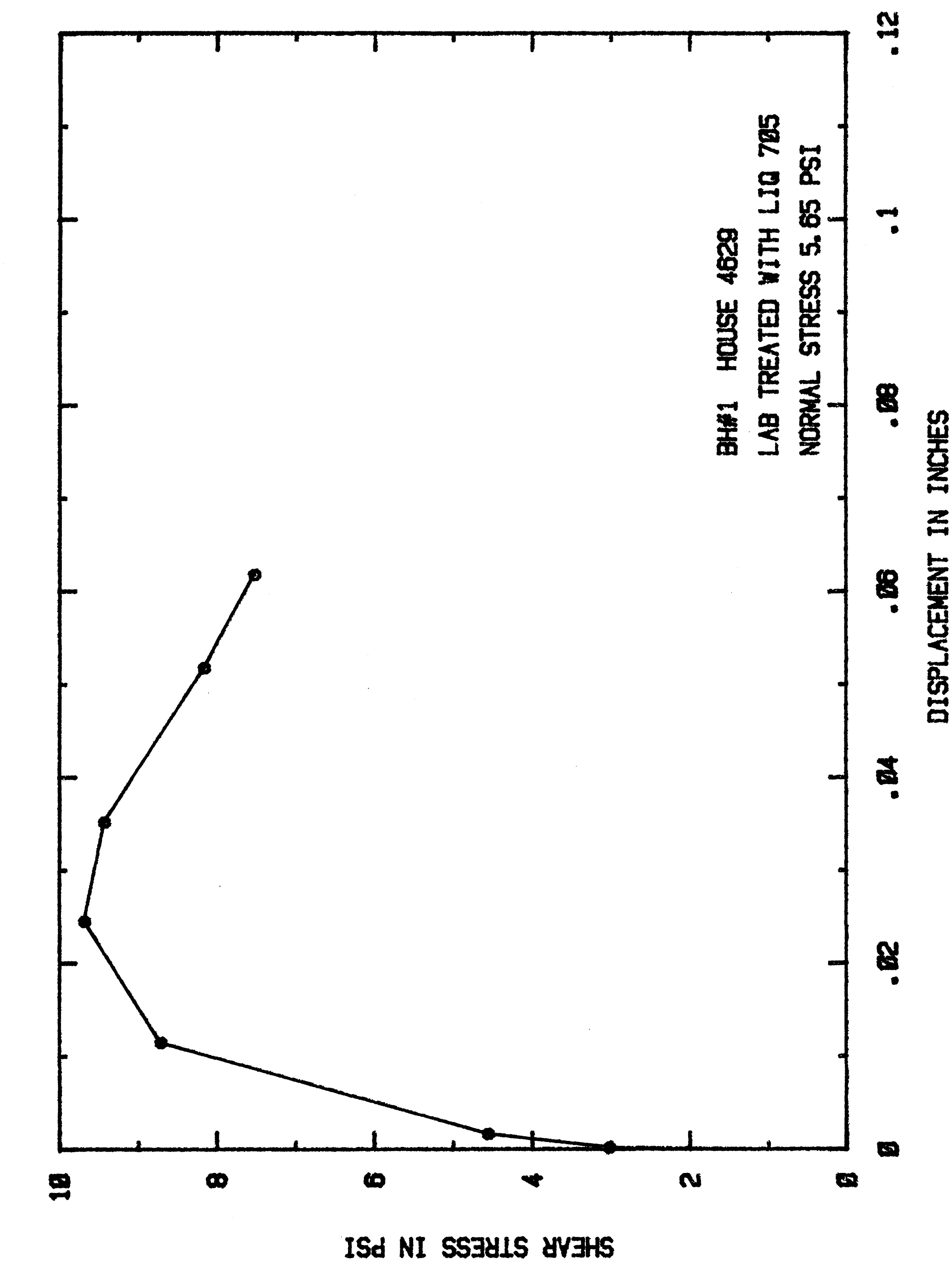
Drained Direct Shear Test

Figure B15



