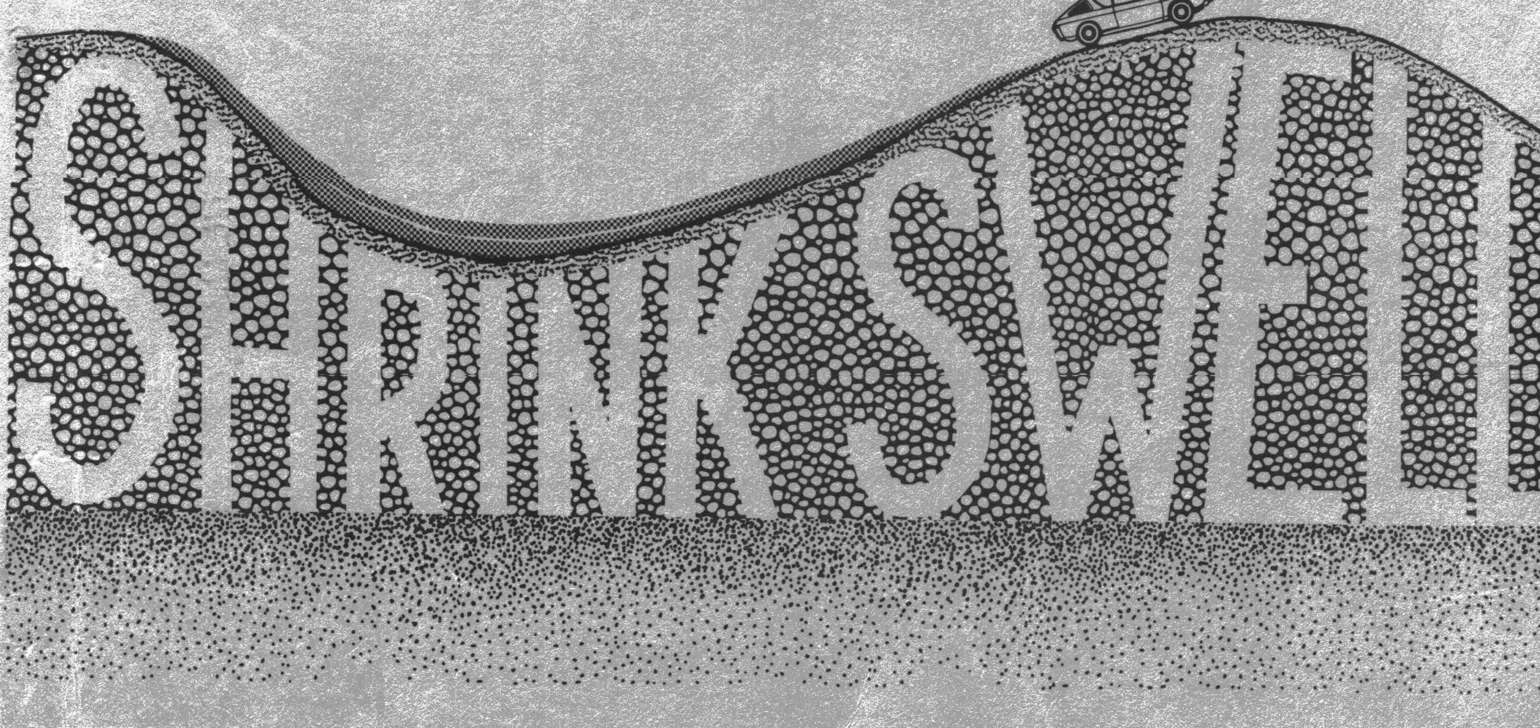
SHRINK and SWELL
of Excavated Earth Materials



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16. Abstract

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This report will be useful to design engineers when making estimates of soil shrinkage or verifying estimates derived from other informatior Savings of up to $30,000 may be realized on a typical grade and drainage project, based on the information provided in this report.

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THE SHRINK AND SWELL OF EXCAVATED EARTH MATERIALS

by

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January, 1983

METRIC CONVERSION FACTORS

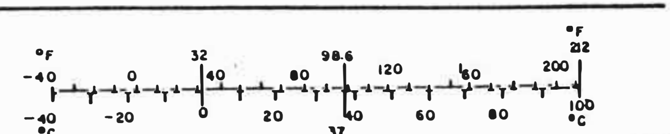
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

This study is an attempt to determine from laboratory tests the shrink or swell characteristics of excavated pedological soils. Twenty-six benchmark soils of various particle size classes were selected for study.

It was found that sandy loam soils shrink the most. They shrink about 14 percent. Clay soils may not shrink at all. Standard Proctor densities (AASHTO T99) were used as the compactive effort to induce the reduction in soil volume. The amount of shrinkage relates to the natural pore sizes and shapes as well as moisture content. Liquid limit values correlate fairly well with shrinkage factors.

This report will be useful to design engineers when making estimates of soil shrinkage or verifying estimates derived from other information. Savings of up to $30,000 may be realized on a typical grade and drainage project, based on the information provided in this report.

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PREFACE

This constitutes the final report on Research Project 71-16-1, "Shrink and Swell of Excavated Earth Materials". Included are description and characterization information concerning densities of soils in their natural and compacted states. The soils are grouped into particle size classes with shrinkage factors related to each size class.

The author wishes to thank the Oklahoma Department of Transportation ODOT Materials Laboratory, Oklahoma Soil Conservation Service, and the ODOT Engineering Test Branch of the Research Division for their help in preparing this report.

INTRODUCTION

Purpose

This study is an attempt to determine more accurately the shrink or swell characteristics of excavated pedological soils. These soils are those excavated from road cuts, hauled, moistened, and compacted in fills. Particle size classes are related to the reduction in volume from the natural to the compacted condition.

This report provides the Design Engineer with a more accurate method of determining the amount of shrinkage or will help verify the results of other methods of calculating shrinkage. It could save up to $30,000 in excavation costs for each project.

This project was done during the period of July, 1975 to January, 1983 by personnel of the Research Division of the Oklahoma Department of Transportation.

Twenty-six Soil Conservation Service "benchmark" soils were sampled and tested to determine their shrinkage factors.

Scope

The benchmark soil series of Oklahoma were selected for testing as a group of extensive representative soils. These soils are representative of a variety of soils of differing particle sizes. Shrinkage and other properties of soils other than benchmark soils may be inferred by use of particle size classifications.

Benchmark soils are chosen from "Land Resource Areas". These are areas selected by the Soil Conservation Service (SCS) as groups of soils having similar potential for growing specific kinds of crops. Land resource areas may include areas as large as 10,000 mis^2 (26,000 km^2). They are somewhat similar to geologic provinces (10).

Particle size classifications are useful tools in developing basic information for a characterization of soils. Three classifications are in common use by highway engineers. These include the American Association of State Highway and Transportation Officials (AASHTO), the Unified, and the Soil Conservation Service (SCS) classification systems (1), (2), (12). All of these systems may be used to relate soil particle size classes to shrinkage values.

MATERIALS AND METHODS

The soils selected for testing were the benchmark soils as established by the Oklahoma SCS as of 1976. The type localities as stated in the SCS Soil Series Description Sheets served as locations for sampling. Pits were dug with block samples taken, sealed, and transported to the ODOT Soils Laboratory for testing. Laboratory tests included: Atterberg limits (AASHTO T89 and T90), particle size analysis (T88), standard Proctor density (T99), and density of natural soil (T233). In cohesionless soils, nuclear (T238) and rubber balloon tests (T205) were used for determining natural densities. Shrinkage values were determined by the following method:

> Standard density/natural density = shrinkage factor. For example, if the dry weight per cubic foot of Pratt loamy sand is 80 lbs/ft^3 (1281 kg/m^3) and the standard compaction test shows dry weight at optimum moisture to be 100 lbs/ft^3 (1600 kg/m^3), then it takes 1.25 ft^3 (0.035 m^3) of natural Pratt soil to equal 1.0 ft^3 (0.028 m^3) of compacted Pratt. The shrinkage factor is therefore 1.25 (11).

Most of the residual soils in Oklahoma are derived from shales. Shales comprise from 60 to 70 percent of the rock types exposed on the land surface (10). Thus, soils derived from shales dominate the landscape. Usually these are clayey. These fine textured USDA soil types include: clays, silty clays, silty clay loams, sandy clays, and sandy clay loams. The less common more granular soil types include: loams, silt loams, sandy loams, loamy sands, silts, and sands derived mostly from sandstones or other granular rock types.

In order to reduce the amount of sampling and testing of over 300 soil series that occur in Oklahoma, 26 benchmark soils were sampled and tested. These soils represent the USDA classes mentioned above. Type locations for each of these soils were found so that the most representative (modal) soil profile would be tested. These soils, plus a few non-benchmark soils, were used to derive the data used in this report.

DISCUSSION

Soil Horizons

Pedological soils are composed of genetic soil layers called horizons. The horizons designated in this report are the A, B, C and R horizons. See Figure 1. The A horizon is considered the topsoil. Usually, the B horizon designation indicates conditions where the soil contains an accumulation of clay. The C horizon is considered to be highly weathered rock. It generally is thought of as that part of the soil not involved in major biological activity. Soils having R horizons are those formed from consolidated (indurated) bed rock e.g. limestone, granite. The R horizons generally were not tested unless the R soil material was soft enough to remove and test.

