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Evaluation of the Flexibility of Northern Mississippi Clays

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FINAL REPORT

EVALUATION OF THE FLEXIBILITY

OF

NORTHERN MISSISSIPPI CLAYS

BY

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ABSTRACT

A limited, one year study was made to evaluate the clay deposits of northern Mississippi as a potential source of material for compacted clay liners as permeability barriers. The project focused on the ability of a compacted clay to differentially deform before cracking which would destroy the integrity of the liner to fluid flow. To evaluate the amount of differential movement before cracking, clay samples collected the previous year for another investigation were tested in the laboratory for flexibility by a compacted clay beam subjected to flexure. The property of flexibility was defined as the amount of deflection the center of the beam underwent prior to cracking. The deflection of each sample at the optimum point on the compaction curve was compared to that clay's Plasticity Index to see if a direct correlation existed. The results were inconclusive. Factors which may have affected the poor correlation are poor testing procedure, change in sample properties with time due to uncontrolled temperature/humidity storage, contamination of the samples, and other influences such as percent of silt and sand that were not evaluated.

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INTRODUCTION

Geographically, Mississippi is located in the Coastal Plains province of the United States. The geology of this physiographic province is madeup of sedimentary deposits laid down under nearshore and deltaic environments. Sands and clays are the predominant surface and near-surface deposits. The strata because of their relatively youthful geologic age and shallow burial are moderately to poorly indurated and thus classify as unconsolidated to weakly cemented sedimentary rocks. The argillaceous deposits generally are called clays by most geologists and engineers although at moderate depths of burial they are more accurately classified as weak shales. The term clay will be used in this report to refer to all the argillaceous deposits whether they classify as shale or indurated clays.

The most exploited mineral deposits in Mississippi are the sands and gravels for aggregate and fill, and the clays for brick, pottery, foundry clay, lightweight aggregate and other clay-based uses. These sands and clays have been mined for over a hundred years. The mining and exploitation continues in many counties at the present.

Clays have a broad based industrial use. With their widespread occurrance, the clay deposits in Mississippi are the most promising mineral resource for future economic development.

1986-87 Clay Project

Prior to the present study, the author was awarded a small research grant to investigate the basic engineering properties of northern Mississippi clays. The purpose of the investigation was to find out if some simple, routine engineering test could be used as a first assessment in evaluating a clay deposit for commercial exploitation.

The Atterberg Limits laboratory test was selected as the primary index test for the investigation. These tests are well established and accepted in evaluating clays for engineering purposes.

Samples were collected both from deposits being actively mined for commercial use and from undeveloped, deposits mostly situated in northern Mississippi. About half of the samples collected and tested were from active mines.

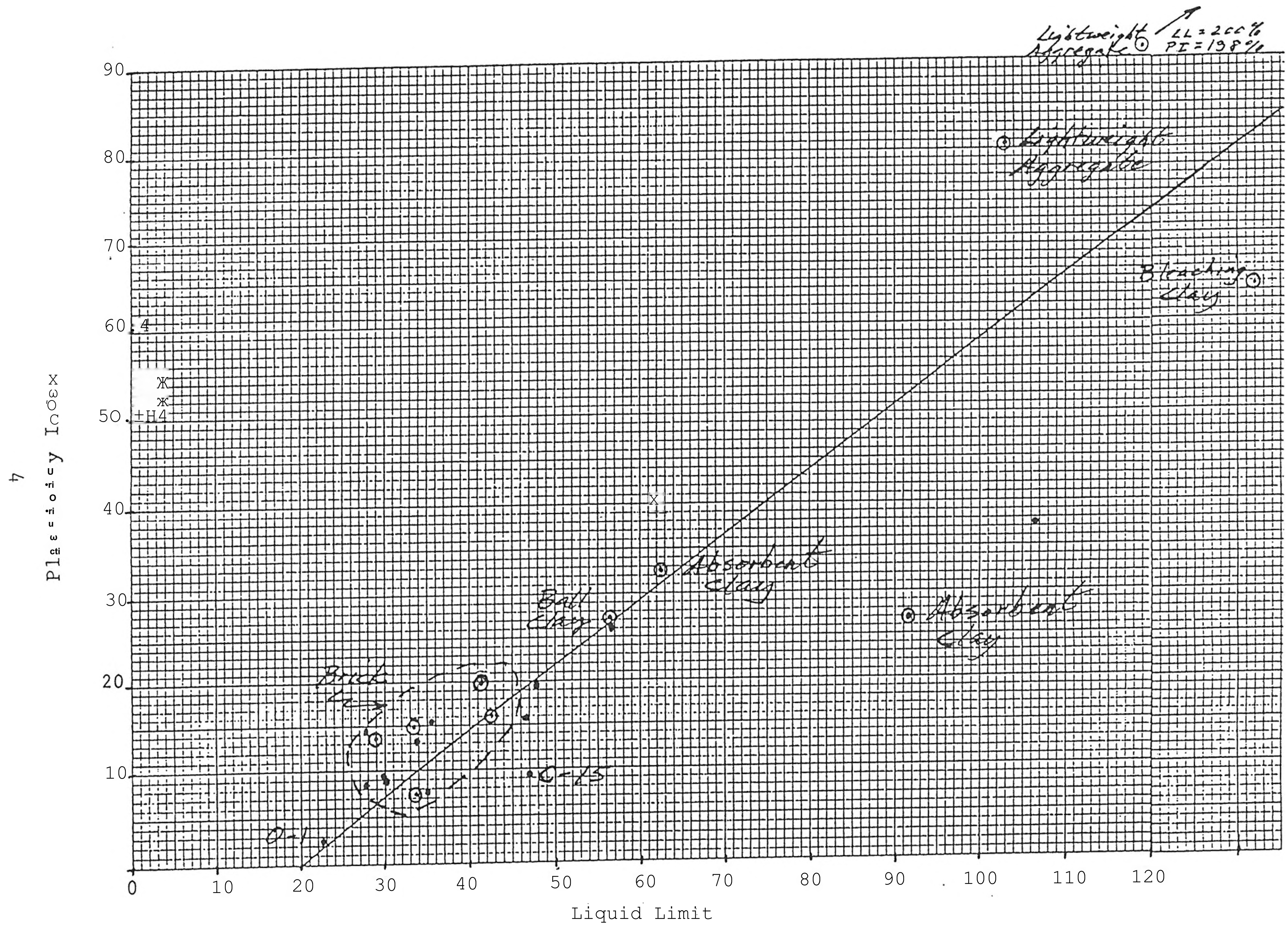
The test results were plotted on a Plasticity Chart which is used in engineering property evaluation. The commercial use was noted next to the samples obtained from the industrial clay mines. Although the number of samples from clay deposits being actively mined was limited, distinct trends were apparent, especially for clays mined to manufacture bricks. Figure 1, is a copy of the Plasticity Chart from the 1987 Final Report. It illustrates the grouping trend noted above.

Project Focus

This report summarizes the findings of a one year study on the ability of a clay to flexurally deform before cracking. The investigation was a continuation of the 1986-87 study on evaluating the basic properties of Mississippi clays for the purpose of defining their most promising economic development.

Since a very common and important use of clays is as impermeable barriers to prevent seepage of contaminated fluids into saturated deposits (aquifers) used for water supply, the investigation focused on the ability of a compacted clay material to bend without cracking. This property is known as flexibility. Compacted clay liners are used in sewage lagoons, sanitary and hazardous waste landfills and heap leaching.

The author has developed a laboratory apparatus to evaluate the flexibility of compacted clays. Building on the Atterberg Limits data, this project concentrated on defining the suitability of northern Mississippi



Lightweight Aggregate
LL = 200%
PI = 198%
Lightweight Aggregate
Bleaching Clay
Absorbent Clay
Ball Clay
Absorbent Clay
Brick
C-15
O-1
Plasticity Index
Liquid Limit
0
10
20
30
40
50
60
70
80
90
100
110
120

FIGURE 1

clays for compacted permeability barriers by the flexibility test.

FLEXIBILITY

The term flexibility was first introduced by Leonards and Narain (1963), as a property parameter in their investigation on the cracking of earth dams. They defined flexibility as the tensile strain at cracking.

Relative to compression, clay-rich soils are weak in tension. As a result, differential movement can cause fracturing transversely across a compacted clay layer. If such a layer is being used as a permeability barrier, the integrety of the mass is breached and fluids can escape through the high permeability fractures. Thus, it is important to evaluate and to define the flexibility of clay deposits being considered as compacted permeability containment liners for lagoons, landfills and heap leaching. Previous research and pilot studies by the author have demostrated different clay deposits will exhibit different amounts of flexibility. Therefore, for a compacted clay liner, it is important to select a clay with high flexibility to prevent against cracking due to differential flexure that can occur.

The disposal of hazardous by-products from mining, mineral processing, industrial and commercial activities has become an acute problem. The amount of hazardous wastes produced is increasing substantially every year.

Burial using landfills and secure tenches are common methods of disposal. Bulk wastes disposal from mineral processing often use clay lined impoundments and impermeable compacted layers to prevent movement of the liquid portion of the wastes from the site. In each case, the integrity of the compacted clay layer is the primary factor of whether or not the site will leak.

In addition to clay liners for waste disposal, flexibility is a property important to:

1) subsidence,
2) earth dams,
3) levees, and
4) tailing impoundents

These earth structures not only relate to public works and industrial uses, but also to mining, mineral exploitation, and mineral processing. Thus flexibility is an important property parameter to both commercial and mineral waste management.

LABORATORY TESTING

The primary research objective of this investigation on the evaluation of the flexibility of northern Mississippi clays was to conduct laboratory flexibility tests on clay samples collected in the 1986-87 project. The testing was done with an apparatus designed and fabricated by the author and two colleagues. The apparatus and test procedure are described below.

Flexibility Apparatus

The flexibility apparatus is a rectangular steel mold with the inside dimensions of 5.7 cm (2.24 in) by 5.7 cm by 24.1 cm (9.49 in.). The mold width was designed so that a Standard Proctor compaction hammer would fit across the soil layer. The bottom base plate is movable to allow for extrusion of the compacted soil beam from the mold. The steel mold, collar, bottom base plate and compaction hammer are shown in Figure 2.