Drained Direct Shear Test

Figure B16



Drained Direct Shear Test

Figure B17

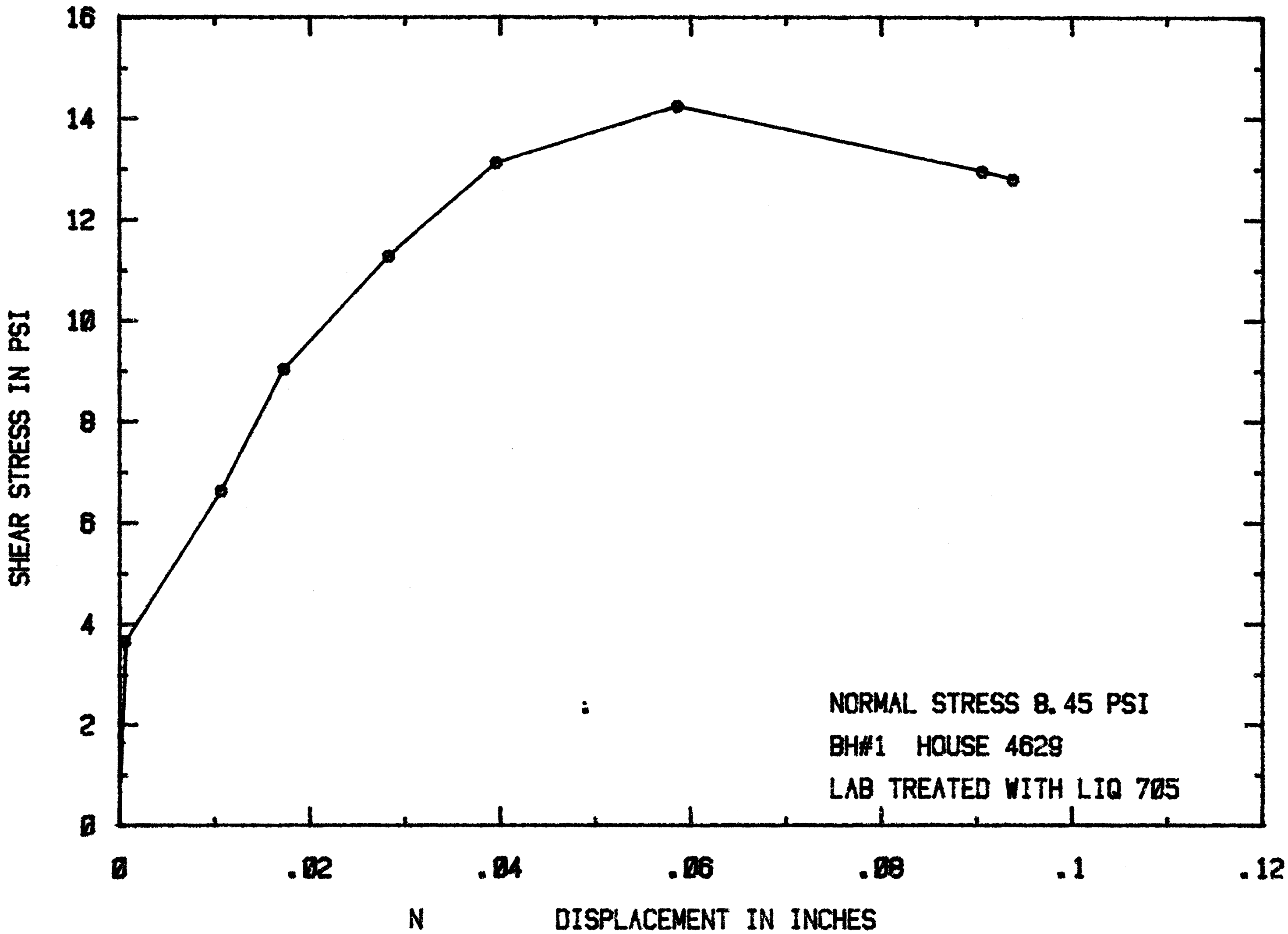
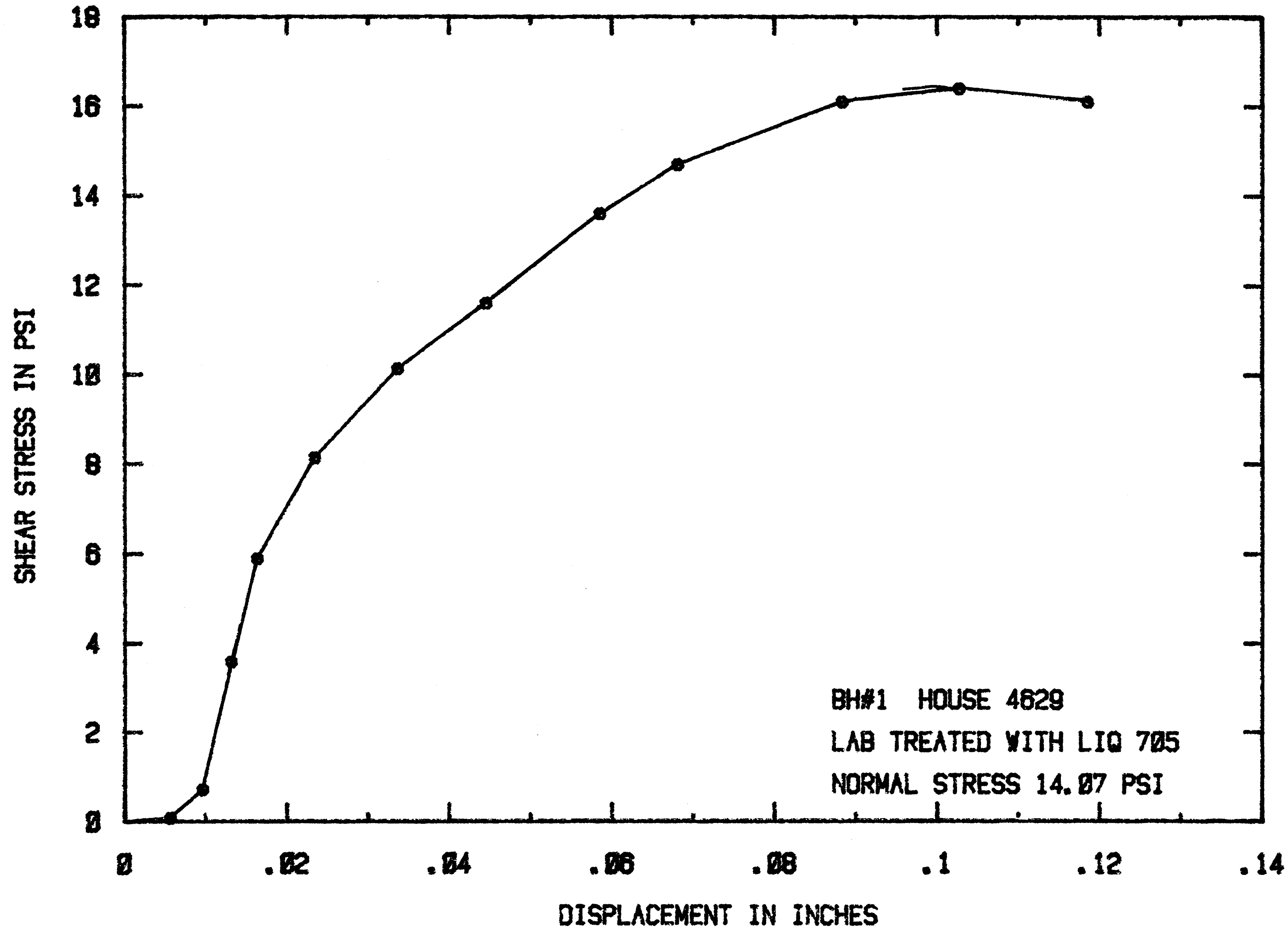