Shrinkage Mechanism

The ability of a natural soil to shrink under compactive effort is directly related to the initial void ratio or porosity. Soils with high porosities possess the potential for considerable consolidation or shrinkage when compacted. See Table 1. Conversely, soils with low porosities have less potential for shrinkage. The compactive effort test used for this study is that of a falling hammer as in AASHTO T99 "Moisture-Density of Soils Using 5.5 lb (2.5 kg) Rammer, 12 in (305 mm) Drop". This test is a laboratory simulation of the utilization of relatively light weight compaction equipment used

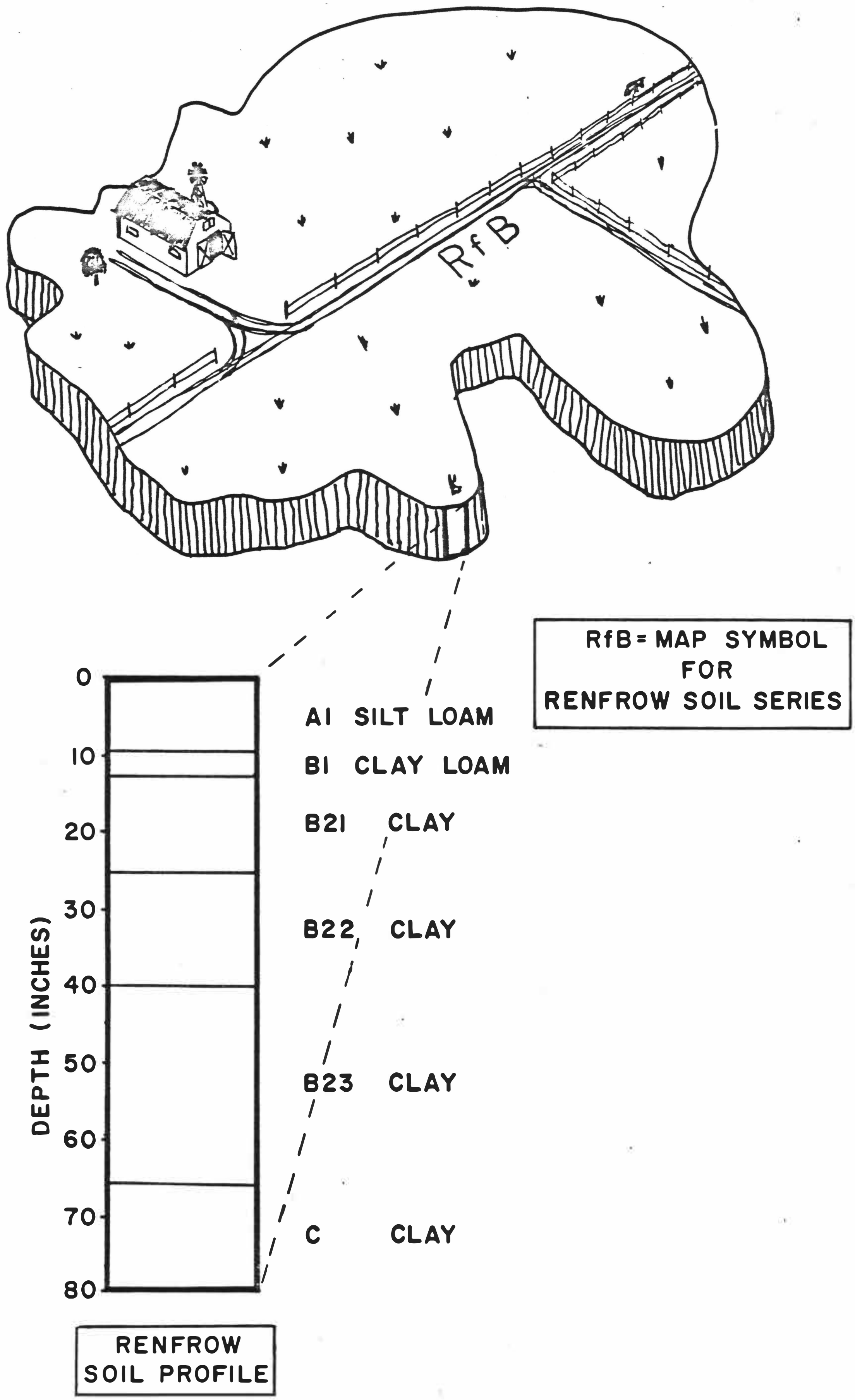


Figure 1. Profile of the Renfrow Soil Series.

TABLE 1

The Total Porosity of Various Soils

Type of soil	Depth inches	Total porosity, per cent by volume
Chernozem-like fine sandy loam	0-3	60.6
Hardeman clay loam	1½-10	44.4
Poncena clay	0-7	49.8
Nipe clay	0-5	56.6
Georgeville silt loam	½-8	57.0
Kirvin fine sandy loam	at 6	35.7
Nacogdoches fine sandy loam	at 5	43.4
Vernon fine sandy loam	at 2½	41.5
Muskingum silt loam	at 3½	45.1
Muskingum silt loam	at 3½	31.3
Cecil sandy clay loam	at 3	45.3
Shelby silt loam	at 3½	45.4
Shelby silt loam	at 13	51.7
Shelby silt loam	at 54	31.7
Palouse silt loam	at 10	50.2
Colby silty clay loam	at 5	48.9
Clinton silt loam	at 4½	51.9
Marshall silt loam	at 6½	56.4
Marshall silt loam	at 18½	60.3
Houston black clay	at 4	61.9
Houston black clay	at 35	40.2

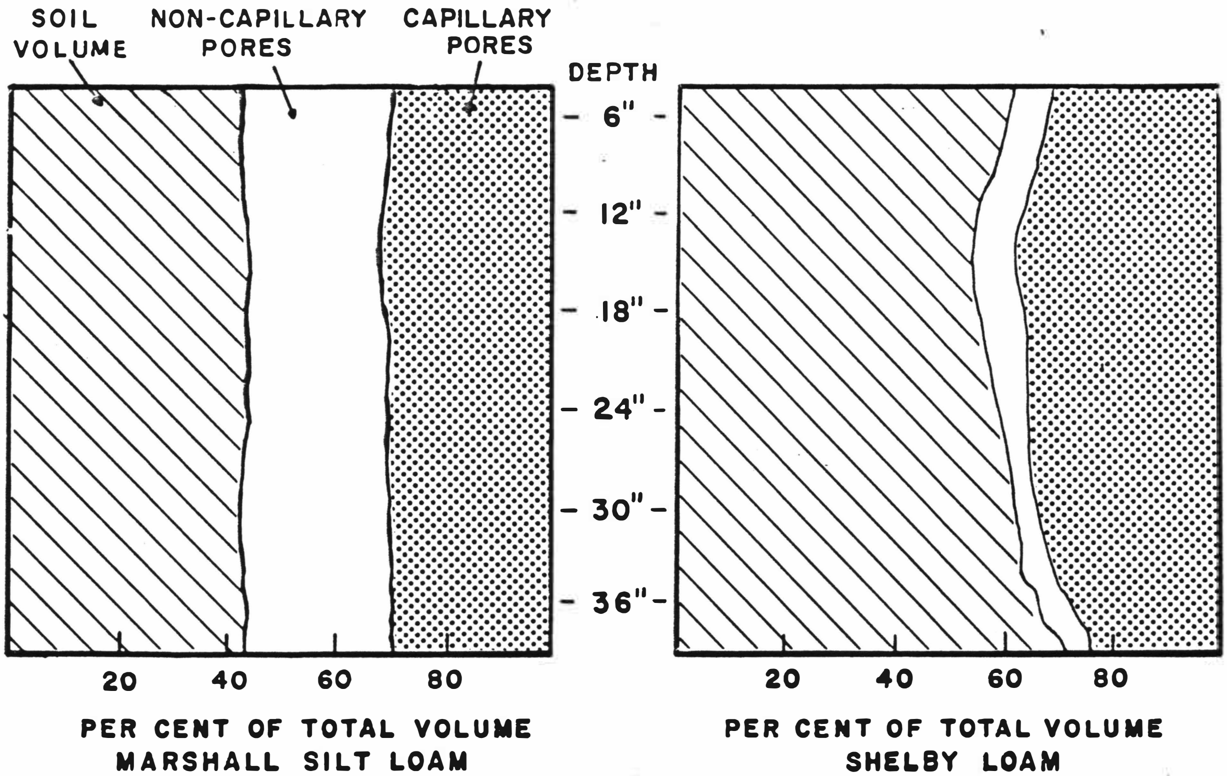
Taken from Baver et. al. and Middleton et. al.

in construction prior to 1940. An example of such equipment would be the 6 to 8 ton (5.5 to 7.3 metric ton) sheeps-foot roller (6).

The compaction curves of Johnson and Sallberg illustrate a density relationship between particle size and moisture contents (7). The ability of a soil to compact under a given load, from a high porosity to a lower porosity, is a function of soil fabric.

Soil fabric is the physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids or pores (4). Natural soils contain porosities of about 50 percent (3). See Figure 2. This includes capillary and non-capillary pores. See Table 2. The percent of soil porosity that is non-capillary varies considerably, however, it decreases rapidly as soils become more clayey. Soils high in clay content may contain up to 10 percent non-capillary pores of a total porosity of 25 percent. The loamy soils contain about 25 percent capillary and 25 percent non-capillary pores of a total porosity of 50 percent. Pores are difficult to classify. They possess different shapes as well as sizes.

Several pore (void) types are listed by Brewer (4). See Table 3. Some of the larger pores such as chambers, planes, channels, vesicles, and vughs are probably the only ones that are affected by compaction. In Figure 3 Mitchell explains some of the factors affected by compaction of soils (9). Brewer also



Taken from Baver

Figure 2. A Profile of Pore Volume.

TABLE 2

The Relationship of Soil Porosity to the Size of Aggregates

Soil property	Diameter of aggregates in mm. Smaller than 0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-5.0
Total porosity, per cent	47.5	50.0	54.7	59.6	62.6
Non-capillary porosity, per cent	2.7	24.5	29.6	35.1	38.7
Capillary porosity, per cent	44.8	25.5	25.1	24.5	23.9
O_2 content of soil air, per cent	5.4	18.6	19.3	19.4	....
O_2 content of soil, per cent	0.1	4.5	5.7	6.7	7.5
Nitrate formation, mg. N per kg. soil	9.0	19.1	....	34.0	45.8

Taken from Doiarenko (Krause, 1931)

TABLE 3

MORPHOLOGICAL CLASSIFICATION OF VOIDS

Void Type	Distribution Pattern	Orientation Pattern	Shapes (ratios of axes)	Conformation (of walls)	Smoothness (of walls)
Packing voids: (i) Simple (ii) Compound	Between solid individuals Between single grains Between unaccomodated peds (interpedal	Random	Usually equant to prolate	Irregular	Orthovoids or metavoids Orthovoids Orthovoids or metavoids (smoothed)
Vughs*	Random	Random	Usually equant to prolate	Irregular to mammillated	Orthovoids or metavoids (smoothed)
Vesicles	Usually random, but sometimes a specific referred distribution	Random or parallel	Usually equant to prolate, or arcuate	A specific form	Usually metavoids (smoothed)
Chambers	Random	Random	Usually equant to prolate	Usually a specific form	Usually metavoids (smoothed)
Joint planes	Random or interpedal	Parallel to subparallel sets with specific referred orientation	Planar	Regular	Usually metavoids (smoothed; sometimes slickensided)
Skew planes	Random	Random	Planar	Regular or irregular	Orthovoids or metavoids (smoothed; sometimes slickensided)
Craze planes	Interpedal (between accommodating equant to prolate peds) or random	Random	Planar	Irregular due to compound nature; small individual planes may be regular	Orthovoids or metavoids (smoothed)
Channels	Branching patterns		Usually acicular; sometimes prolate	Regular with specific cross-sectional shapes	Metavoids (smoothed)

*When vughs are very numerous they may intersect, thus forming a network of large voids; these are interconnected vughs.