Test Procedure

To simulate the Proctor compaction test, the clay to be tested was broken up so that all particles passed through U.S. Standard Sieve Number 4 (4.75mm). The soil was then mixed with the desired amount of water and allowed to cure for at least 24 hours.

Prior to emplacement of the soil the mold was sprayed with WD-40, to insure the clay beam would be ejected smoothly. The soil was compacted in three even layers with the standard Proctor compaction hammer. To

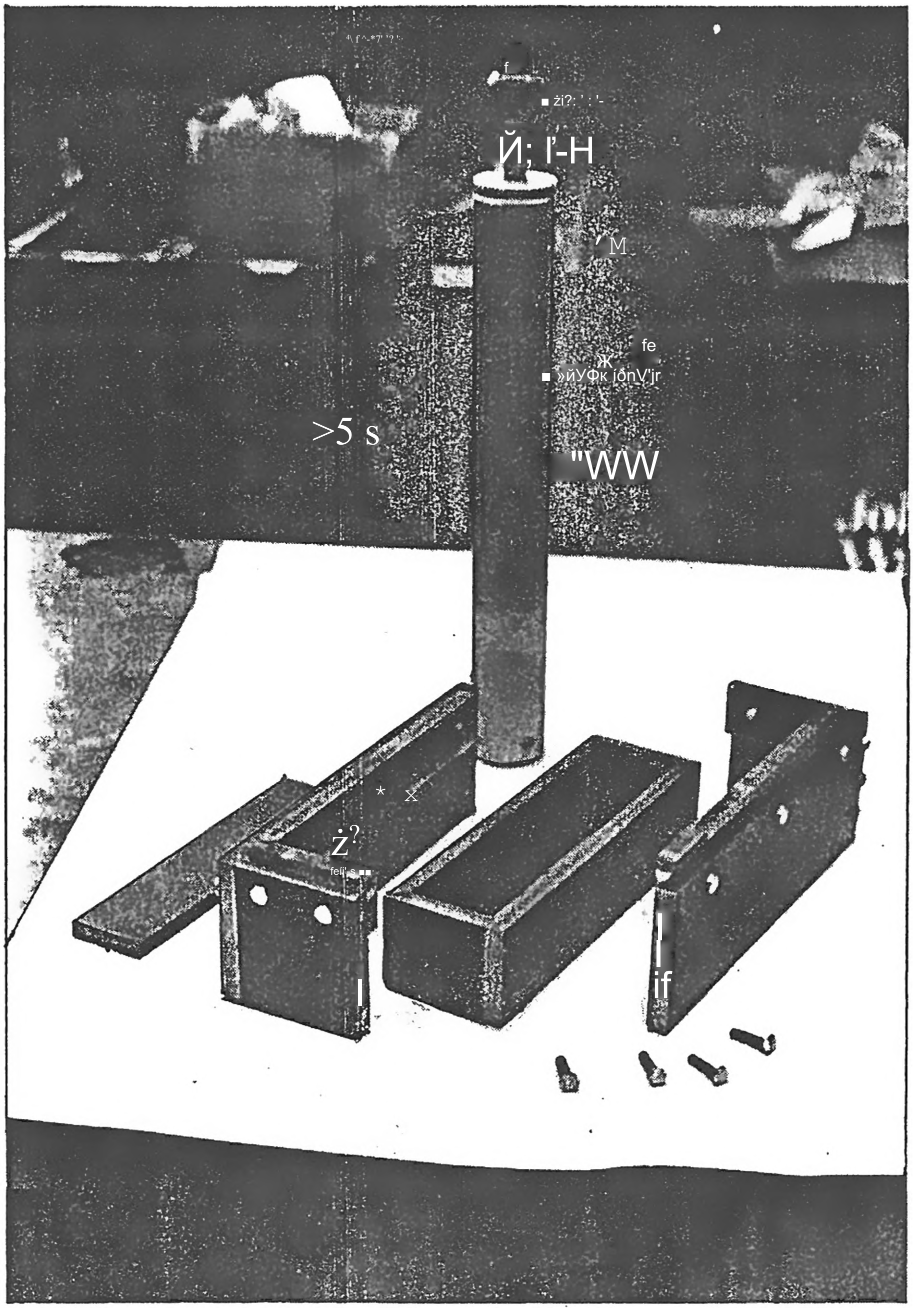


Figure 2 Flexibility Apparatus

achieve standard Proctor density each layer was given 21 hammer blows. After the clay sample was compacted, the collar was removed and the excess soil was cut smoothly to the top level of the mold. The mold and the soil were weighed together before the beam was ejected so that the dry unit weight could be determined for each water content. This allowed for a plotting of a compaction curve for each clay sample for analysis and correlative purposes.

The extruded soil beams were tested using a two-point flexural loading schematically illustrated in Figure 3. Each soil beam was loaded to failure at a uniform loading rate. Both the load and deflection were monitored and recorded. Failure always occurred as a tension fracture initiating at the bottom of the sample approximately midway of the length. For more details on the compaction apparatus, the soil beams and the testing procedure refer to the master's thesis by Walton, 1987.

TEST RESULTS

The flexibility tests data are summarized in Table I. For each clay sample at least four flexibility tests were made at different compaction water contents.

Both the water content and the dry unit weight were measured and recorded. From these two data points compaction curves were plotted for each clay sample.

The loading and beam deflection at the midpoint

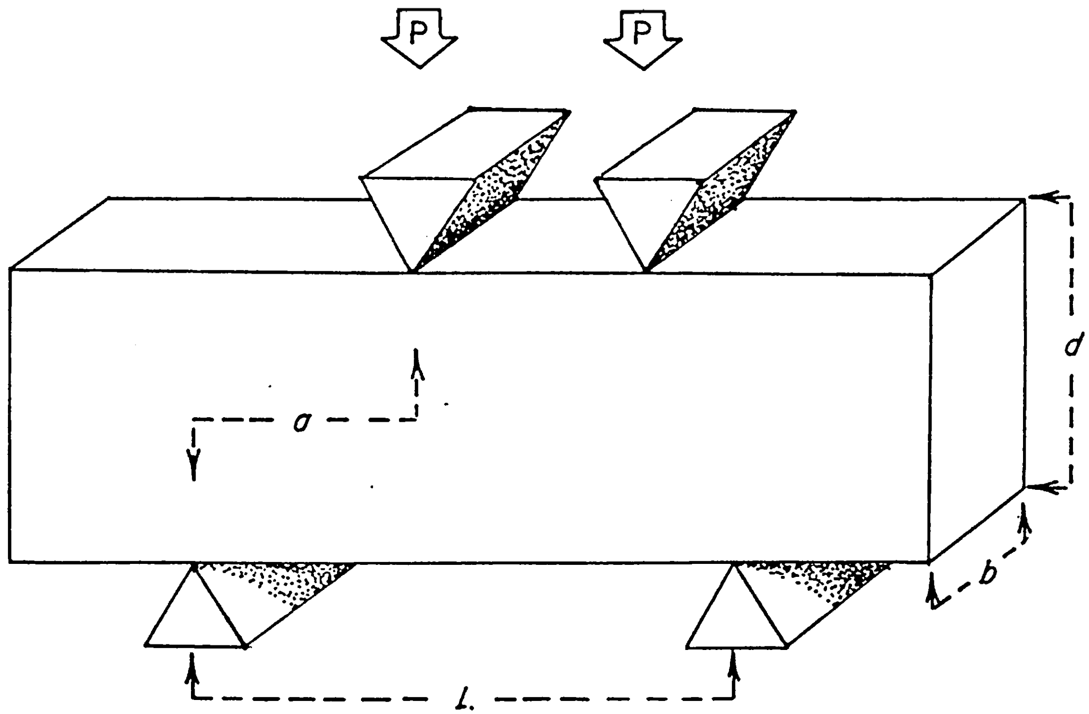


Figure 3, Two-Point Flexure Loading

TABLE I

SUMMARY FLEXIBILITY TEST DATA

Sample	Test	Water Content /	Dry Unit Weight, Pcf.	Load lbs	Deflection 1Ш1
C-2	1	17,3	99.0	2.57	2.29
	2	20.4	99.4	1.93	2.54
	3	24.5	98.0	1.23	3.02
	4	26.9	95.2	0.62	4.34
C-5	1	15.1	103.2	2.46	2.23
	2	17.6	104.6	2.57	2.49
	3	20.0	106.3	1.41	3.05
	4	22.6 .	103.5	0.77	4.83
C-6	1	14.7	96.6	1.05	2.13
	2	15.6	100.1	1.41	2.21
	3	18.6	104.1	1.60	2.41
	4	22.9	102.9	0.53	1.00
C-8	" 1	17.1	107.2	2.04	2.03
	2	19.3	106.1	1.50	2.59
	' 3	21.3	105.1	0.83	3.07
	4	24.0	105.2	0.46	6.32
C-9	r	18.8	95.3	2.37	2.31
	2	20.3	95.4	2.43	2.24
	3	23.5	99.1	4.26	3.91
	4	27.2	96.7	2.70	5.94
C-10	1	17.5	91.5	1.44	2.39
	2	20.4	95.4	2.94	2.51
	3	22.7	97.5	3.35	3.0ö
	4	26.0	96.6	2.95	3.81
C-11	1 '	53.8	56.8	0.89	2.36
	2	57.7	58.8	1.44	2.57
	3	62.4	58.9	1.05	2.41
	4	67.6	58.3	0.48	4.04
C-12	1	58.4	54.0	1.14	1.83
	2	64.1	55.1	1.13	2.18
	3	66.9	55.7	1.16	2.18
-,	4	73.2	54.8	0.44	4.54