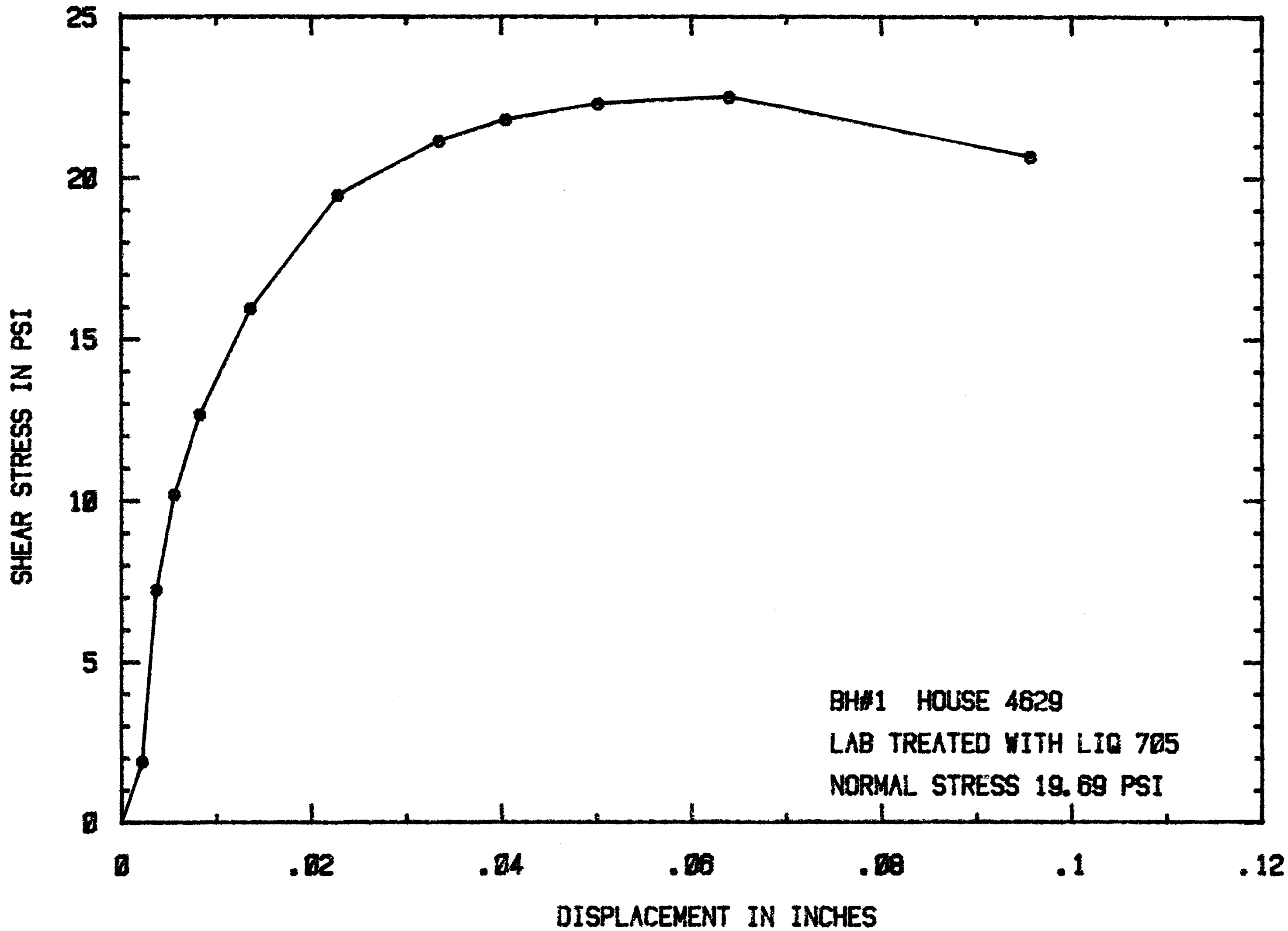
Figure B18

Drained Direct Shear Test

Figure B19



Drained Direct Shear Test



Drained Direct Shear Test

Figure B20

APPENDIX C

DESCRIPTION OF SOIL SAMPLES AFTER EXTRUSIONS FROM THE SHELBY TUBES

During extrusion, each sample was split into several pieces. The appearance of the ends of the trimmed pieces of samples was not uniform. The visual descriptions of these samples are summarized as follows:

House # 4629

Borehole # 1 This sample was split into four pieces with lengths approximately, 12, 5, 4, and 3 inches. The 12 inch piece had highly fissured dark gray clay on one end and dark brown clay with some sand on the other end. The 5 inch piece had similar characteristics at both ends and a cross sectional view of this sample is shown in Fig. C-1. This piece was essentially in two pieces due to the presence of equal amounts of clay and sand.