Taken from Brewer.

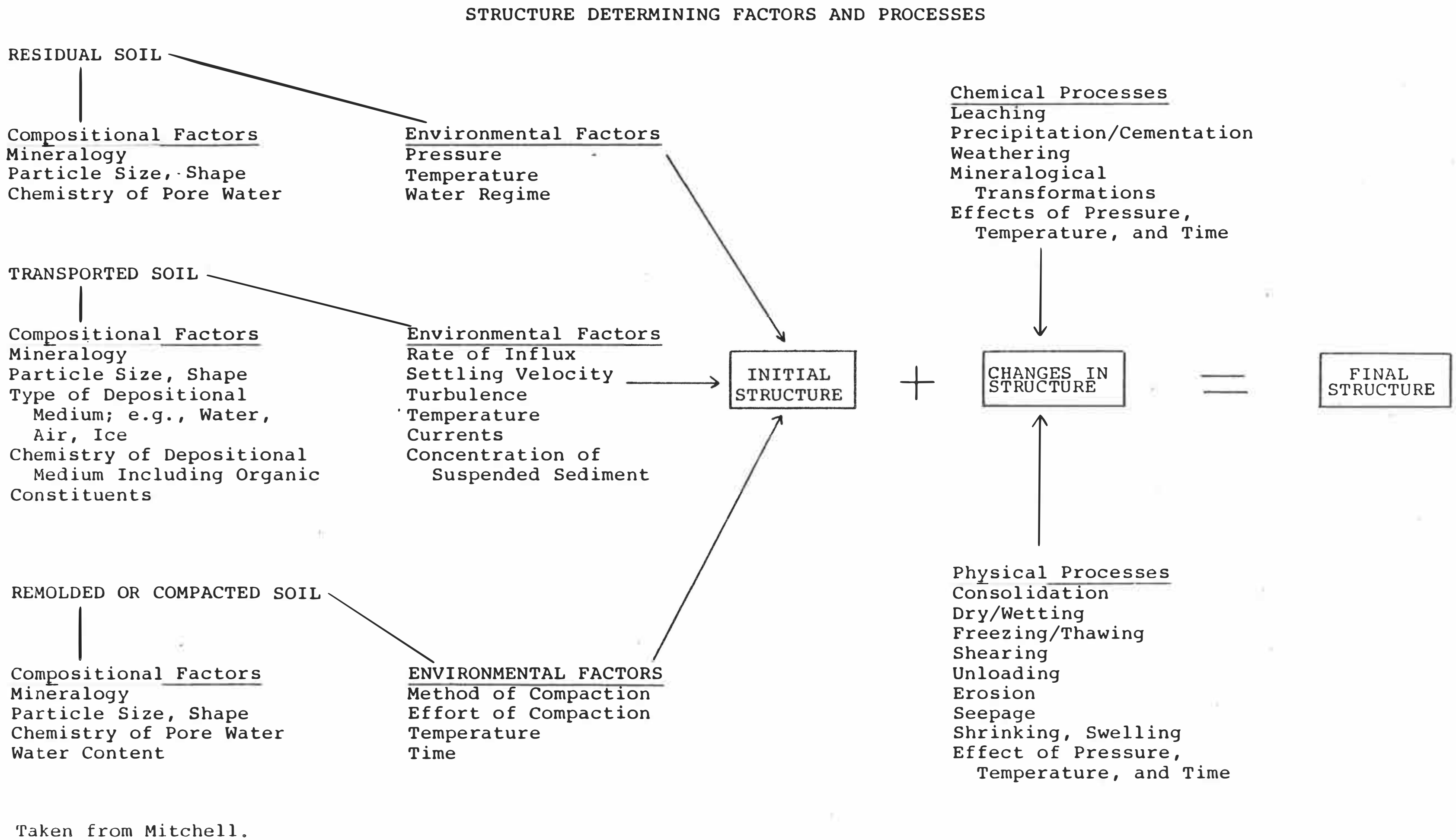


Figure 3. Structure Determining Factors and Processes.

has developed a pore (void) size classification showing the sizes that occur in natural soils. These range from his cryptovoids, of less than 0.1 μm, to coarse macro voids, of greater than 5 mm. See Table 4. Most likely, only the macro voids (pores) could be affected by compaction efforts. Such pores are derived from grain packing (arrangement), gas movement, ice formation, root systems, worm activity, insect activity, burrowing animals, shrink and swell, wetting and drying, and inherited bedding planes and joints of the parent rock.

Compaction occurs as pores are reduced in size. Baver says that the fluid-like flow of moistened clay particles under stress will cause destruction of the larger pores in a natural soil (3). Collins and McGowan have noted that single particle (grain) interaction is rare (5). This concept indicates that in soil with even small amounts of clay, only the clay is contiguous, not the grains. Thus, soil strengths, or resistance to shear, comes from bridges or "connections" of clay or grain-clay assemblages in a soil. A reduction in porosity occurs as the connections are sheared by compaction.

Particle Size Relationships

The loamy soils, such as loam, silt loam, sandy loam (USDA); SM-SC, ML-CL, SM (Unified); A-2-6, A-2-4, A-4, (AASHTO); show the greatest average shrinkage factors. See Appendix A. This is thought to be due to an "open" or high porosity soil fabric.

TABLE 4

Size Classification of Voids

Class Name	Subclass	Class Limits
Macrovoids		75u
	Very fine macrovoids	75-1000u
	Fine macrovoids	1000-2000u
	Medium macrovoids	2000-5000u
	Coarse macrovoids	5000u
Mesovoids		30-75u
Microvoids		5-30u
Ultramicrovoids		5u
Cryptovoids*		0.1u

* The water in cryptovoids is generally accepted as being unavailable to plants.

Taken from Brewer

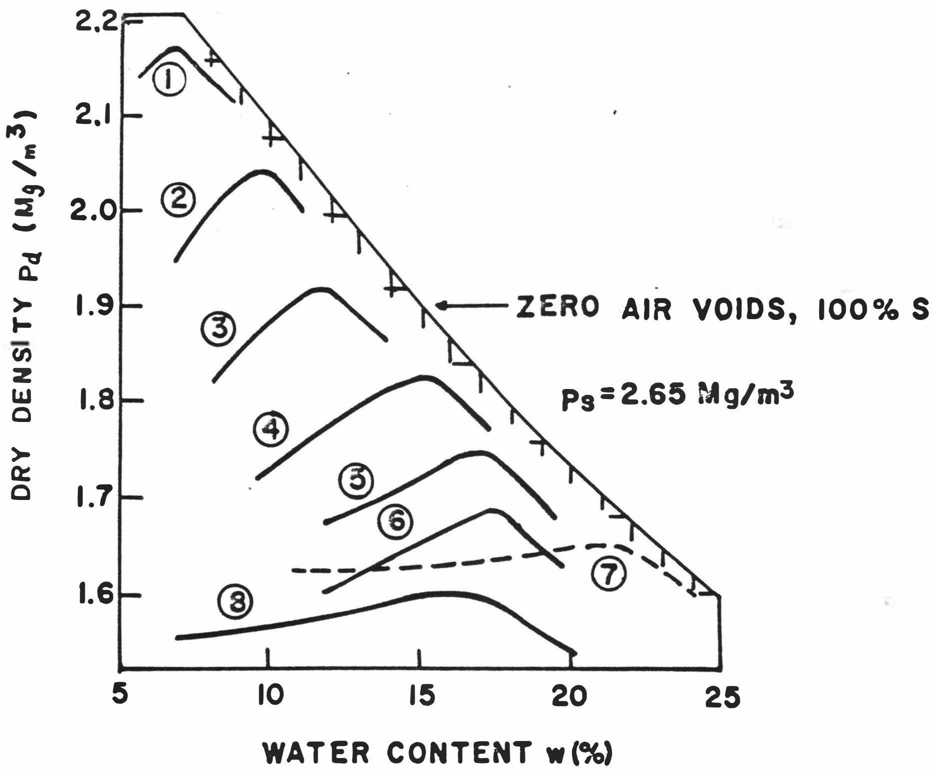
The open fabric is easily disturbed by compactive effort when the soil is at optimum moisture content. See Figure 4. The opposite is true for the clay soils. Usually, these soils cannot be compacted as well as Mother Nature has done. In many cases these soils appear to swell slightly when excavated and compacted in a fill.

As mentioned above, the degree of compaction is strongly related to soil moisture content. Water in the soil acts as a lubricator to allow a closer proximity of grains and a consequent alteration of fabric as compression of the soil mass occurs. At optimum moisture content the soil particles may be brought as close together as possible with normal compaction efforts.

Statistical Analysis

One of the problems when using a limited number of soil samples, is the degree of scatter of test values. When dealing with soils the scatter is sometimes considerable and sometimes reasonably narrow. See Appendix A.

A regression analysis was used to determine the relationship between particle size systems and shrinkage factors. The graphs in Appendix A show the relationship between the three particle size systems and shrinkage factors. The trend is for clayey soil to approach a shrinkage factor of 1.00 or somewhat less. This means that large pores are few. Soils high in silt and sand show shrinkage factors of 1.10 or more. These soils



SOIL TEXTURE AND PLASTICITY DATA

No.	Description	Sand	Silt	Clay	LL	PI
1	Well-graded loamy sand	88	10	2	16	N.P.
2	Well-graded sandy loam	72	15	13	16	N.P.
3	Med-graded sandy loam	73	9	18	22	4
4	Lean sandy silty clay	32	33	35	28	9
5	Lean silty clay	5	64	31	36	15
6	Loessial silt	5	85	10	26	2
7	Heavy clay	6	22	72	67	40
8	Poorly graded sand	94	----6----		N.P.	--

Taken from Johnson and Sallberg

Figure 4. The relationship of moisture-density to soil properties.

contain relatively high percentages of large pores that can be collapsed to reduce the soil volume.