TABLE I

SUMMARY FLEXIBILITY TEST DATA

Sample	Table	Water Content /	Dry Unit Weight, Pcf.	Load lbs	Deflection mm
C-13	1	21.2	91.7	1.14	2.06
	2	23.9	93.4	1.42	1.98
	3	27.1	93.8	1.49	2.44
	4	31.7	90.2	0.72	2.67
C-14	1	17.0	91.5	0.52	1.93
	2	19.7	96.5	0.99	2.29
	3	24.2	94.0	1.68	2.72
	4	29.6	92.8	0.82	3.10
C-15	1	22.1	91.1	0.96	2.31
	2	25.3	92.2	1.48	2.18
	3	28.4	92.7	1.73	2.59
	4	31.9	91.5	0.98	2.79
L-1	1	19.7	91.2	0.45	2.36
	2	23.4	93.7	1.74	2.69
	3	26.5	94.7	1.18	2.82
	4	30.7	90.6	0.77	3.30
P-1	1	18.4	94.5	1.34	2.49
	2	20.1	96.8	1.59	2.13
	3	23.3	96.88	1.46	2.39
	4	24.8	96.94	0.97	2.62
	5	27.1	95.0	0.70	2.77
P-2	1	11.7	104.7	2.Û3 ■″	4.80
	2	12.3	117.4	3.56	5.51
	3 '	14.Ô "	115.2	2.43	6.40
	4	15.9 "	113.7	3.14	3.35
	5	19.7	107.0	0.84	2.82
P-3	1	14.6	93.1	1.36	2.34
	2	16.5	95.1	1.34	2.03
	3	18.3	96.6	1.44	2.29
	4	20.6	98.3	1.46	2.41
	5	22.9 '	99.6...	1.08	2.54
	6	25.8	96.7	0.64	3.61

TABLE I

SUMMARY FLEXIBILITY TEST DATA

Sample	Test	Water Content %	Dry Unit Weight, Pcf.	Load lbs	Deflection mm
P-4	I	8.1	100.6	1.05	2.21
	2	10.1	101.4	0.92	2.29
	3	11.8	102.7	0.67	2.54
	4	12.4	104.5	0.94	2.39
	5	15.3	108.8	0.89	2.25
	6	17.8	109.4	0.35	3.10
	7	18.8	107.4	0.35	3.63
		- -			
K-1	1	10.6	108.8		1.83
	2	12.1	111.6		2.08
	3	13.2	112.0		2.16
	4	13.6	113.3		2.21
	5	15.7	112.5		2.29
	6	17.8	109.2		2.92
K-2	1	20.6	98.1		2.29
	2	21.8	99.4		2.45
	3	22.9	97.4		2.34
	4	24.3	98.0		2.41
	5	26.1	96.2		2.72
	6	26.5	95.7		2.79
	/	27.6	94.9		2.63
IK-3	30.0		83.3		3.30
	32.0		82.7		3.20
	33.5		84.9		4.83
	37.2		80.7		5.13
	39.7		78.5		7.01

were recorded at the instance the soil beam failed by cracking. Each of the data were plotted versus the water content at which the test was ran.

Graphs of the plotted test data for the dry unit weight, the load and the beam deflection are included in the Appendix. The three graphs are stacked on top of each other in the Appendix figures for correlative purposes. The water content is the same for all three horizontal axes.

Evaluation of the Test Data

The test data were much more erratic than anticipated. This may be due to several reasons.

The first and most probable explanation was poor testing procedures by the personnel conducting the tests. The tests were done as special projects by different students to give them experience with laboratory tests, especially the flexibility test. Even though these students were shown how to conduct the test properly and were strongly warned to carefully follow the test procedures, they may have omitted certain aspects, or altered the method. Also, they were told to redo any test for which the results seemed wrong. No such duplicate tests were made.

A second possibility is the samples stored for over a year in uncontrolled temperature and humidity conditions may have changed some in their physical properties. Most of the samples were collected over a year ago for the Atterberg Limits project. Other investigators have found that some soil samples do undergo a change in their properties when stored for long periods of time.

It is possible some samples were contaminated by intermixing when students returned the used test material to the sample bags during previous tests.

A plot of all the tests to the corresponding Atterberg Limits yielded no definable correlation or trend. The test data originally were evaluated in several different ways; as maximum deflection, differential deflection between two water contents and maximum load. All exhibited very scattered plots with no obvious trends.

Pilot tests conducted on three significantly different clay soils prior to this study gave the following results:

1. The deflection increases as the compaction water content increases. Wet of optimum (maximum unit weight)the deflection increases rapidly before cracking occurs. This trend is to be expected because the increase in water content moves the clay soil closer to the liquid limit and thus increases its plasticity.
2. As a clay soil becomes more silty and/or sandy, it is more brittle. Therefore, silty and sandy

clays exhibit lower plasticity and will undergo very little flexure (deflection) before cracking.

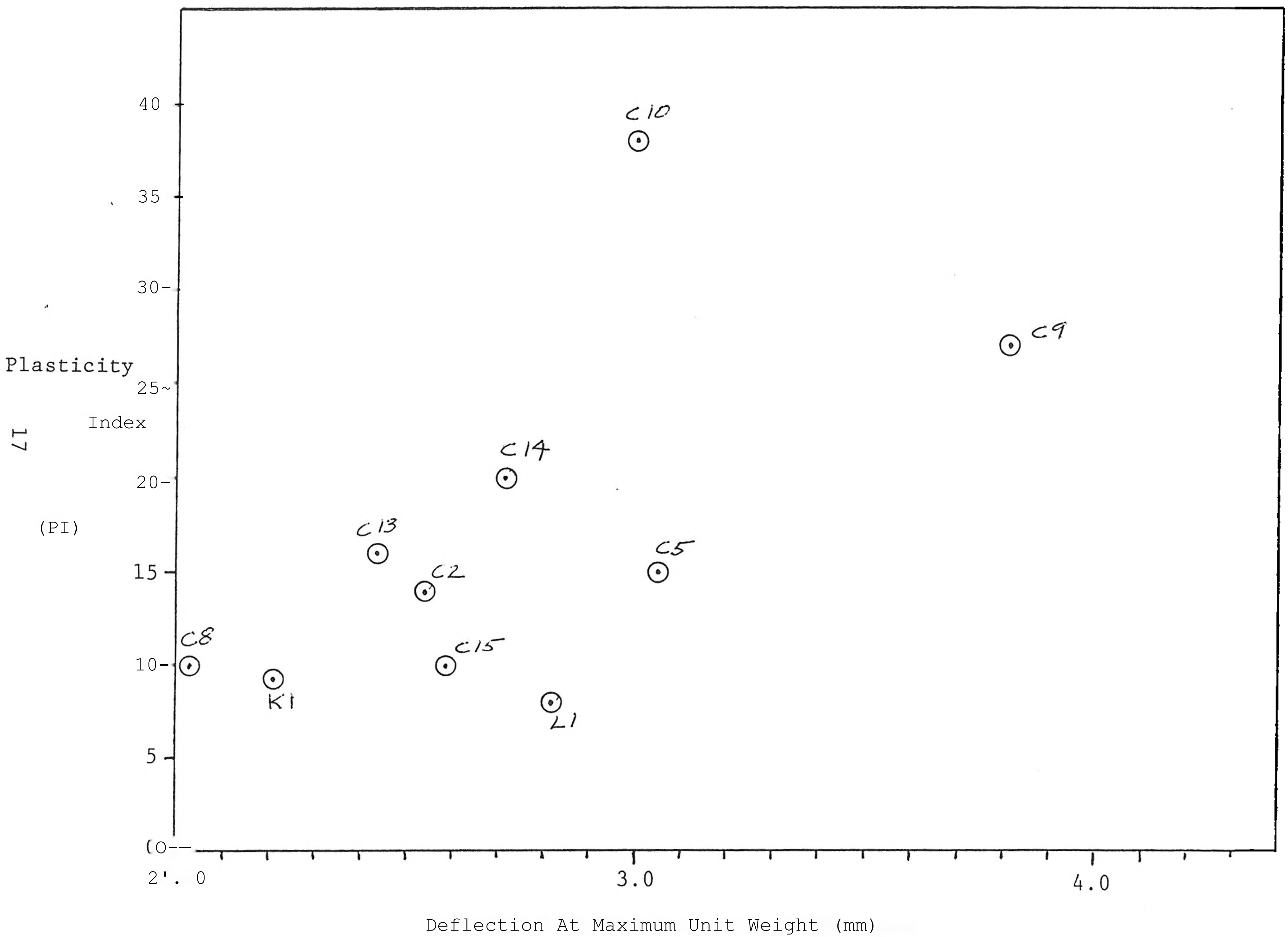
3. The clay mineral type dominant in a soil will influence the plasticity and flexibility. Smectite or montmorillonite-rich soils exhibit higher plasticity than soils rich in kaolinite or illite.

The pilot study, although limited to just three clay soils, was conducted under very controlled test conditions. The author feels the data and results are an accurate representation of the flexural behavior of clay soils.

Using the pilot study results and trends for evaluating the reliability of this project's test data, the author reviewed all the tests and rejected as erroneous results those tests that did not exhibit an increase in deflection at cracking at water contents at and above optimum (maximum dry unit weight) of the compaction curves. This judgement value analysis limited the number of reliable tests to ten.

The point on the compaction curve that probably is the most valid to compare the deflection of different clays is the peak or optimum. Therefore, this point was chosen to see if a relationship between flexibility, as defined by the deflection, and the Atterberg Limits, as defined by the Plasticity Index, exists.

Figure 4, is a plot of the ten samples whose test


40
35
30
25
20
15
10
5
0
Plasticity
Index
(PI)
C10
C9
C14
C13
C5
C2
C8
C15
K1
L1
2.0
3.0
4.0
Deflection At Maximum Unit Weight (mm)
Figure 4

results seemed the most reliable. A general trend does exist but the data points exhibit considerable scatter. If tests C-10 and L-1 are omitted, the other eight give a good correlation between the Plasticity Index and deflection.

The flexibility of a compacted clay may not have a direct relationship to the Atterberg Limits. Other factors, such as the percent of silt and sand in the material, may have significant influence on the flexural behavior.