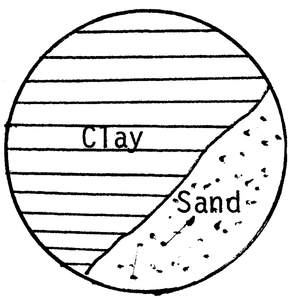


Fig. C-1

Both the 4 inch and 3 inch pieces had similar features. The 4 inch piece appeared to be split in the middle due to the presence of equal amounts of clay and sand at one end. The other end was predominantly clay. The 3 inch piece had sand at one end.

Borehole # 2a The sample from this borehole was split into two pieces of approximately 4 and 5 inches in length. The 4 inch piece had highly disturbed brown clay at one end and greenish gray silty clay with sand lenses at the other end. The 5 inch had greenish gray clay at one end and dark gray clay at the other end.

Page C-2 missing from original.

Borehole # 2b This core was split into two pieces of 10 and 4 inches in length. The 4 inch piece had sand at one end and a mixture of sand and highly fissured dark gray clay at the other end as shown in Fig. C-2. The 10 inch piece had sand at one end and highly disturbed clay at the other end.

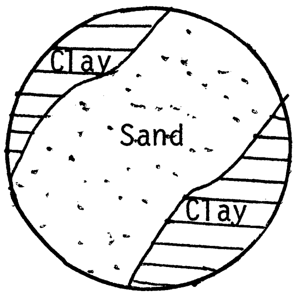


Fig. C-2

House # 10667

Borehole # 1 This core was split into three pieces of 10, 5, and 4 inches in length. All the pieces had the same appearance of yellowish brown sandy clay with some gravel.

Borehole # 2 This core was split into three pieces of 10, 6, and 6 inches in length. The 10 inch piece was very wet and had a longitudinal void along the core. The soil appeared to be highly disturbed. The other two 6 inch pieces had an appearance similar to that seen in Borehole # 1.

APPENDIX D

PHYSICO CHEMICAL PROPERTIES OF FLUID 705

A subsample of the Fluid 705 was used to determine the physico-chemical properties of this stabilizing agent. The physical properties included the boiling point temperature, the density, and the total amount of dissolved solids. The dissolved solids determination was implemented by oven drying a known volume of fluid at 150°C. The results of these tests are presented in Table D-1 below:

TABLE D-1

Physical Characteristics of Fluid 705

Boiling Point Temperature (°C)	100 - 102
Density (gram/milliliter)	1.2112
Total Dissolved Solids (gram/milliliter)	0.35

The pH of the Fluid 705 was measured to be 8.6. The chemical composition was then attempted by identifying those more current ions that could be expected in solution in significant amounts at that pH. The results are summarized below in Table D-2.

TABLE D-2

Chemical Species Identified in Fluid 705

Cations		Anions	
$[K^{+}]$	1.8 (m/l)	$[Cl^{-}]$	0.56 (m/l)
$[Na^{+}]$	3.9 (m/l)	$[SO_4^{2-}]$	Trace
$[Ca^{2+}]$	0.04 (m/l)	$[NO_3^{2-}]$	Trace
$[Mg^{2+}]$	30.00 ppm - Trace	$[PO_4^{3-}]$	not present

Carbonates and/or bicarbonates were present, as indicated by the bubbling upon addition of acid. Nevertheless, the amount of them present was not determined. Instead, the Fluid 705 was titrated with 0.1 N HCl; using a phenolphtaleine end point, it was determined that the total titratable base was 1.34 moles/liter.

The molar concentrations of major ions identified were converted to grams per milliliter and are shown in Table D-3 below.

TABLE D-3

Dissolved Solids Identified

Ionic Species		gr/ml
$[K^+]$		0.0704
$[Na^+]$		0.0897
$[Ca^{2+}]$		0.0016
$[Cl^-]$		0.0198
	Sub-Total	0.1815
$[CO_3^{2-}]$		0.0804
	Sub-Total	0.2619

The total amount of dissolved solids positively identified was 0.1815 gr/ml. Furthermore, if it is assumed that all the titratable base correspond to the carbonates, then a total of 0.2619 gr/ml would have been accounted for. The remaining 0.1685 gr/ml (or 0.0881 gr/ml in the second case) of dissolved solids has not been identified. However, it is believed that most of them can be attributed to colloidal organic matter in suspension.

The confirmation of the presence of organics was attempted by infrared spectra. Two samples of two solid extracts obtained by two different procedures were mounted in kBr pellets and the spectra recorded; the results are presented in Figure D-1. and D-2.