Among the usual laboratory tests, liquid limit serves best when estimating soil shrinkage. Note that the liquid limit test was not run on non-plastic soils. See Figure B-1 in Appendix B. Neither the plasticity index nor the clay content correlate well with shrinkage factors. Soils that are granular, with just a small amount of clay, seem to shrink the most. These are soils that have very low plasticity indices or are non-plastic. Very clean cohesionless sands do not shrink as much as soils of very low plasticities. Highly plastic soils may not shrink at all.

COST ANALYSIS

The information presented in this report provides a means for a more accurate prediction or verification of the changes in soil volume that result from earthwork construction operations. In a typical six mile long grade and drainage project, about 500,000 to 1,000,000 yd^3 (382,000 to 765,000 m^3) of soil material are excavated (8). Current methods of estimating shrinkage are based on the history of adjacent or close-by projects.

For example: Plans indicate that a six mile project will require 700,000 yd^3 (535,000 m^3) of excavation. The soil survey indicates that a USDA class of sandy clay loam is predominant. Without this information, design engineers probably would use the standard shrinkage factor of 1.20. Table A-1 in Appendix A shows a shrinkage factor of 1.11 should be used to compute changes in volume. This difference in the method of calculating shrinkage would produce an error of 63,000 yd^3 (48,000 m^3). In terms of dollars this would be an error of \$126,000 (assuming \$2.00/yd^3 for excavation). While it is not expected that the use of this report would save over \$100,000 on every project, it could assist in saving about \$20,000 to \$30,000 for each project of this magnitude.

CONCLUSION

The results of this study are based on the shrinkage in volume occurring as soils are compacted to standard Proctor density (AASHTO T99). Modern heavy construction equipment, heavier than an 8 ton (7.3 metric tons) roller is capable of compacting soils to a greater density than standard Proctor. For example: This report indicates that sandy loam has a shrinkage factor of 1.14. It is very probable that modern equipment will compact the soil more than this - perhaps up to a shrinkage factor of about 1.20.

The information in this report indicates the relative differences in shrinkage based on particle size classes. The coarser soils such as sandy loam (USDA), ML-CL(Unified), and A-2-6(AASHTO) will shrink the most, usually about a 1.14 shrinkage factor. The finer soils such as clay (USDA), CH(Unified), and A-7-6(AASHTO) shrink the least, usually near a 1.00 shrinkage factor.

Liquid limit test (AASHTO T89) values are a fairly good indicator of shrinkage.

The results of the soil tests as provided in this report will allow a more accurate method of determining soil shrinkage factors. It can also assist in verifying the results of other methods of calculating shrinkage.

This report should be helpful in producing savings of up to $30,000 for each project.

RECOMMENDATIONS

In order to implement properly the results of this study, the following steps should be taken:

1. A manual should be developed incorporating the steps outlined below. This manual should include a method to assure that soil test information is available for making shrinkage factor determinations.
2. A table listing the soil series of Oklahoma and their particle size relationship to the tested benchmark soils should be compiled.
3. A method for making soil shrinkage determinations from soil maps should be provided.

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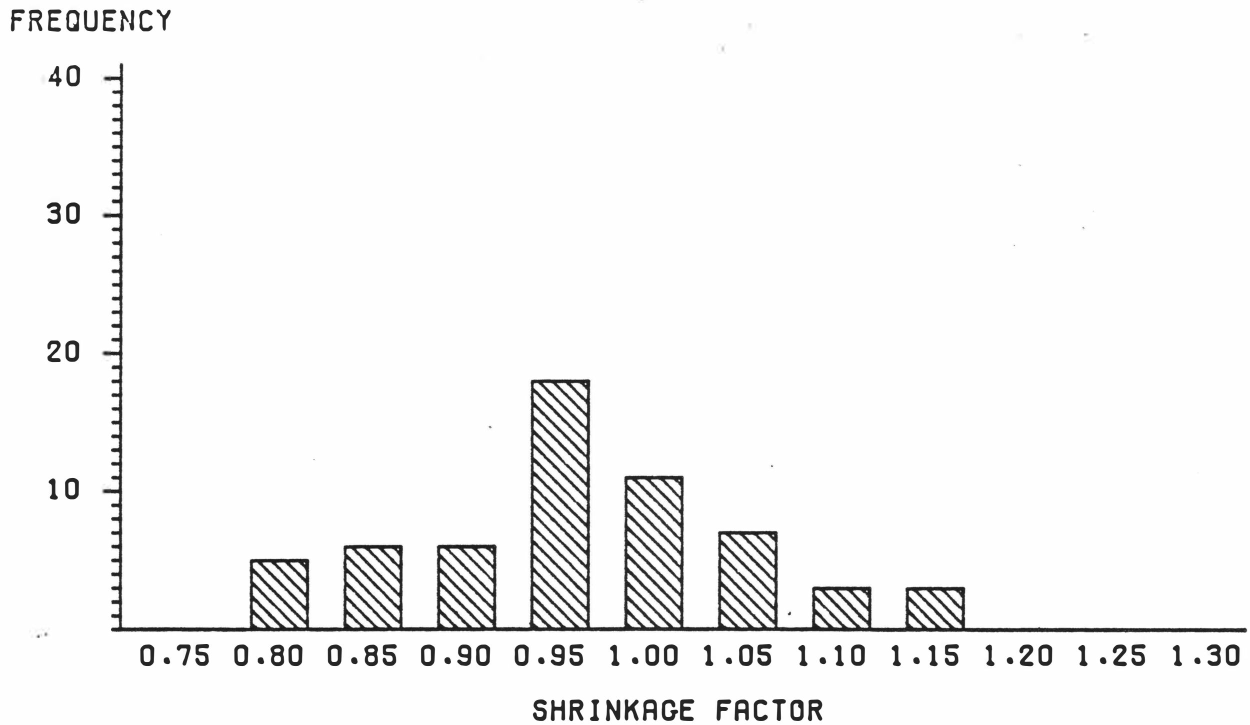
APPENDIX A

SHRINKAGE FACTORS

This appendix describes and illustrates the relationship of the number of tests and the resulting shrinkage factors for each particle size class. The distribution of test values is shown graphically. Also, a statistical summary is given. The particle size class, horizon, number of observations, mean, standard deviation, minimum, and maximum values are presented in the table on page A-17 to A-19. A chart comparing the particle sizes of the USDA, Unified, and AASHTO classes is on page A-20.

USDA Classification

CLASS=C



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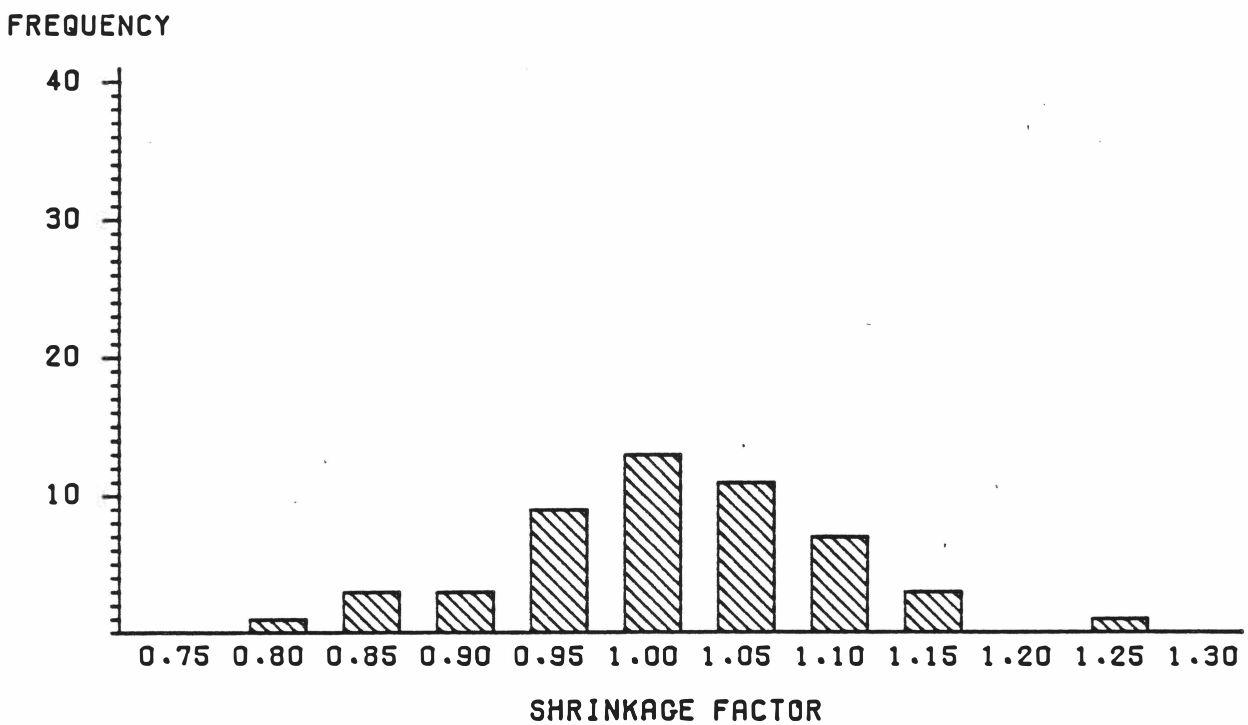

USDA Classification (Continued)