SUMMARY AND CONCLUSIONS

Laboratory flexibility tests were made on clay samples collected and tested by the Atterberg Limits of a previous study. The purpose of the investigation was to see if a relationship exists between the Atterberg Limits and flexibility so that clay deposits in northern Mississippi could be rapidly evaluated by the Atterberg Limits as potential sources for compacted permeability barriers.

Results of the investigation were inconclusive. The flexibility test data were very erractic in over half of the tests. Thus when all the tests results were plotted on a Plasticity Index — Deflection chart a ”shotgun" pattern existed. When ten tests data that were considered the most reliable were plotted, a general trend was apparent even though data point scatter still occurred.

Based upon the results and findings of the investigation there is no conclusive evidence that the Atterberg Limits are directly correlative to the flexibility of a compacted clay material. Other material characteristics in addition to the plasticity, as evaluated by the Atterberg Limits, may have an equally significant influence on how much a compacted clay will differentially deform before cracking.

More research should be done to establish what index properties and laboratory/field tests correlate to the flexibility test. Because much of the laboratory test data for this study was erratic and of questionable reliability, it is recommended additional investigation be made on the relationship of the Atterberg Limits to flexibility.

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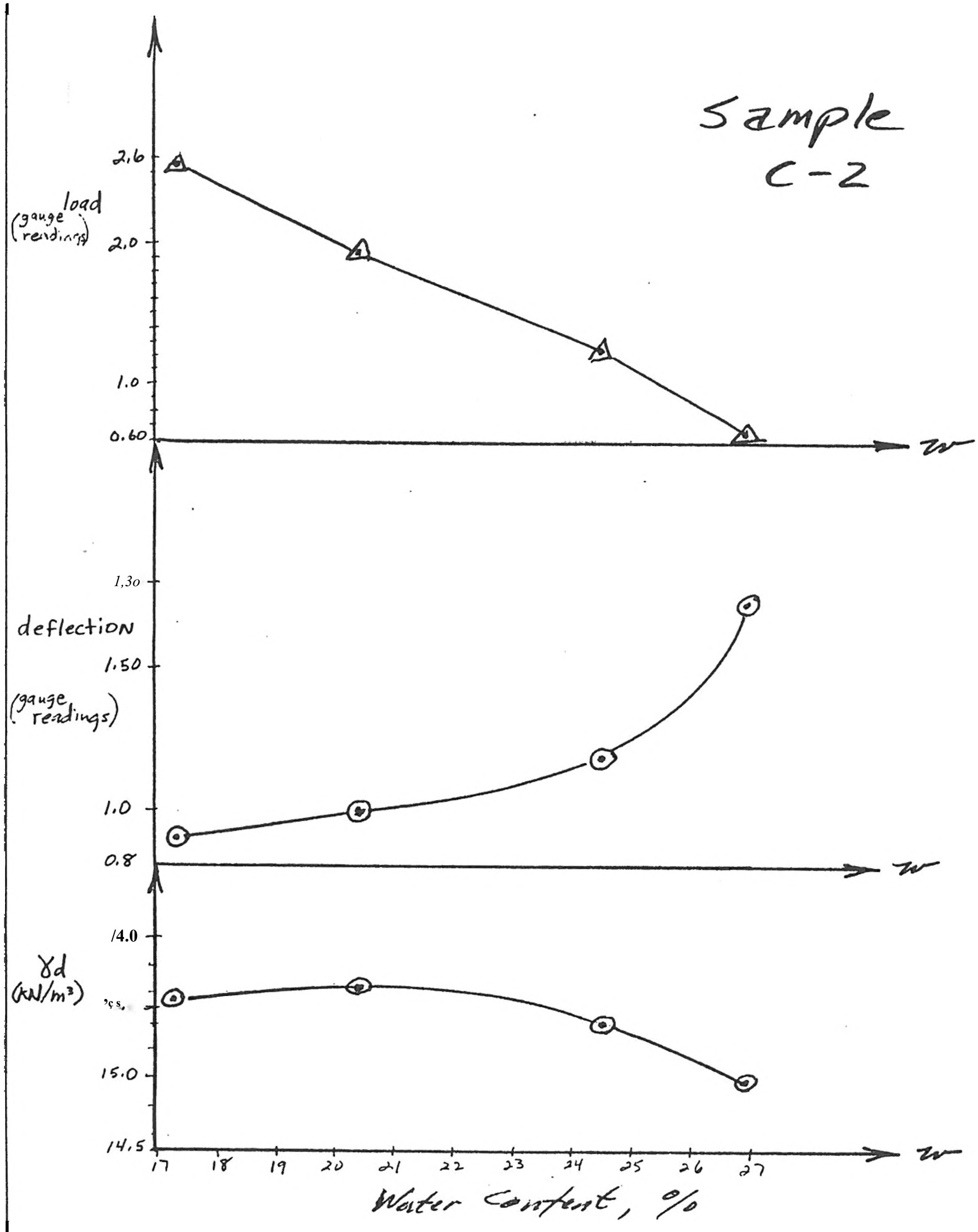
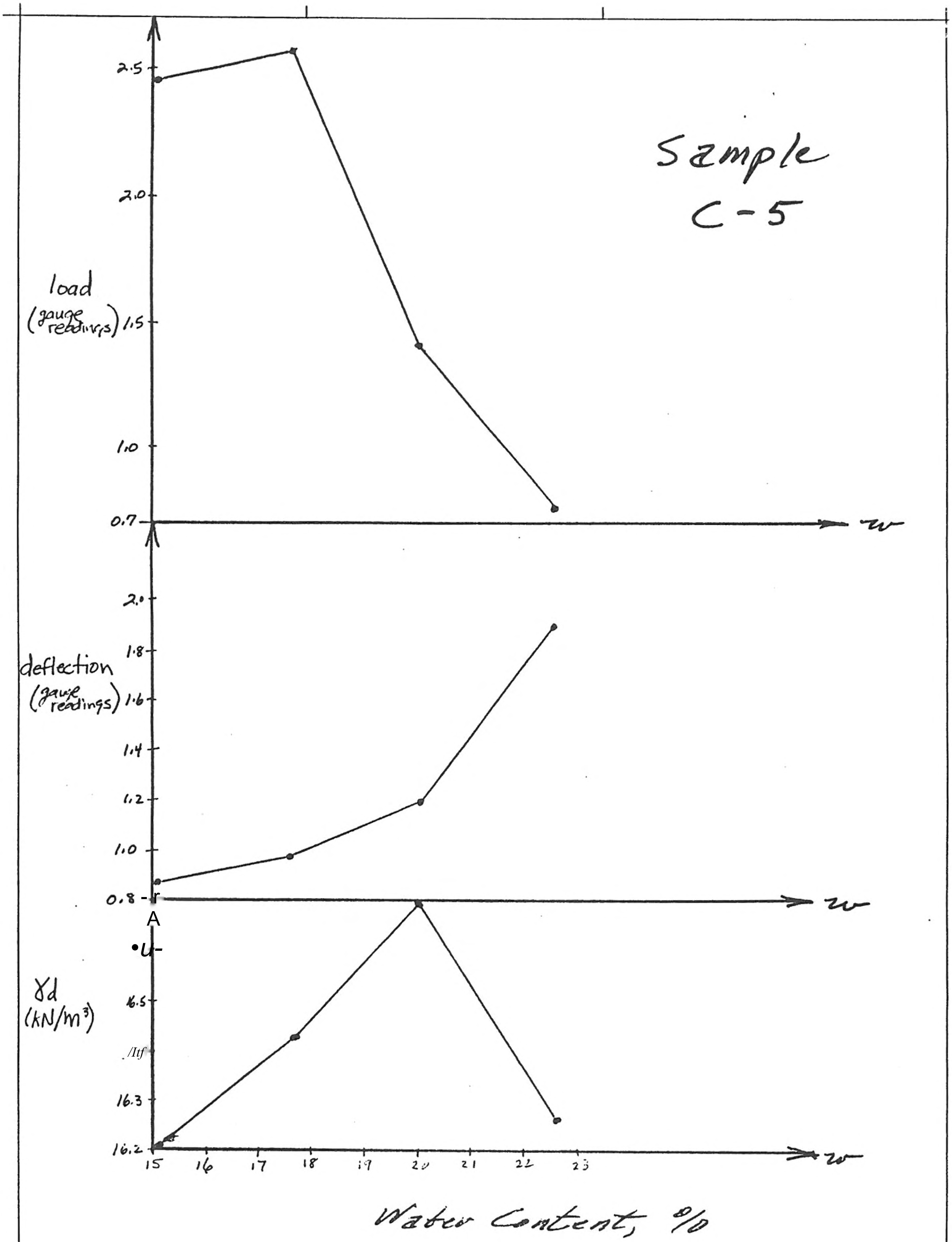
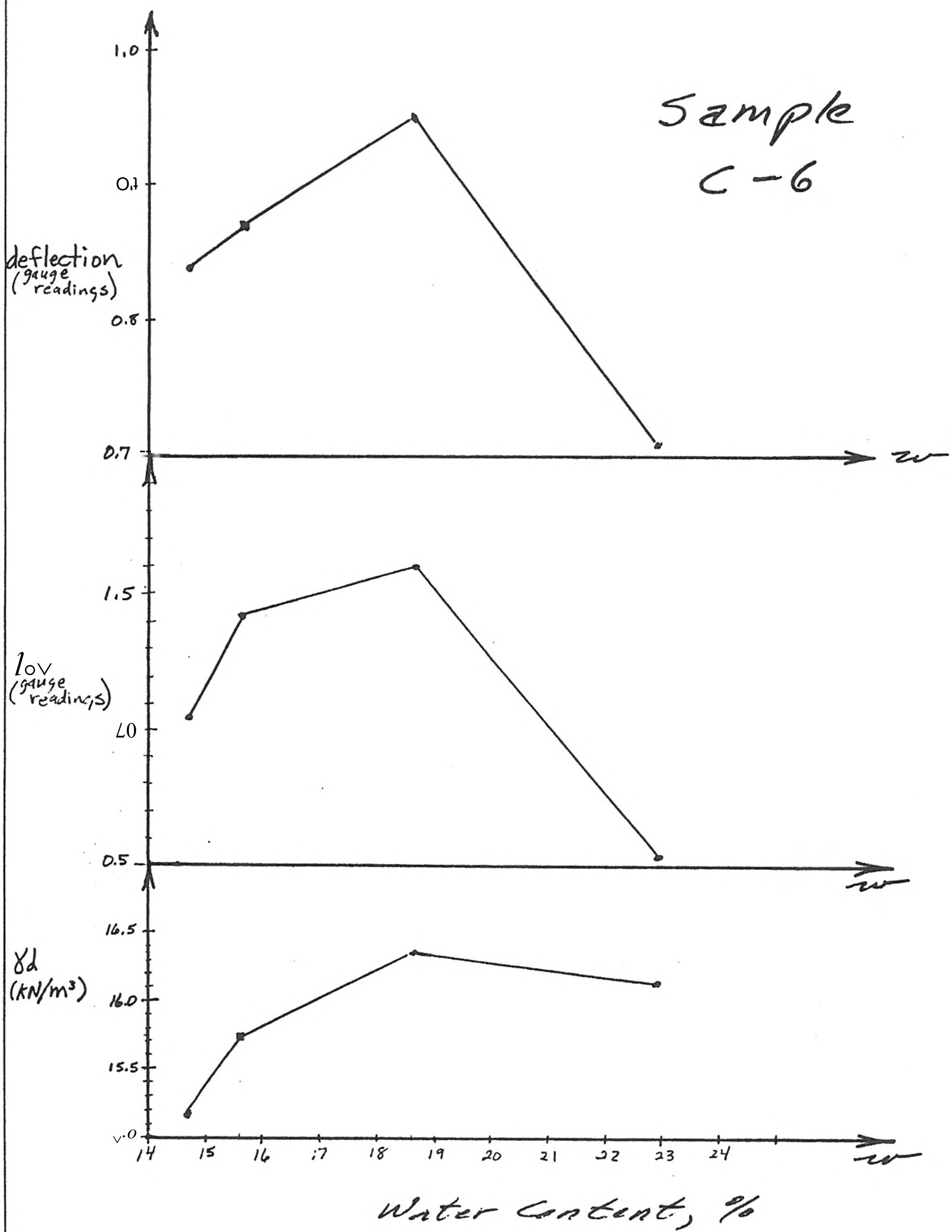
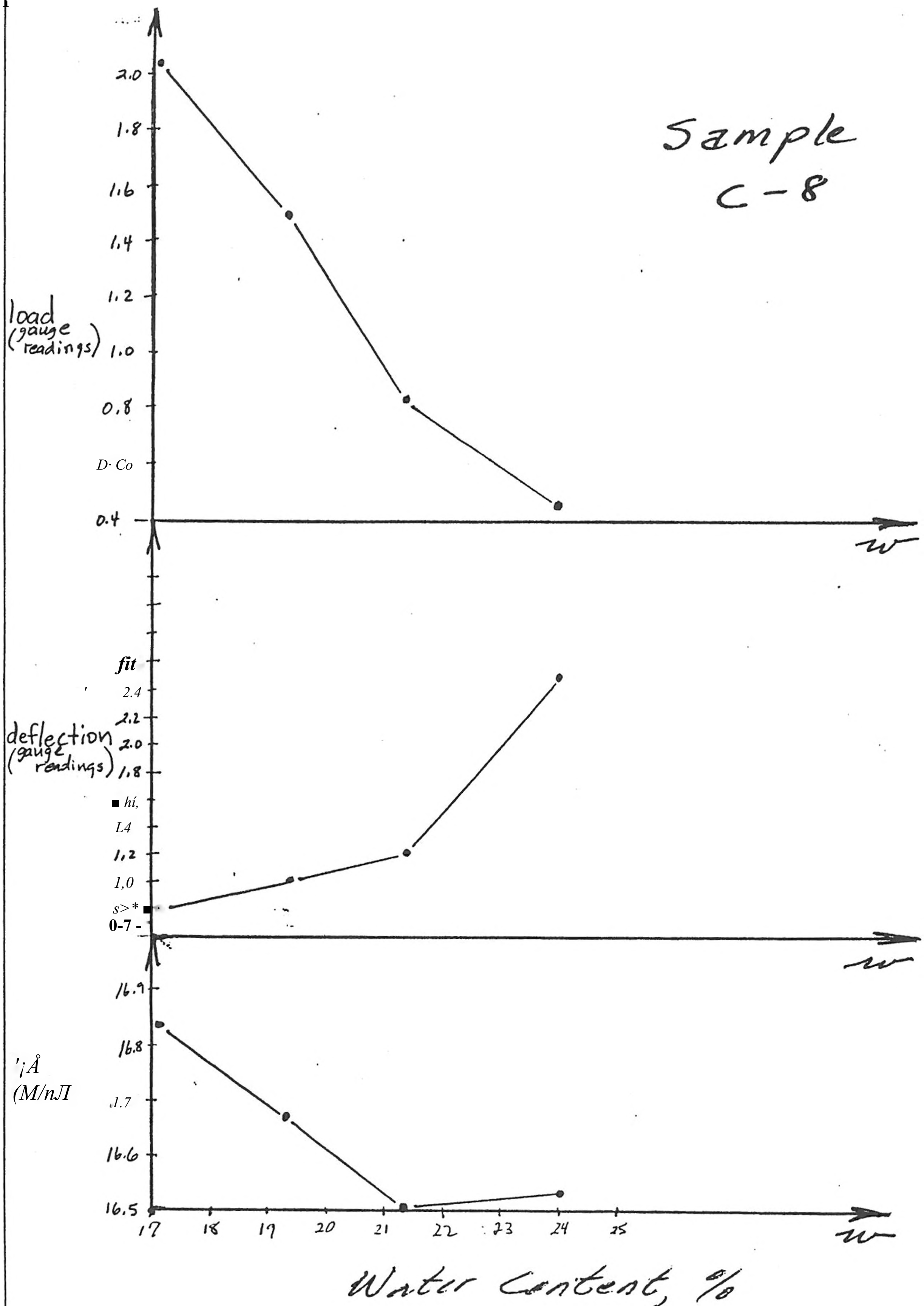
APPENDIX