In the first sample, the Fluid 705 was evaporated by oven drying at 150°C. The solid residue was then used to obtain the spectra presented in Figure D-1. The second sample was obtained from the precipitate formed upon addition of HCl to the Fluid 705, the infrared spectra obtained corresponds to the spectra in Figure D-2.

Organic matter in soils is usually extracted by means of strongly basic solvents (0.5 N Na OH is most frequently used.). The dissolved material is further fractionated by precipitating the portion not soluble in acidic medium. This precipitate obtained by acidulation from the basic solution, is known as humic acid. The process for separation of humic acid is similar to the treatment used in obtaining the sample for the spectra in Figure D-2. The Fluid 705 is basic to start with, pH 8.6, and the fraction extracted was that precipitated by acidulation. Therefore, if humic colloids were present in Fluid 705, it is reasonable to expect a humic acid type of extract with the procedure followed. For comparison purposes, a typical spectra for Humic Acid and some extracts are presented in Figure D-3.

The IR spectra in Figure D-1 only shows the characteristic peaks of OH stretching and rocking corresponding to water. Most probably the extract was not completely dry; this can be thought of as an indication of the presence of humic substances. These are generally highly hygroscopic; when exposed to air of 50% relative humidity, humic substances can absorb on the order of 25% of its own weight in water. This is most likely the cause of why the presence of water has engulfed any other pattern of absorbance of IR radiation.

The second IR spectra, that in Figure D-2, is considered to be fairly typical for a humic acid, as it can be seen by comparison with Figure D-3. This is considered to confirm the presence of organic colloids in the Fluid 705. Further breakdown of components or a more detailed identification of organic compounds in Fluid 705 is considered unfeasible. The "state-of-the-art" in this particular field of knowledge would not allow such refinement.