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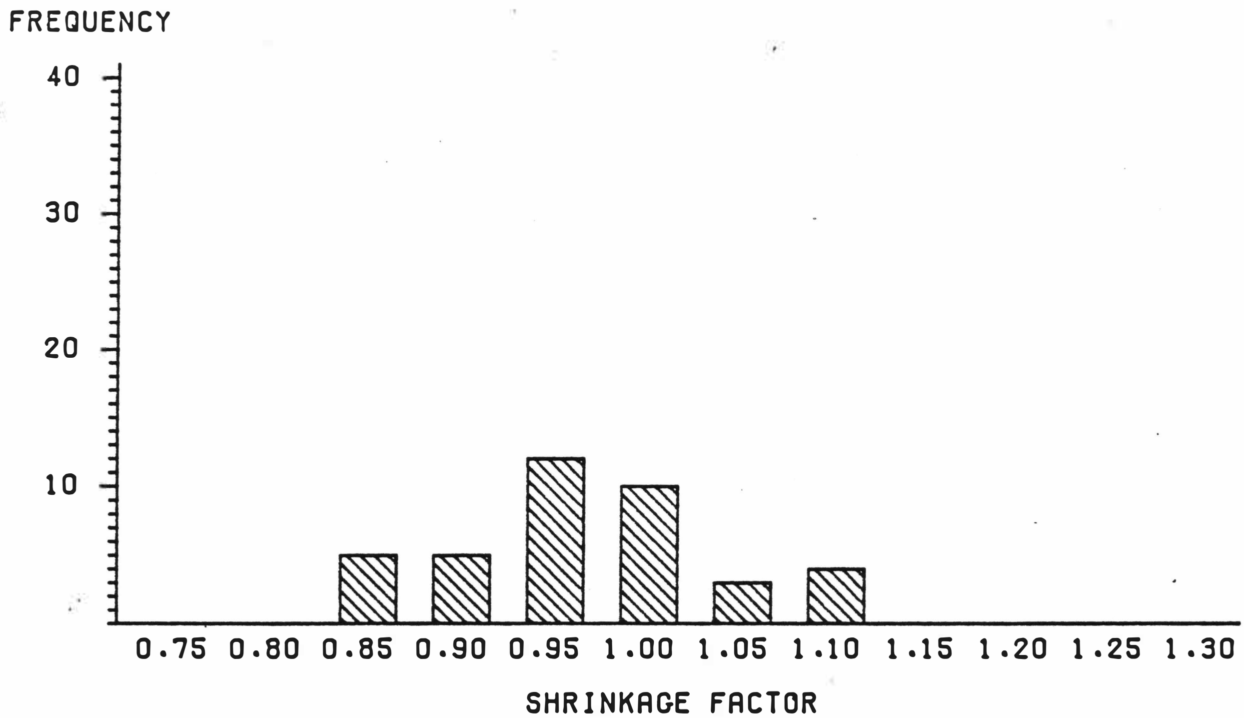

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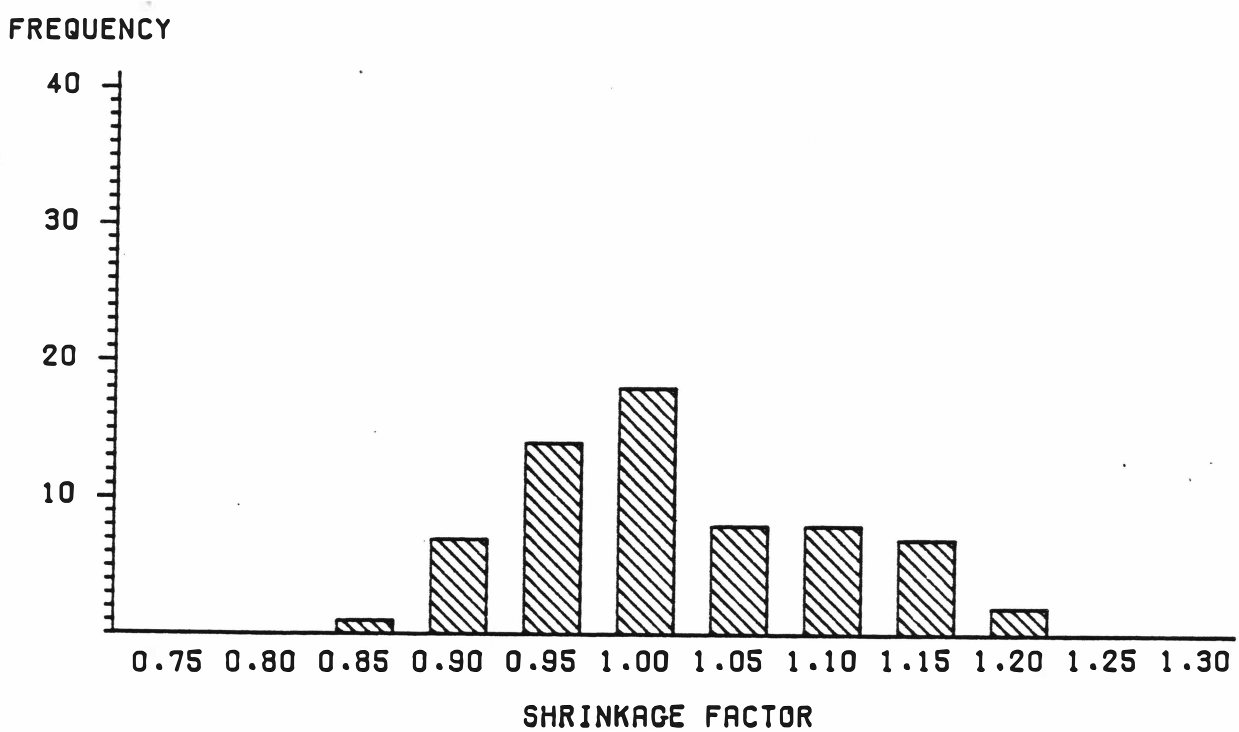
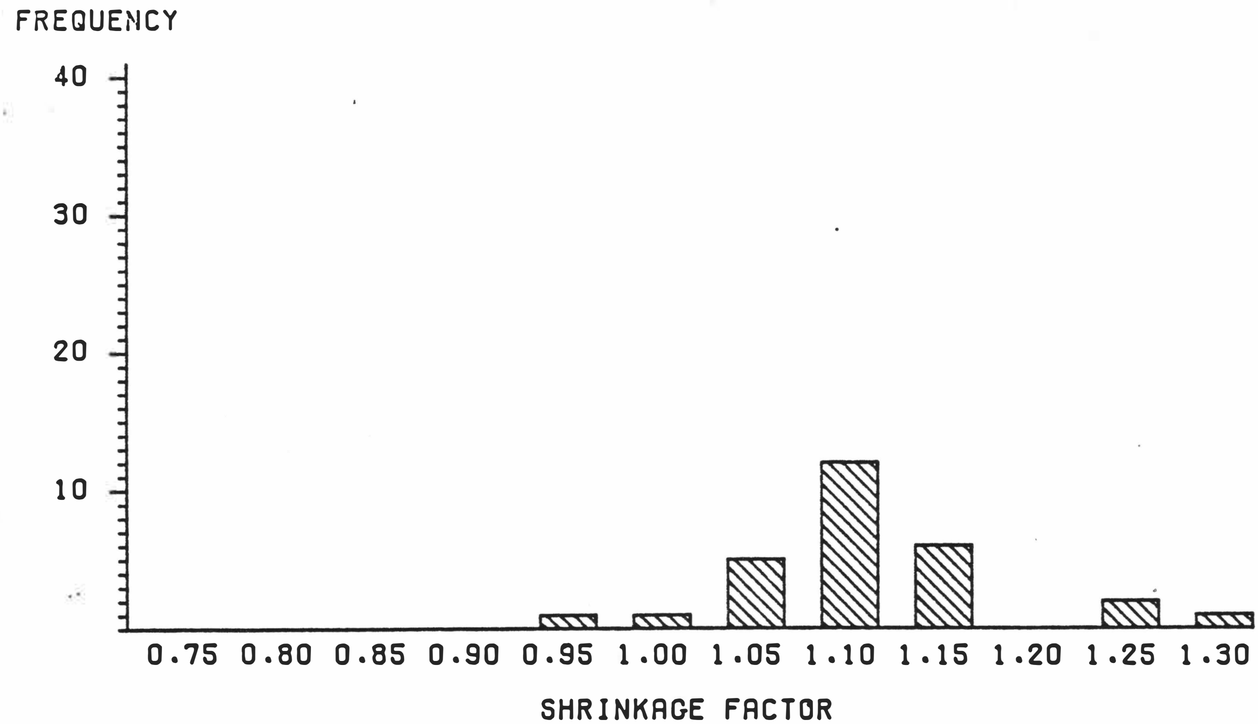


USDA Classification (Continued)

CLASS=L



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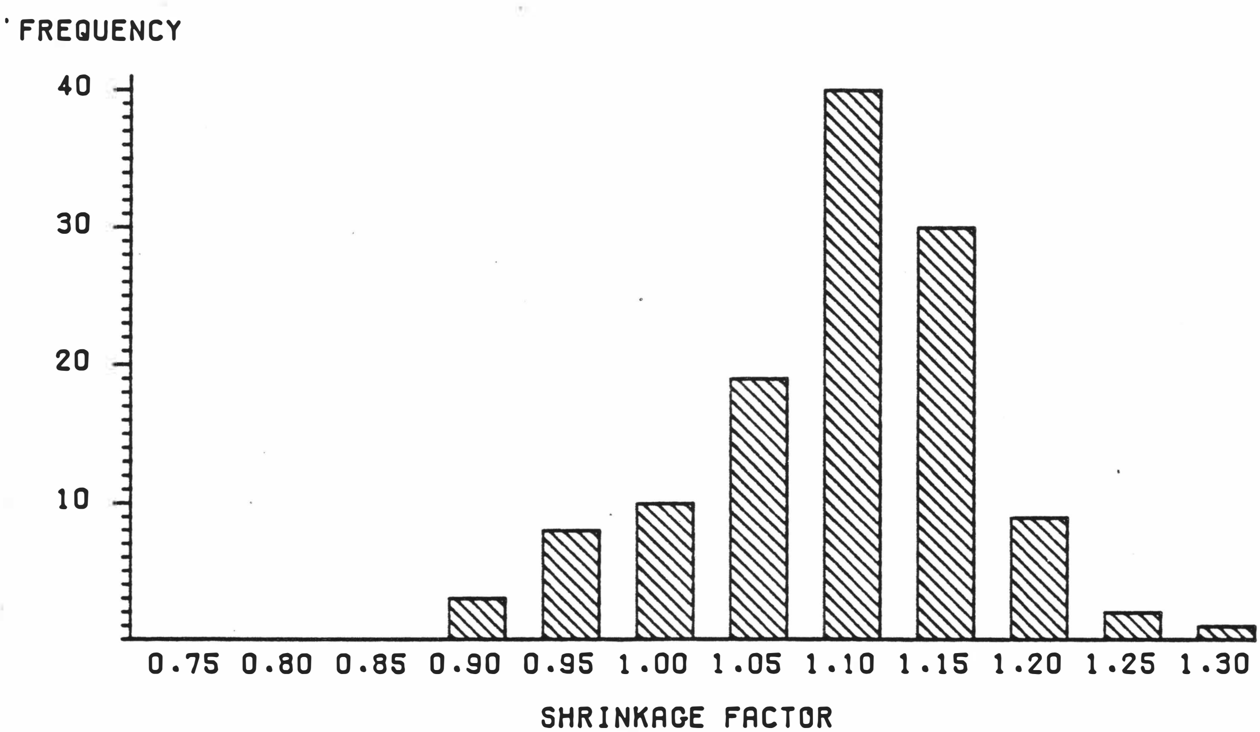