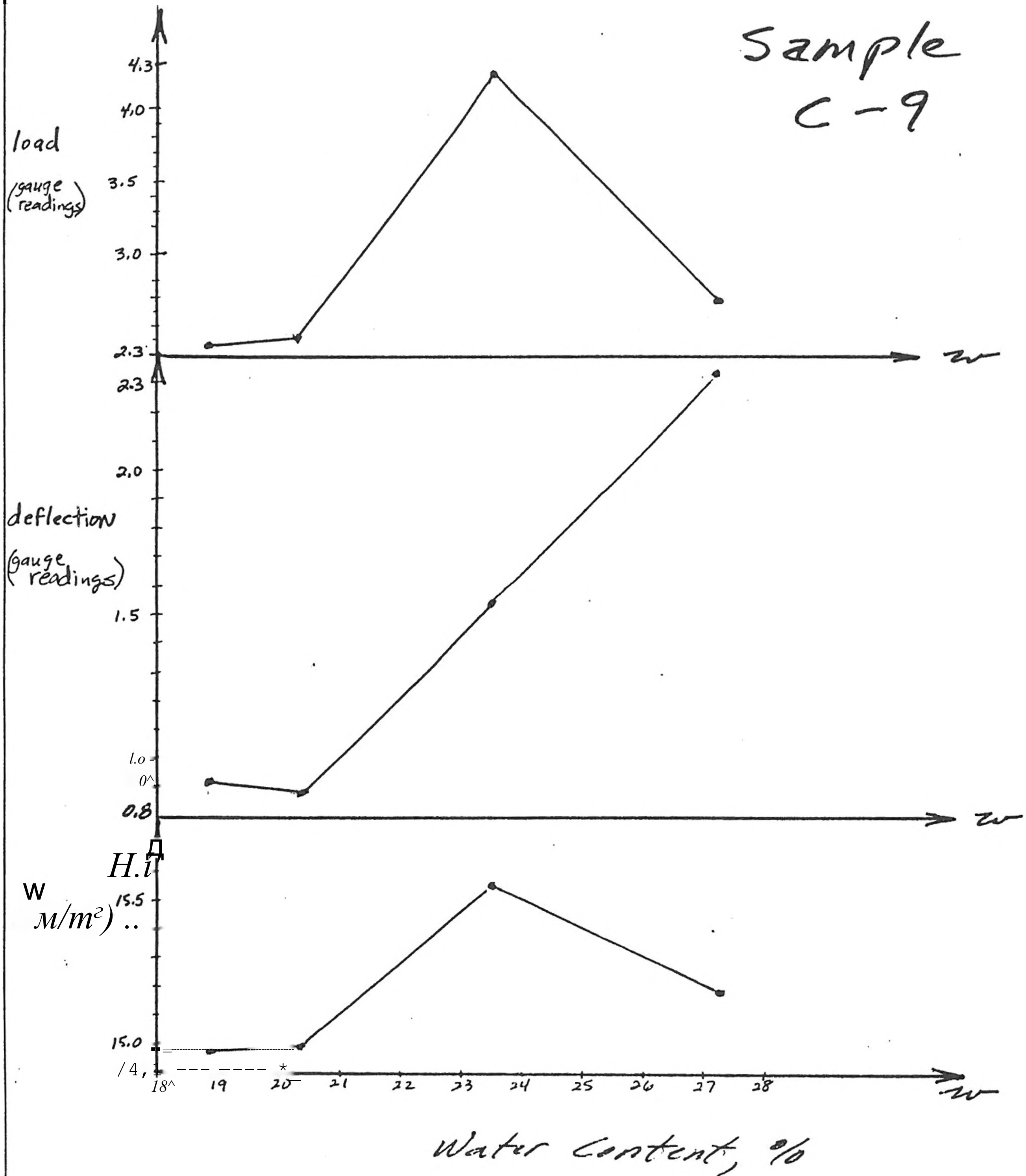


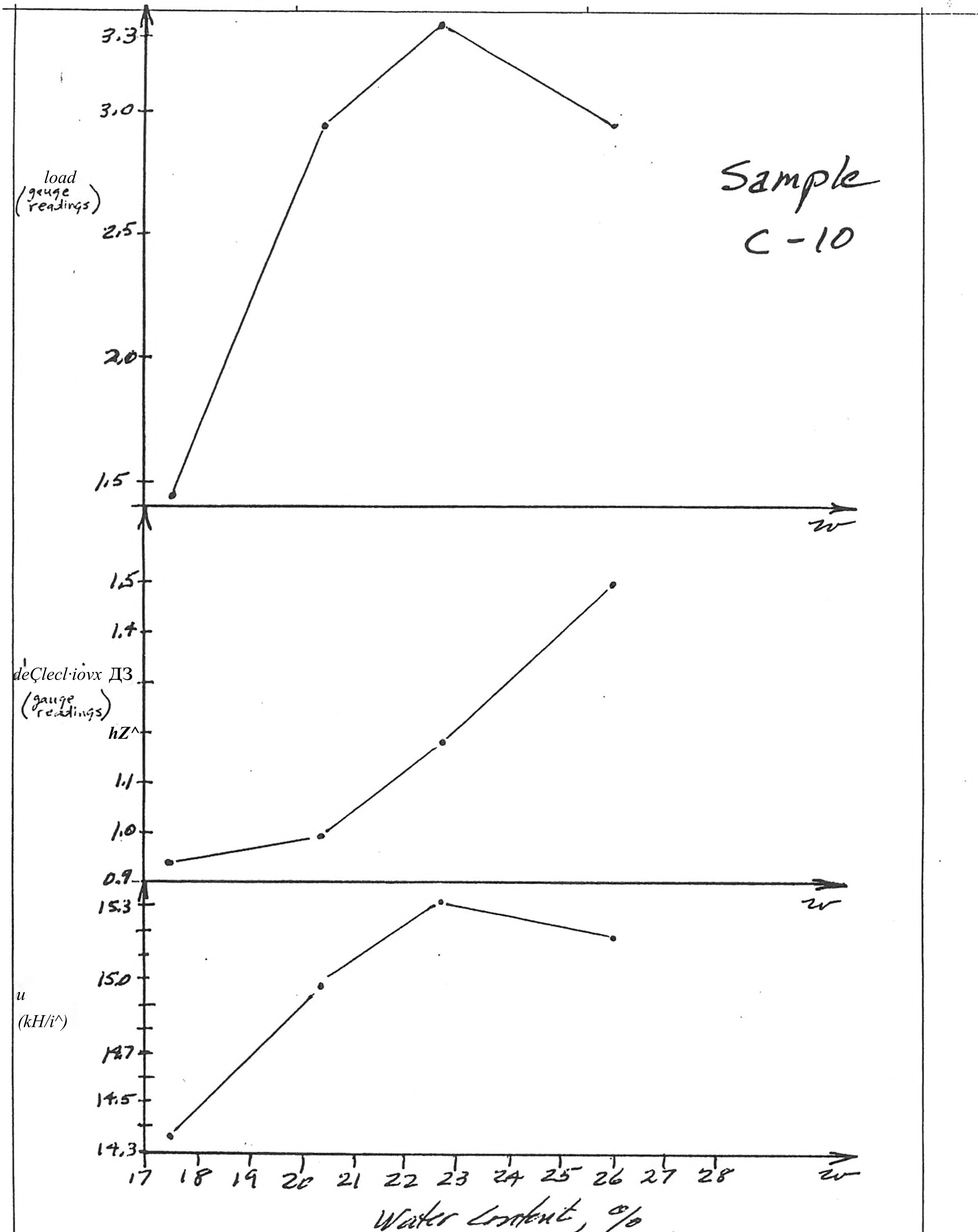
Sample
C-2
2.6
2.0
1.0
0.60
load
(gauge readings)
w
1.50
1.0
0.8
deflection
(gauge readings)
w
γd
(kN/m³)
15.0
14.5
w
17
18
19
20
21
22
23
24
25
26
27
Water Content, %

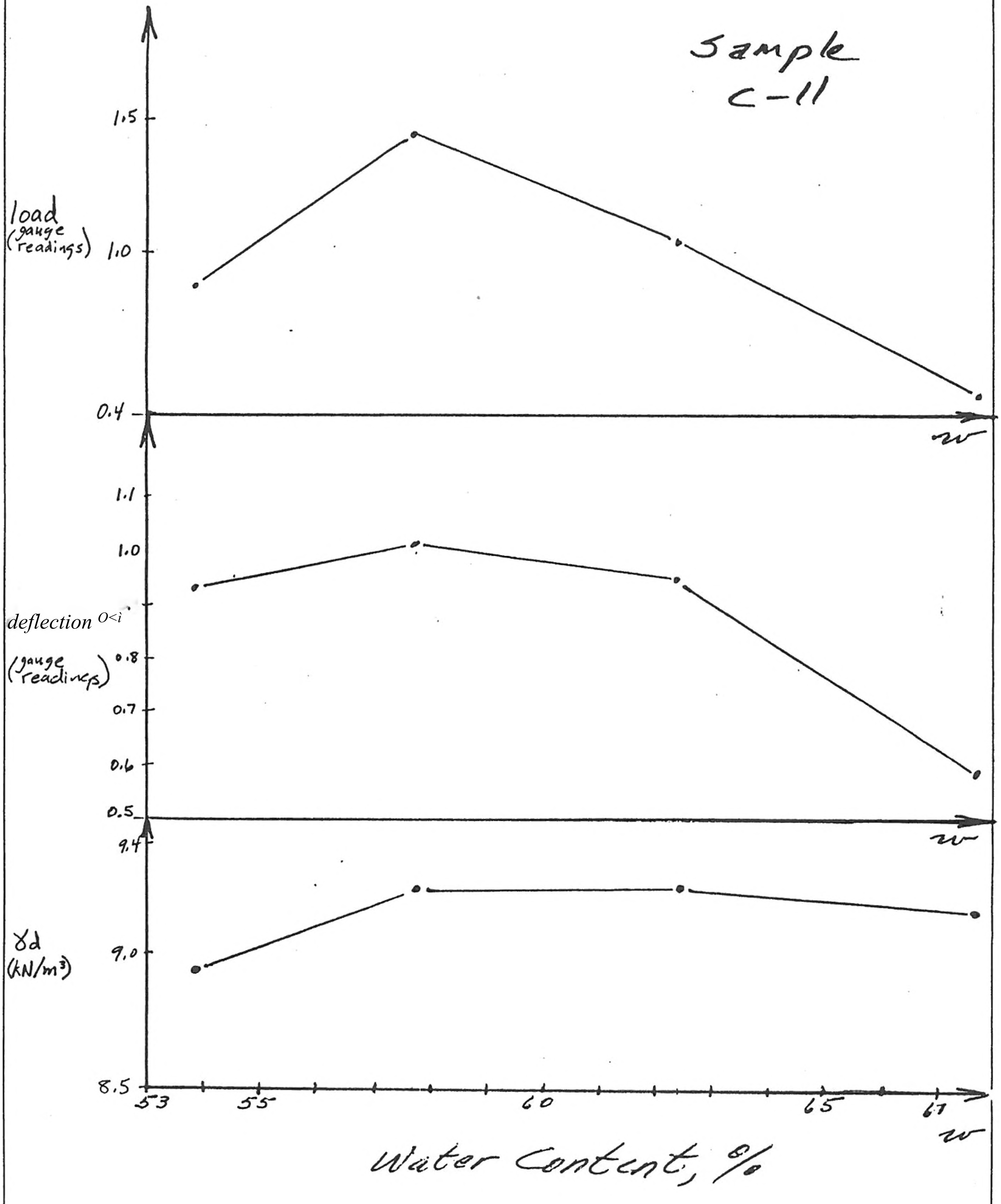

Sample C-5
load (gauge readings)
2.5
2.0
1.5
1.0
0.7
deflection (gauge readings)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
γd (kN/m³)
16.5
16.3
16.2
15 16 17 18 19 20 21 22 23
w
Water Content, %