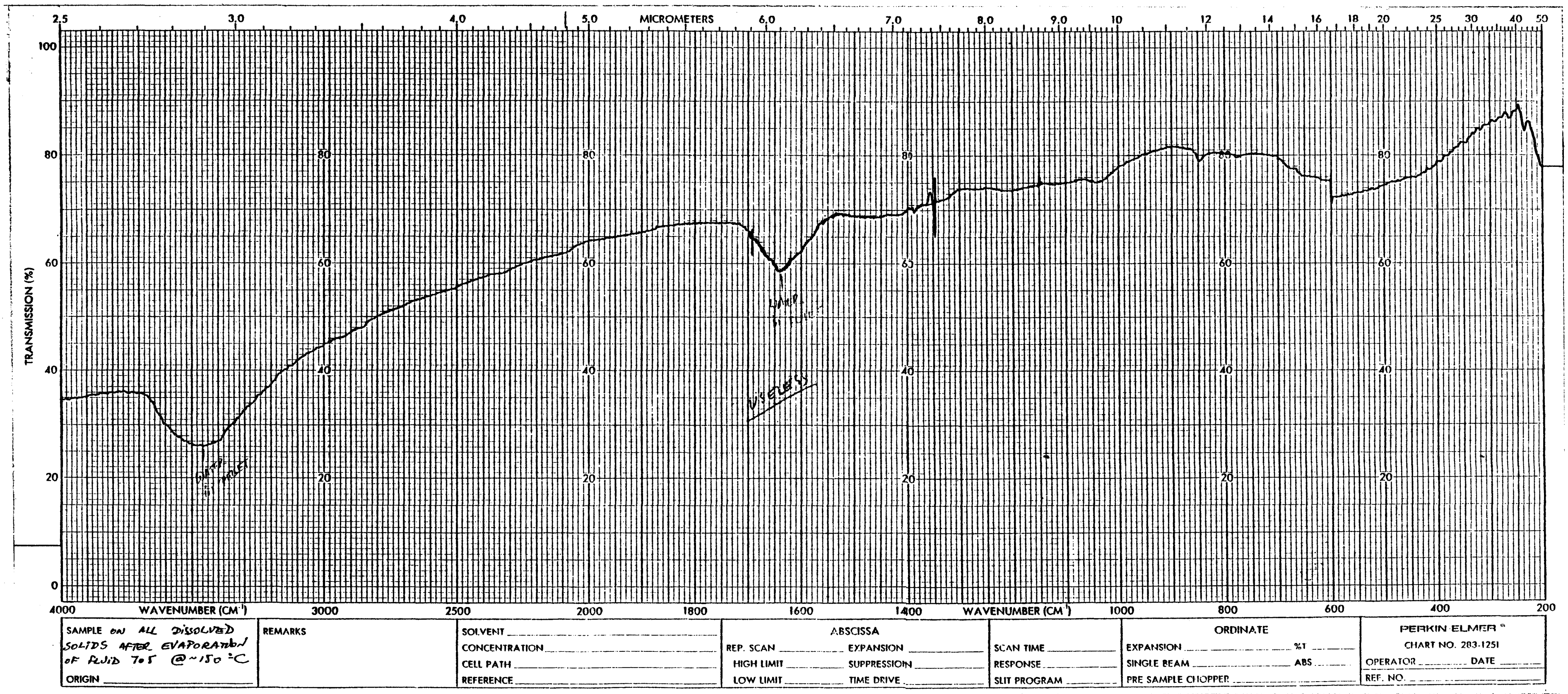


Figure D-1. Infrared Spectra on the Total Fraction of Dissolved Solids of Fluid "705"