USDA Classification (Continued)

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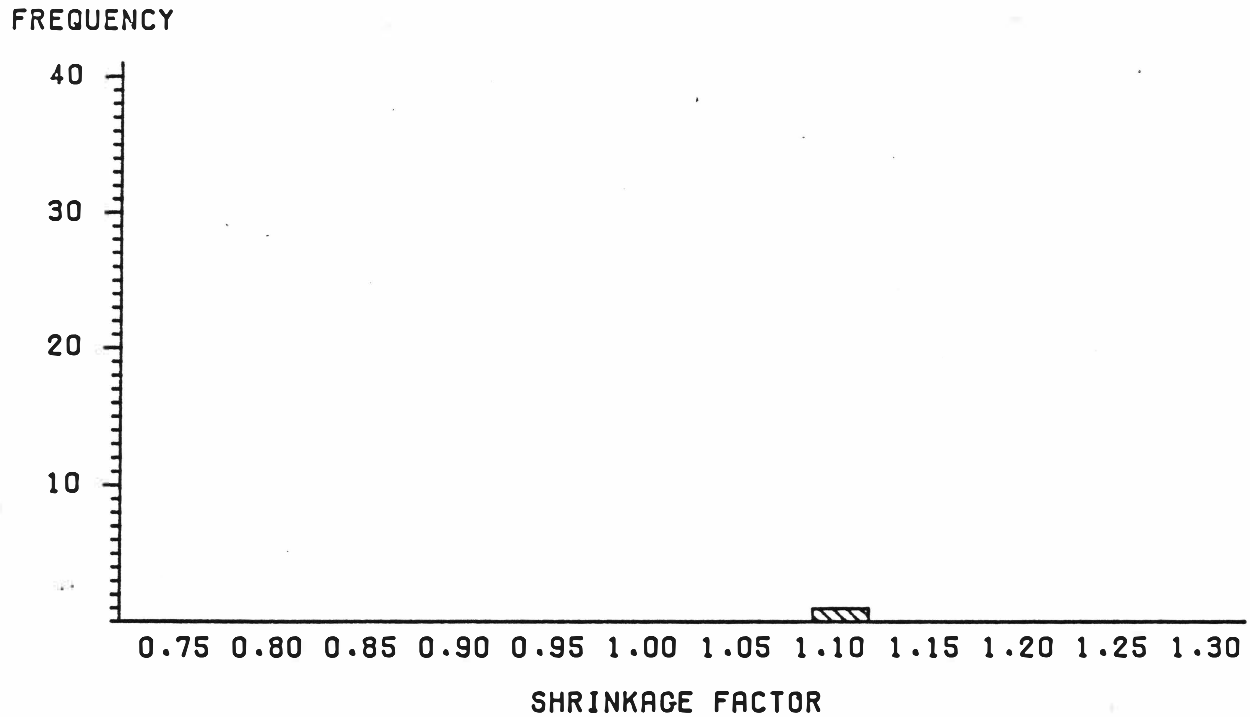
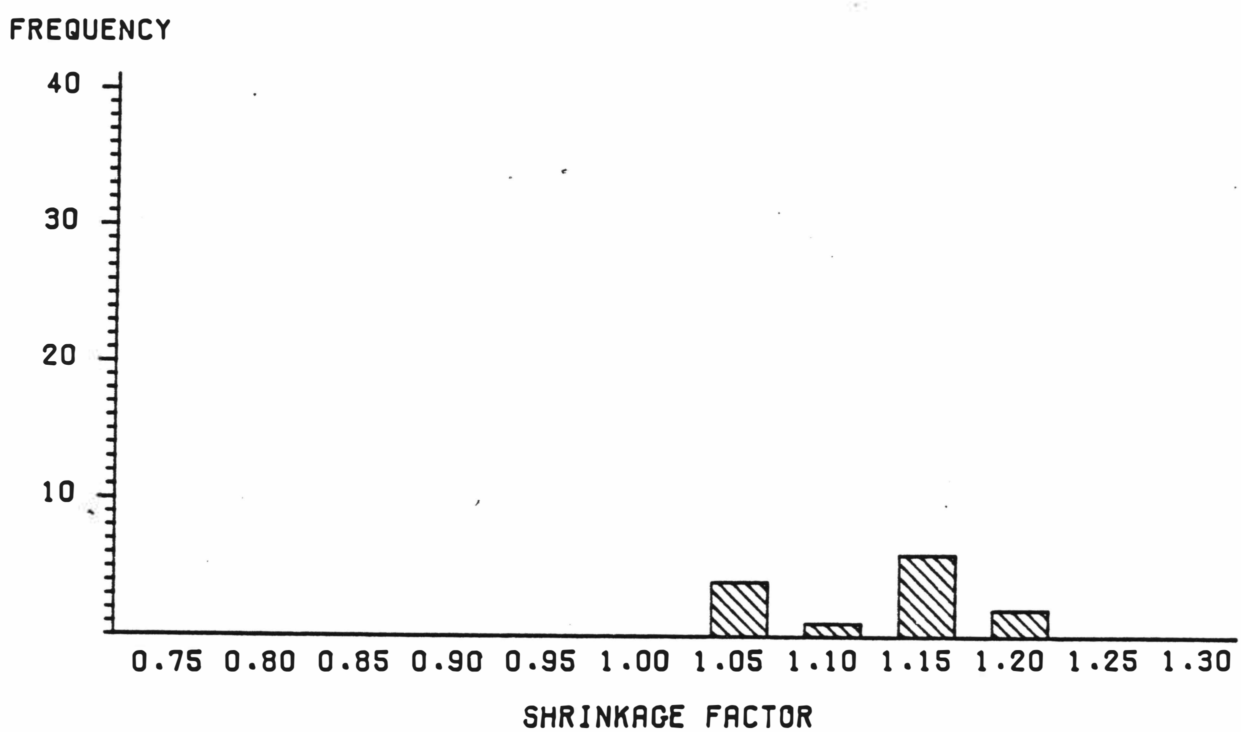
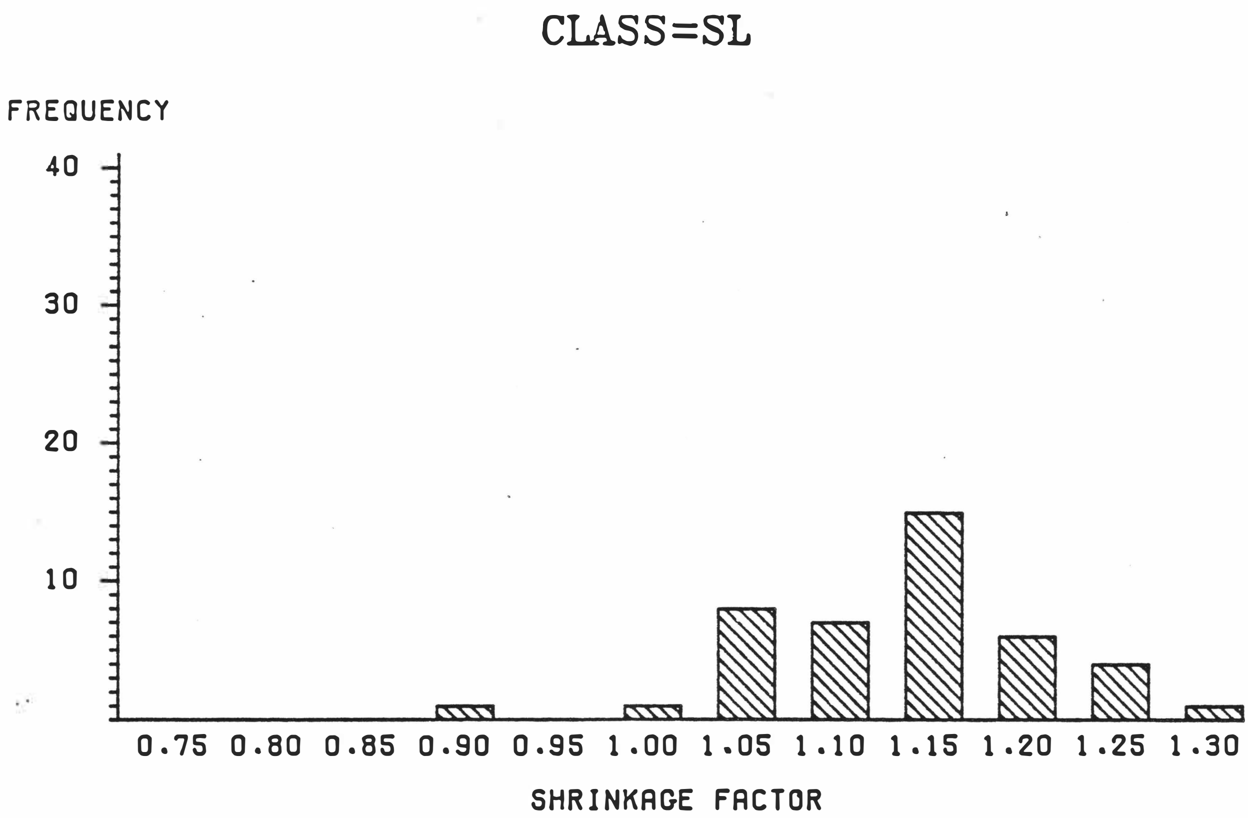
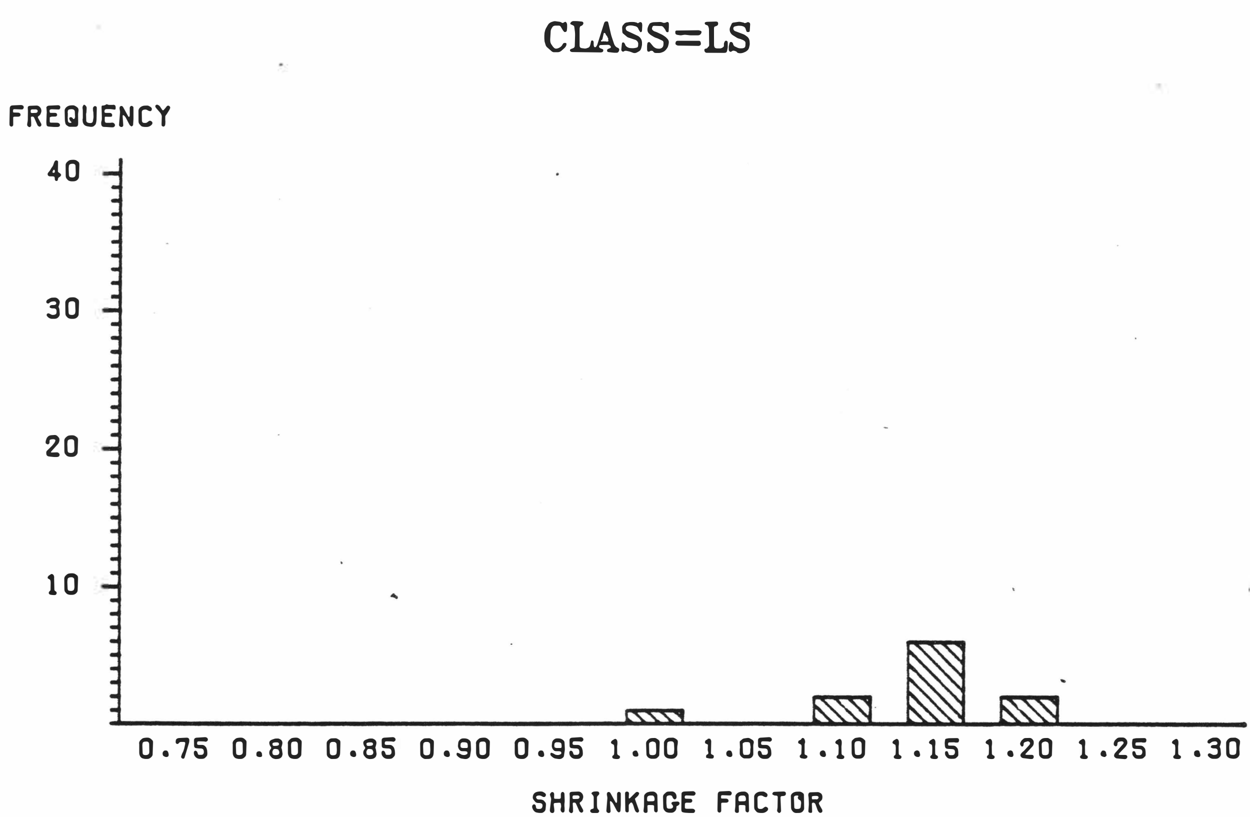