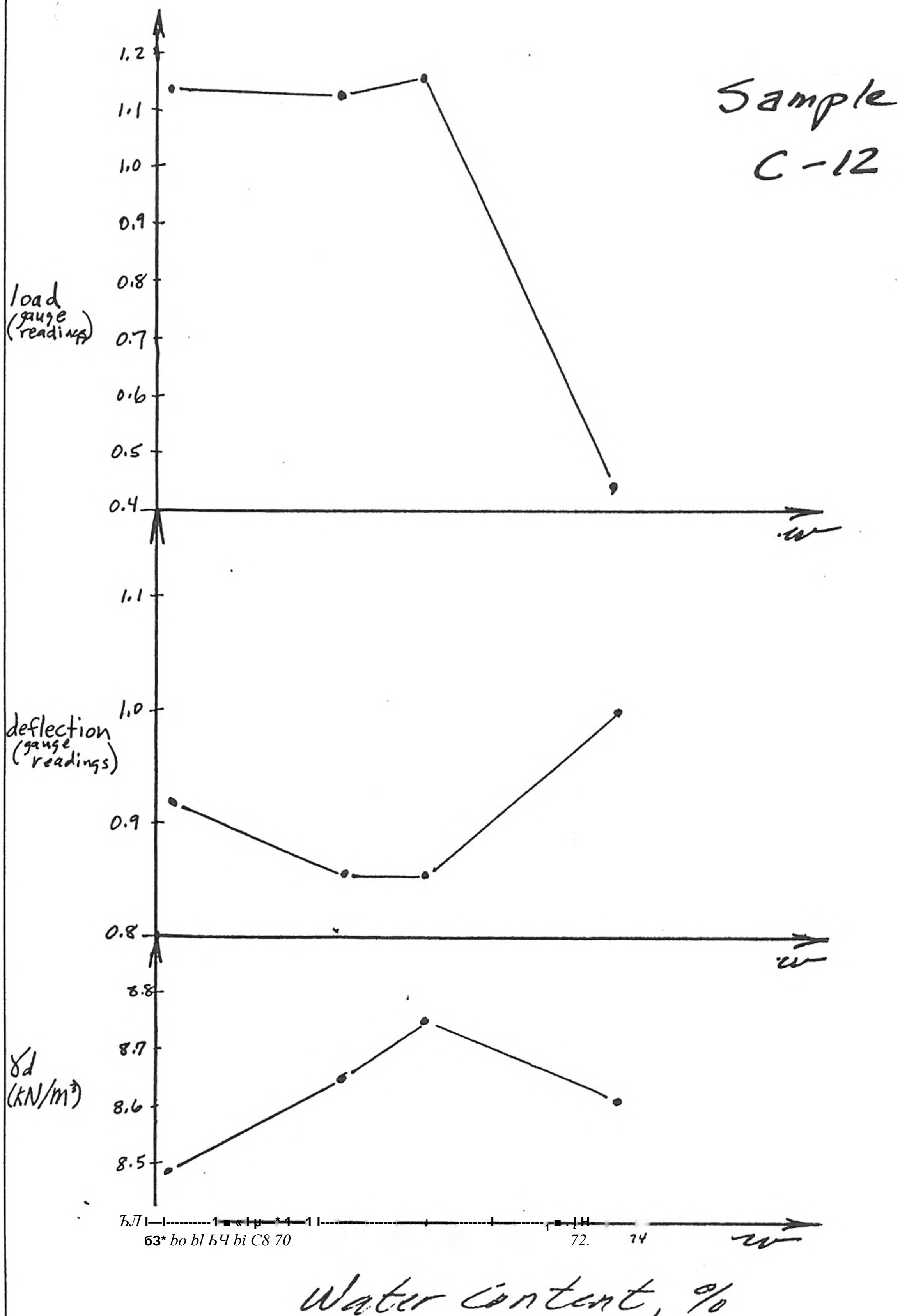

Sample
C-6
deflection
(gauge readings)
1.0
0.8
0.7
w
1.5
0.5
16.5
16.0
15.5
γd
(kN/m³)
14
15
16
17
18
19
20
21
22
23
24
Water Content, %

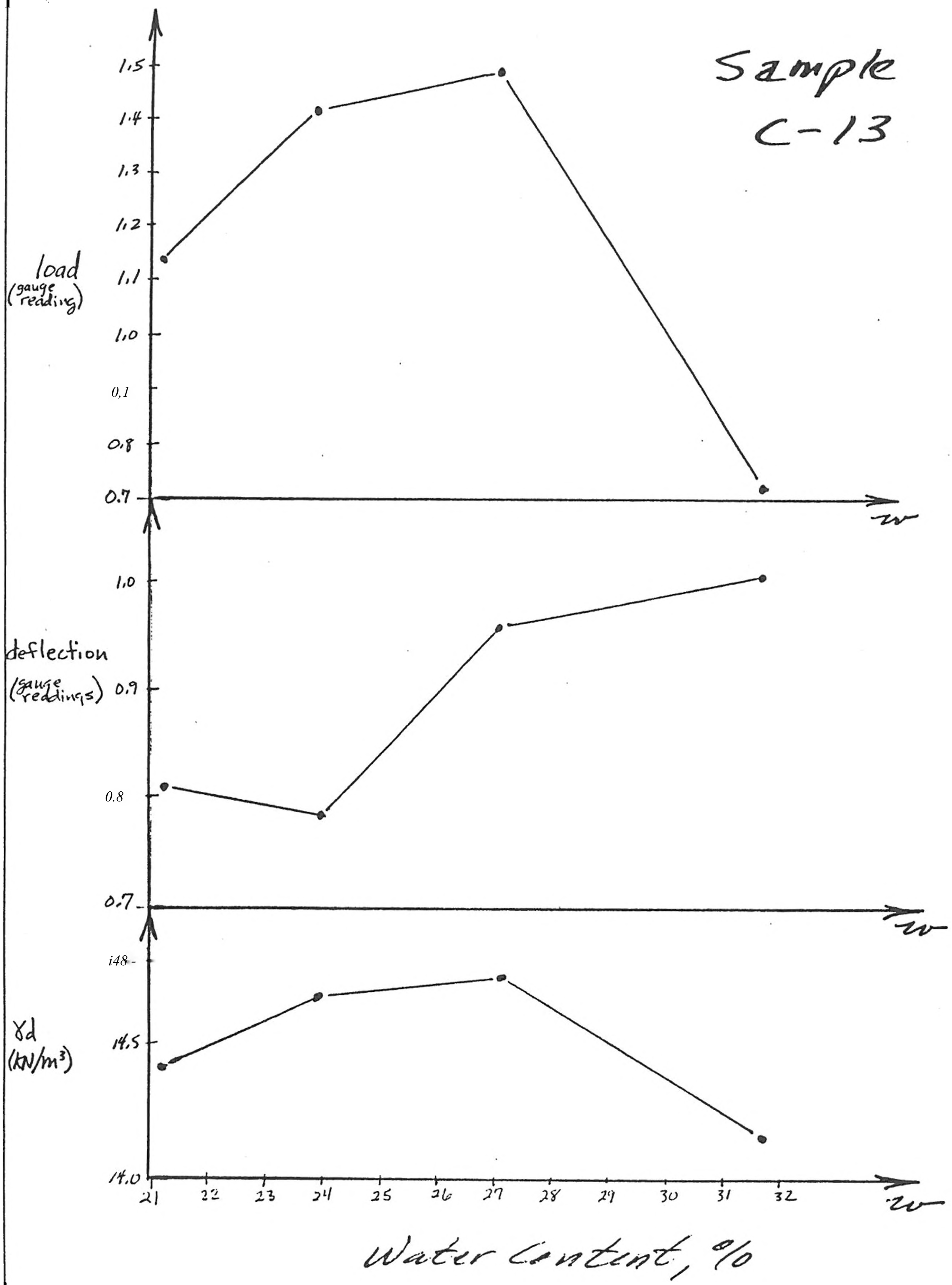

Sample C-8
load (gauge readings)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.4
w
deflection (gauge readings)
2.2
2.0
1.8
1.2
w
16.9
16.8
16.6
16.5
17
18
19
20
21
22
23
24
25
w
Water Content, %


Sample
C-9
load
(gauge readings)
4.3
4.0
3.5
3.0
2.3
w
2.3
2.0
deflection
(gauge readings)
1.5
1.0
0.8
w
15.5
15.0
19
20
21
22
23
24
25
26
27
28
w
Water Content, %

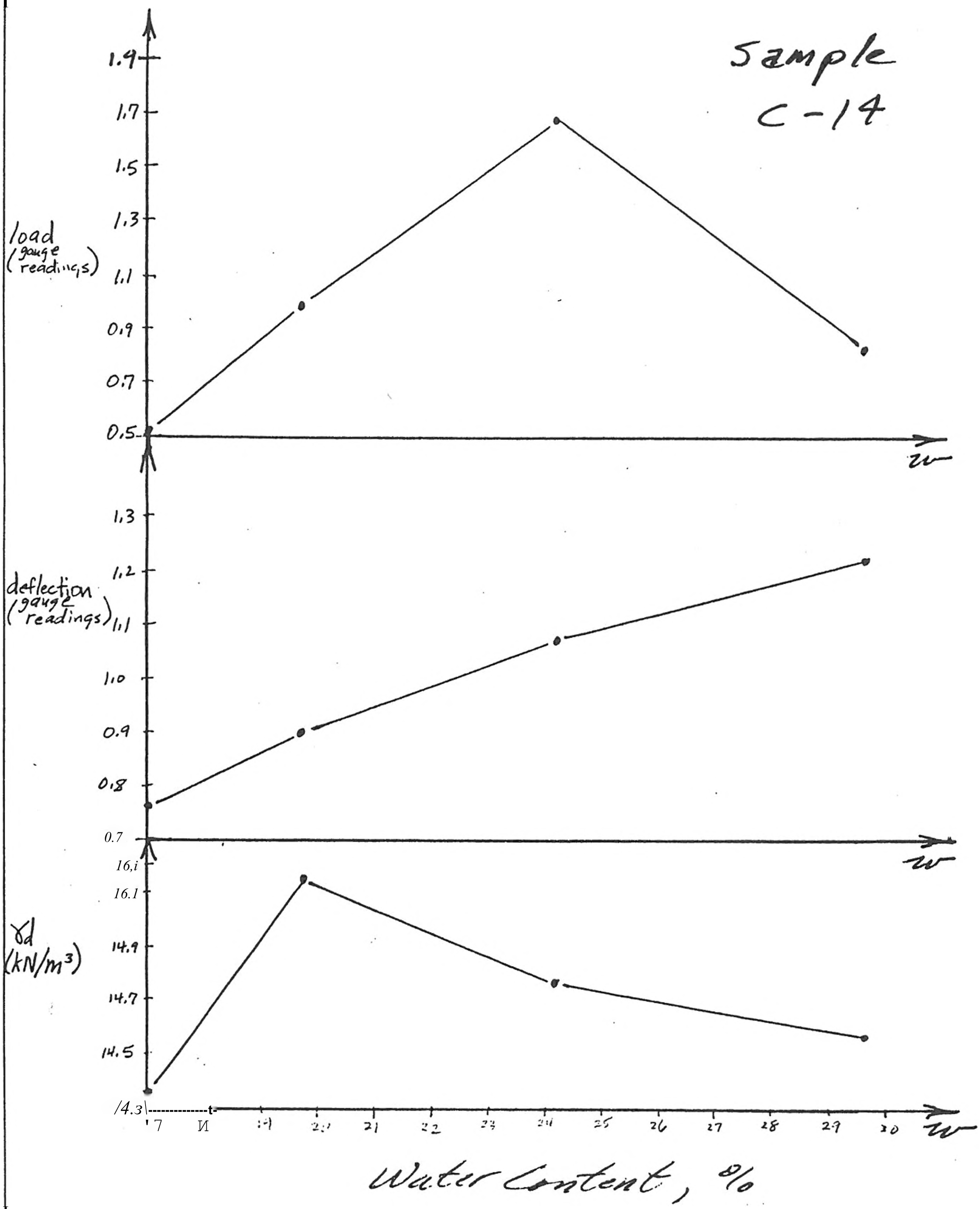

Sample C-10
load
(gauge readings)
3.3
3.0
2.5
2.0
1.5
w
(gauge readings)
1.5
1.4
1.1
1.0
0.9
w
15.3
15.0
14.7
14.5
14.3
17 18 19 20 21 22 23 24 25 26 27 28
w
Water Content, %