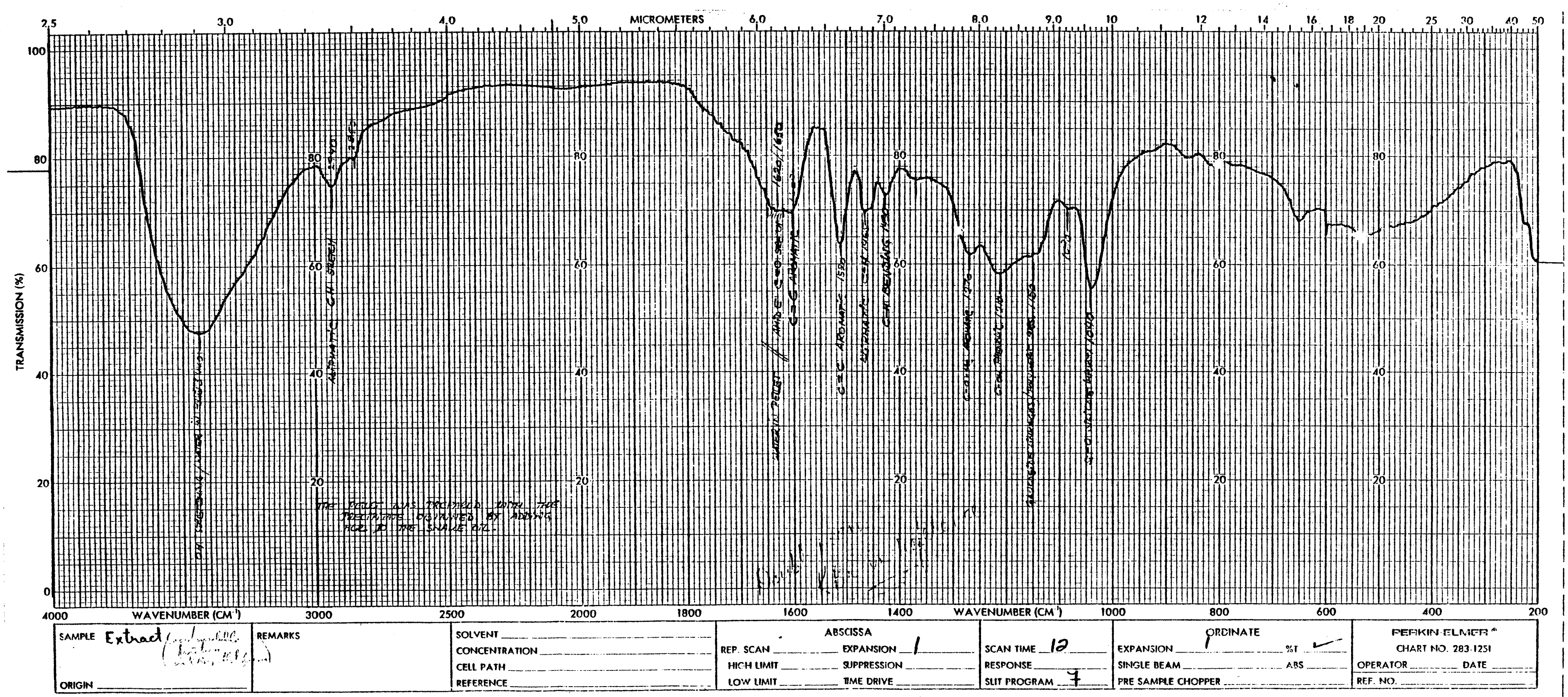


Figure D-2. Infrared Spectra on the Precipitate Obtained by Acidulation of Fluid "705"

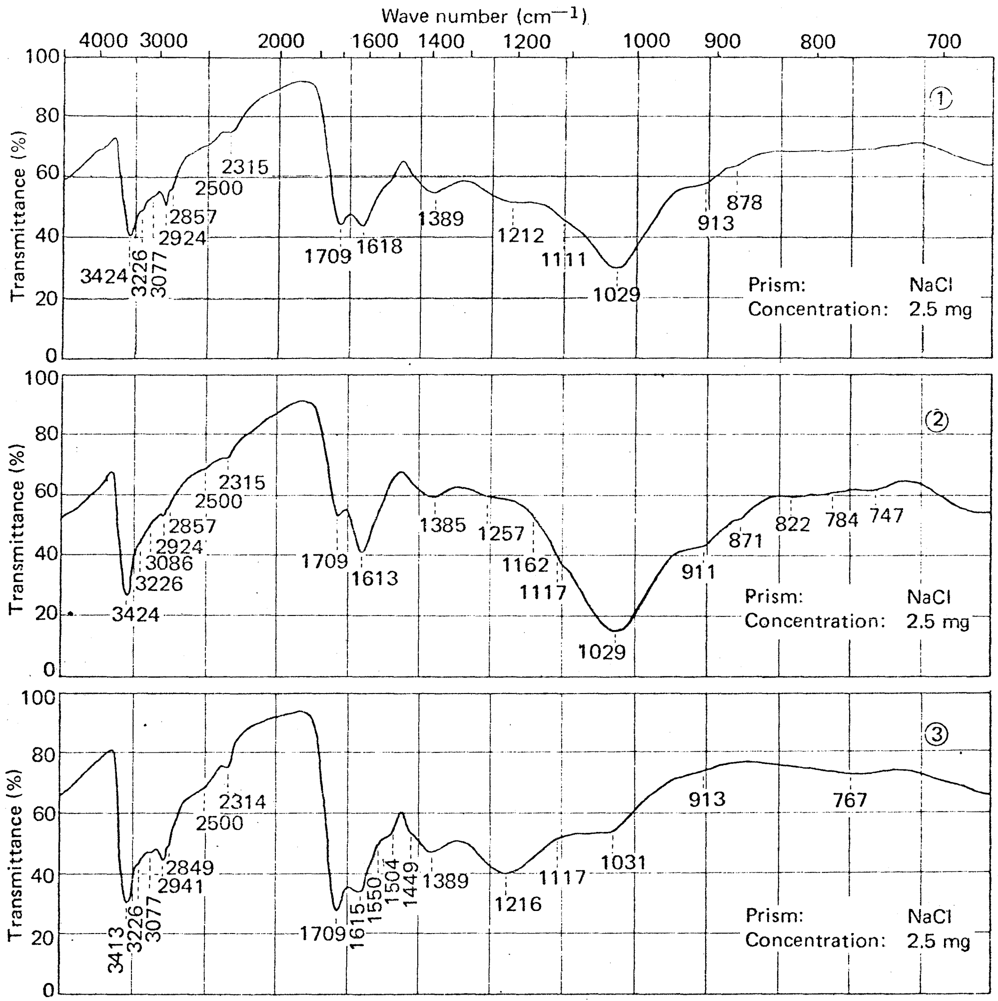


Figure D-3. Typical Infrared Spectra of Humic Substances

Key

(1) Raw Humic Acid

(2) Gray Humic Acid fraction

(3) Brown Humic Acid fraction

Reference: Soil Components, Vol. 1,
Ed. John E. Gieseking, Springer-Verlag,
New York, 1975, pg. 110.