CLASS=SCL



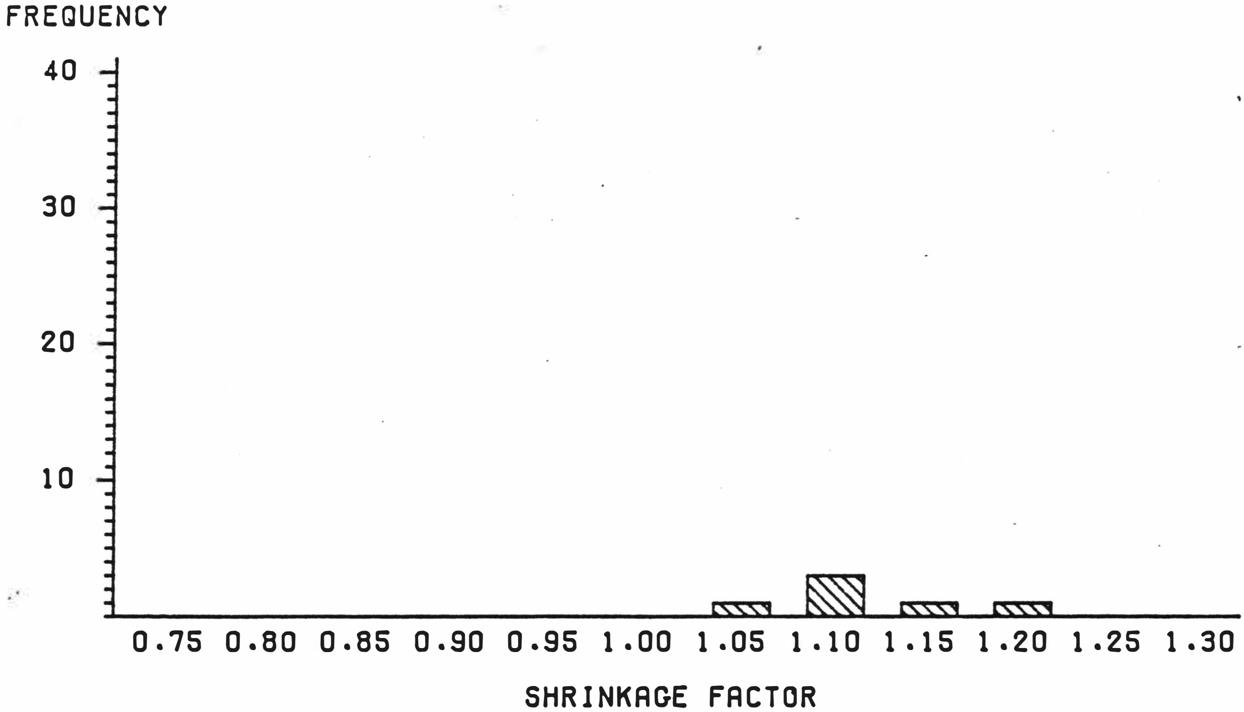
USDA Classification (Continued)





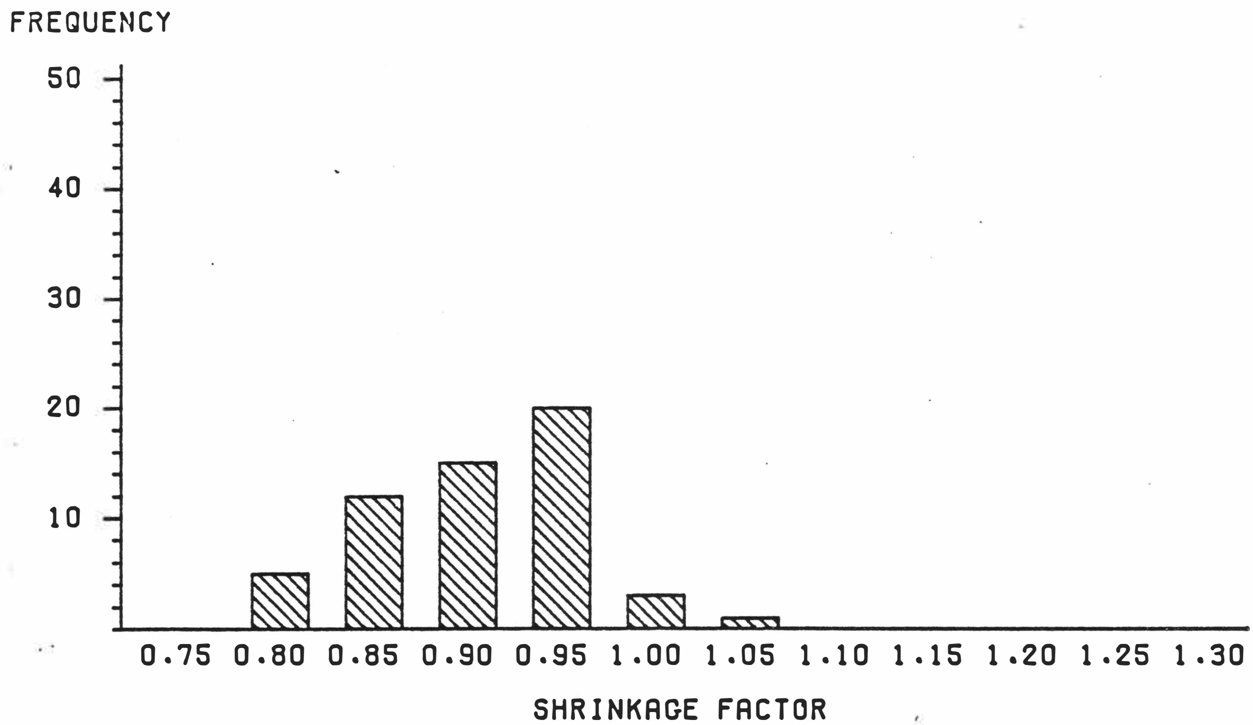
USDA Classification (Continued)