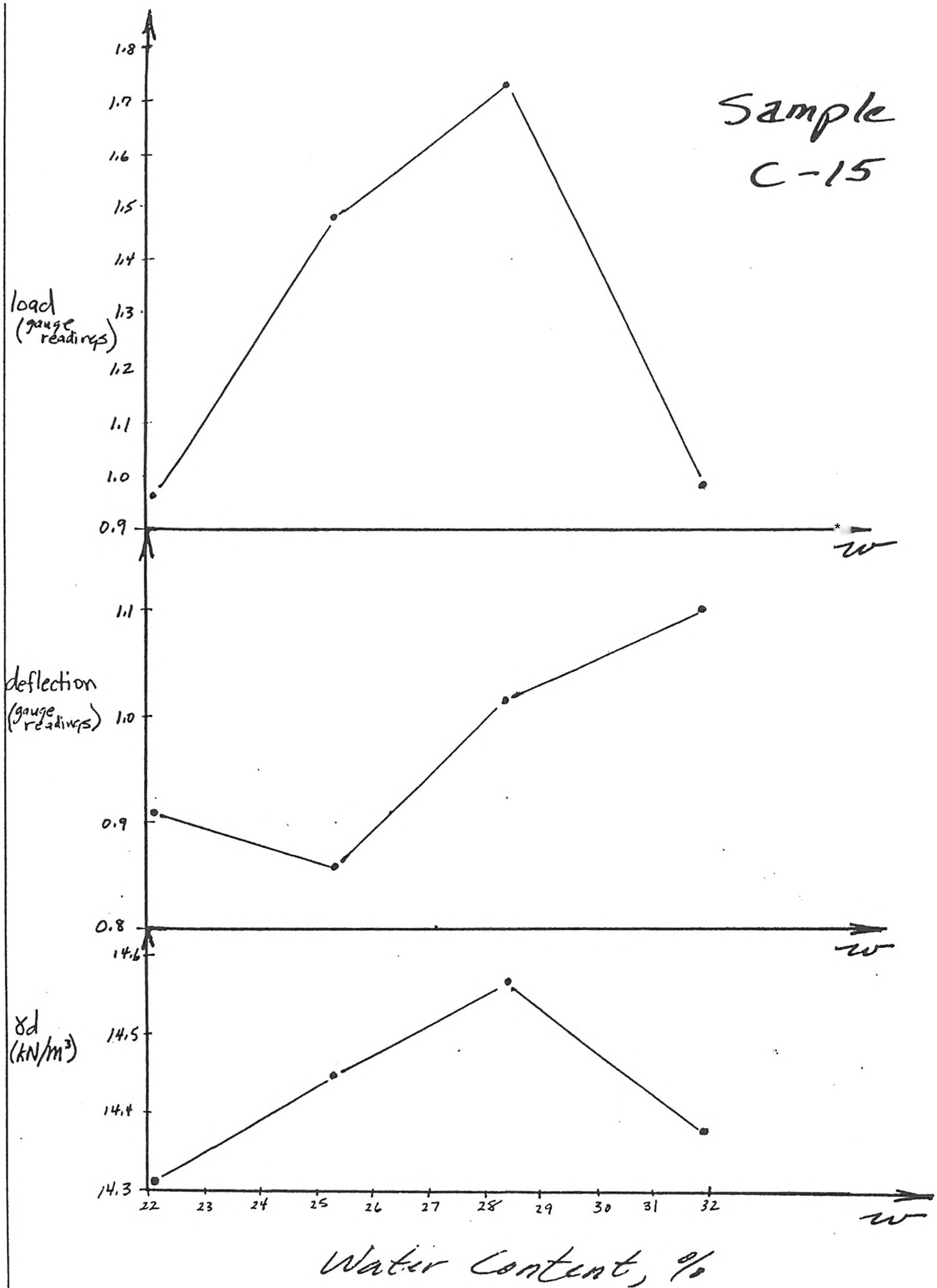

Sample
C-11
load
(gauge readings)
1.5
1.0
0.4
w
1.1
1.0
deflection
(gauge readings)
0.8
0.7
0.6
0.5
w
9.4
γd
(kN/m³)
9.0
8.5
53
55
60
65
67
w
Water Content, %


Sample C-12
load (gauge readings)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
w
deflection (gauge readings)
1.1
1.0
0.9
0.8
w
γd (kN/m³)
8.8
8.7
8.6
8.5
72.
74
w
Water content, %

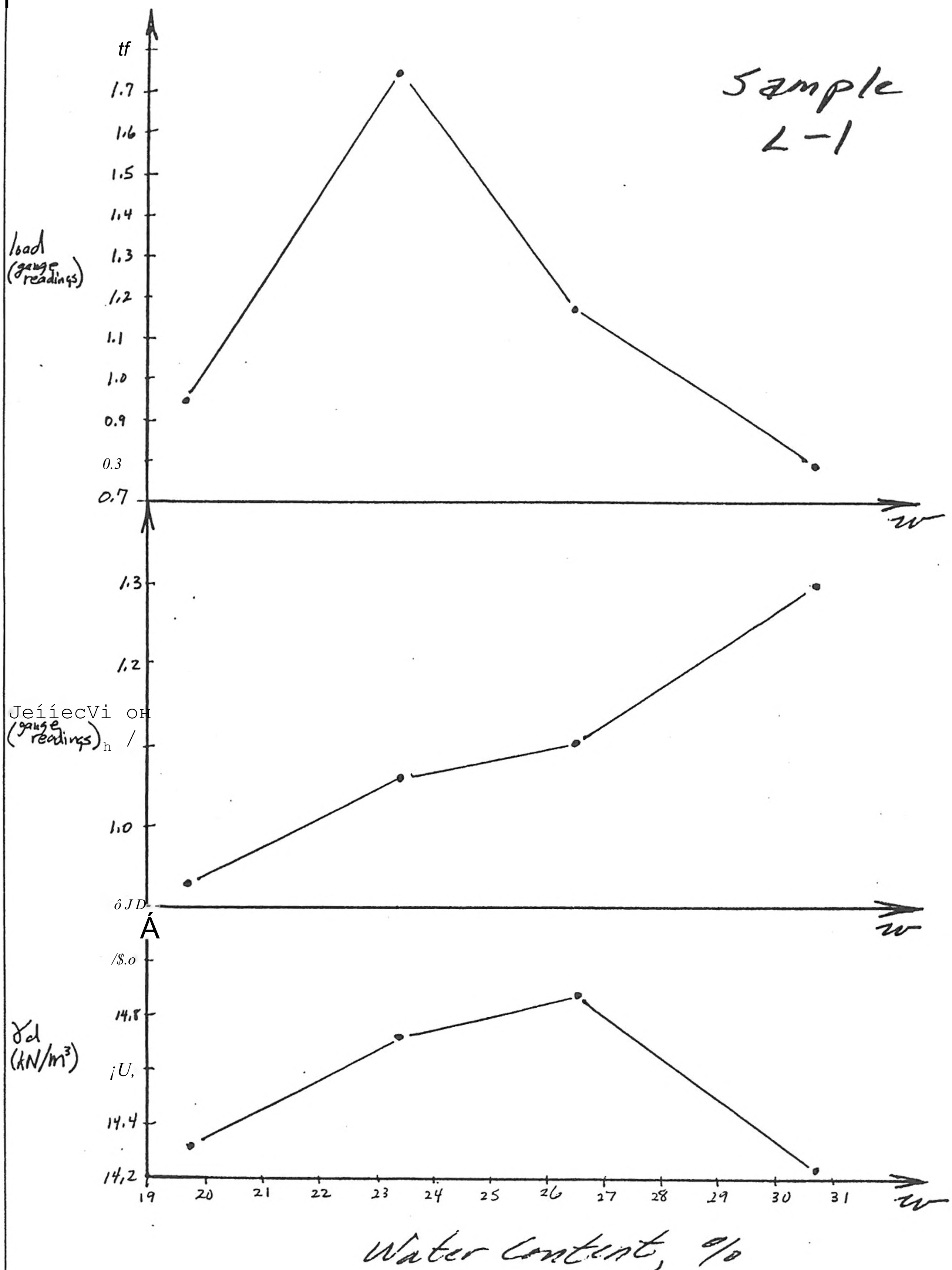


Sample C-13
load (gauge reading)
1.5
1.4
1.3
1.2
1.1
1.0
0,1
0.8
0.7
w
deflection (gauge readings)
1.0
0.9
0.8
0.7
w
γd (kN/m³)
i48
14.5
14.0
21
22
23
24
25
26
27
28
29
30
31
32
w
Water Content, %


Sample
C-14
load
(gauge readings)
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
w
deflection
(gauge readings)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
w
γd
(kN/m³)
16.1
14.9
14.7
14.5
21
22
25
26
27
28
w
Water Content, %



Sample
C-15
load
(gauge readings)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
w
deflection
(gauge readings)
1.1
1.0
0.9
0.8
w
γd
(kN/m³)
14.6
14.5
14.4
14.3
22
23
24
25
26
27
28
29
30
31
32
w
Water Content, %


Sample L-1
load (gauge readings)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.7
w
(gauge readings)
1.3
1.2
1.0
w
γd (kN/m³)
14.8
14.4
14.2
19
20
21
22
23
24
25
26
27
28
29
30
31
w
Water Content, %