CLASS=S

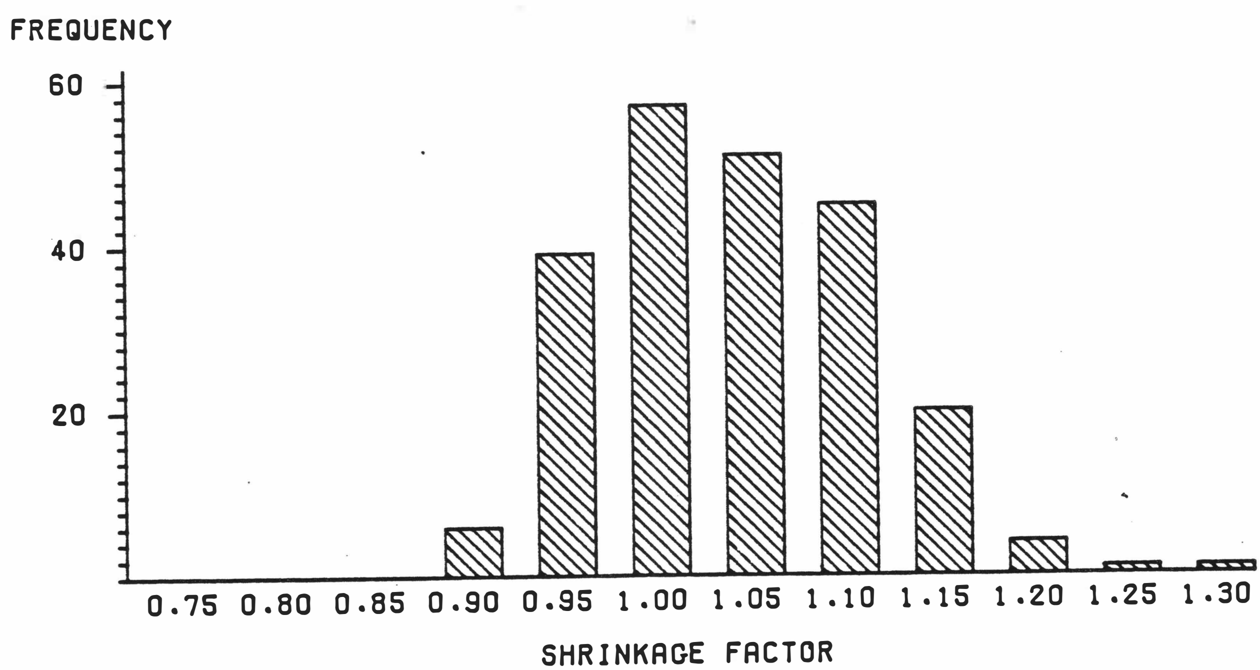


Unified Classification

CLASS=CH

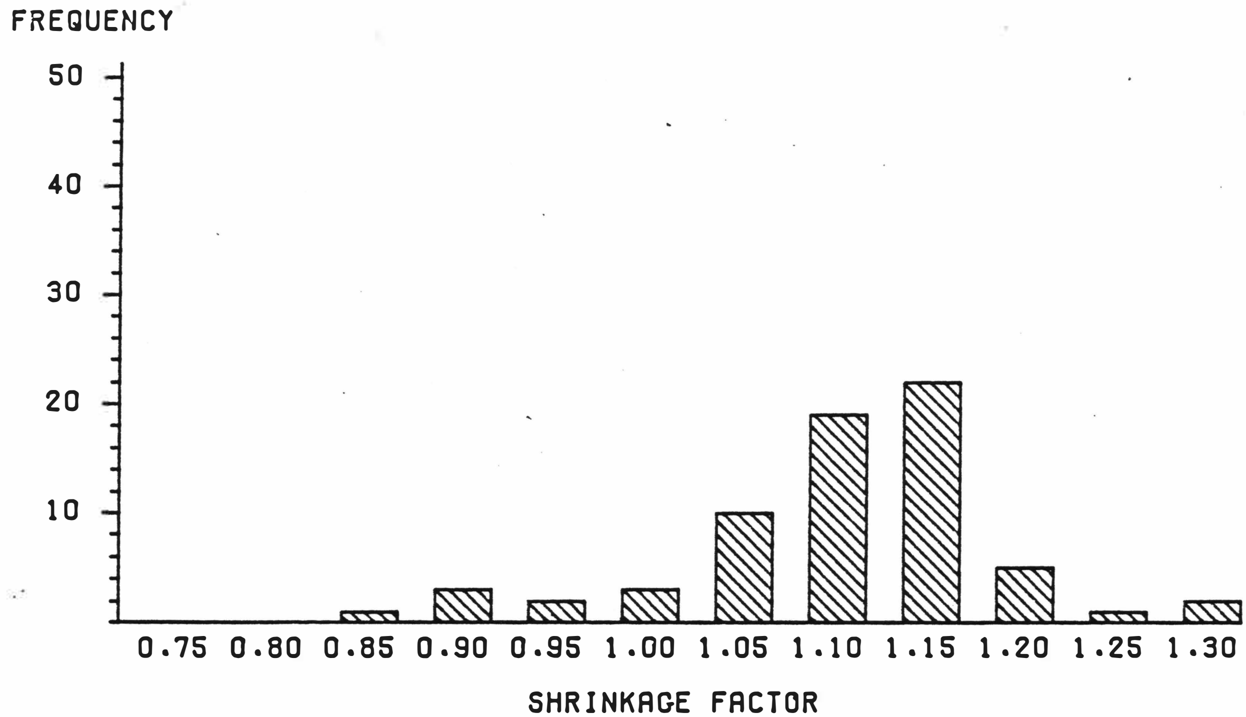


CLASS=CL

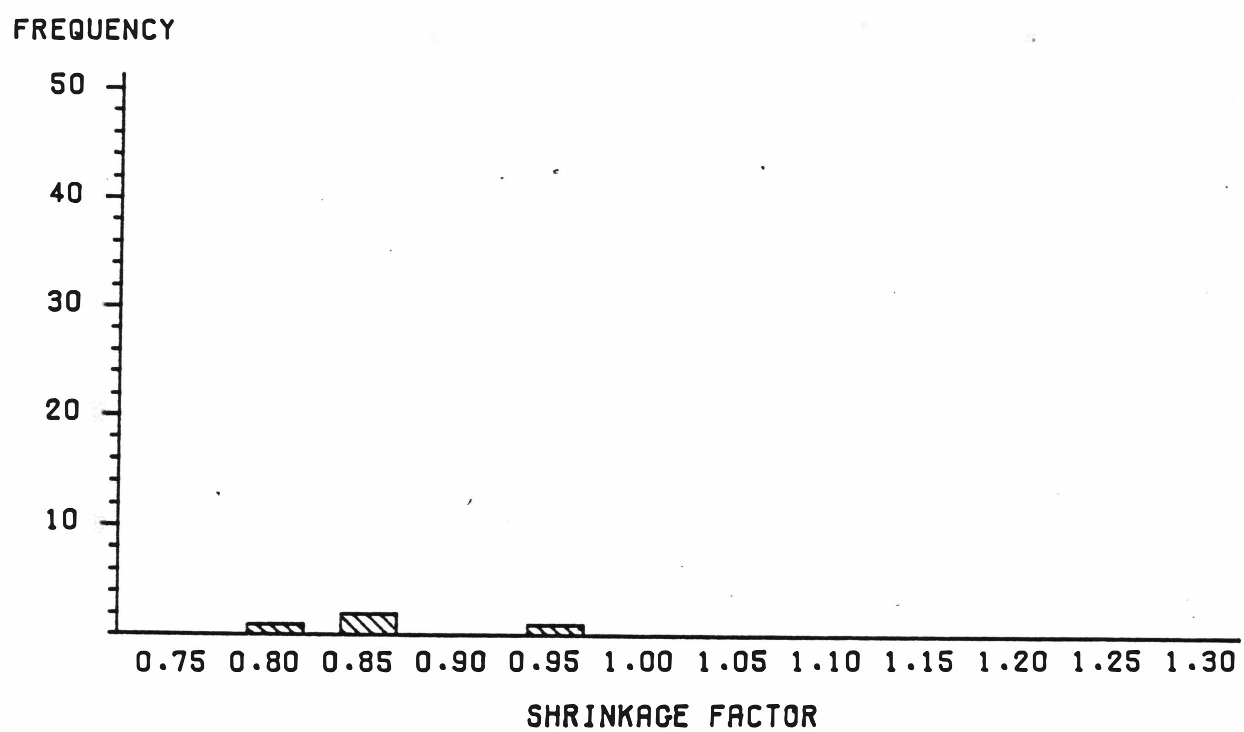


Unified Classification (Continued)

CLASS=ML

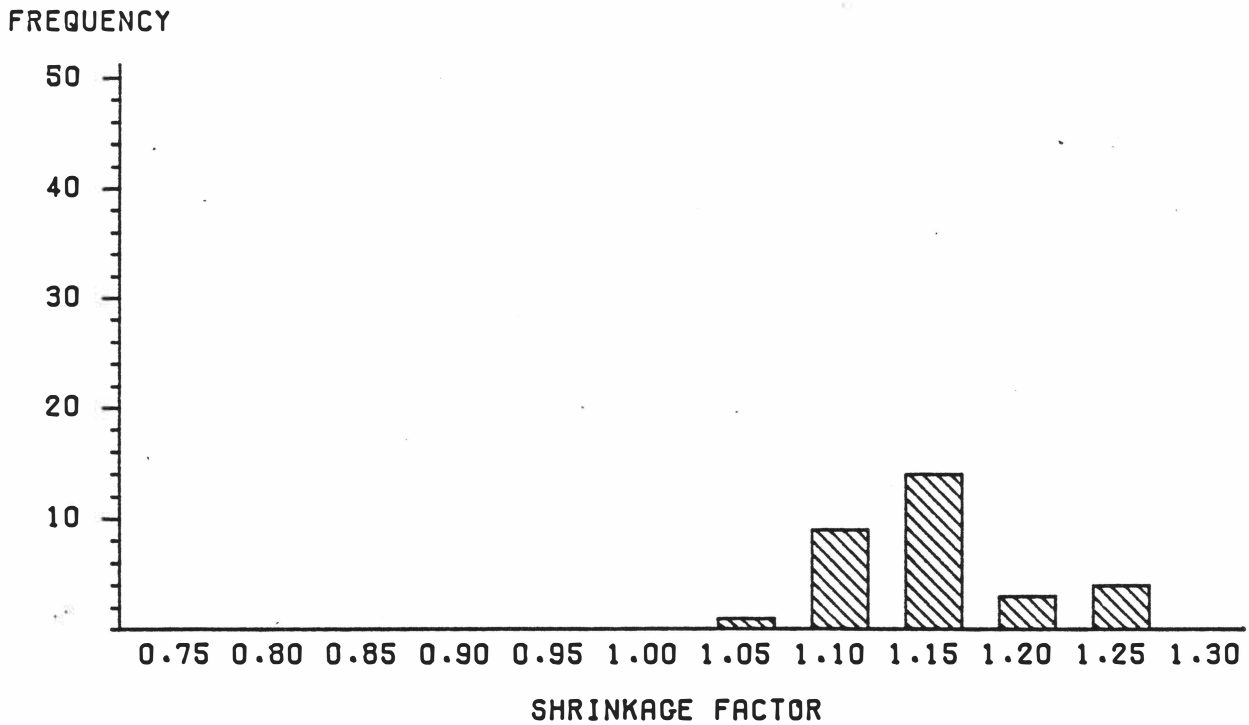


CLASS=MH

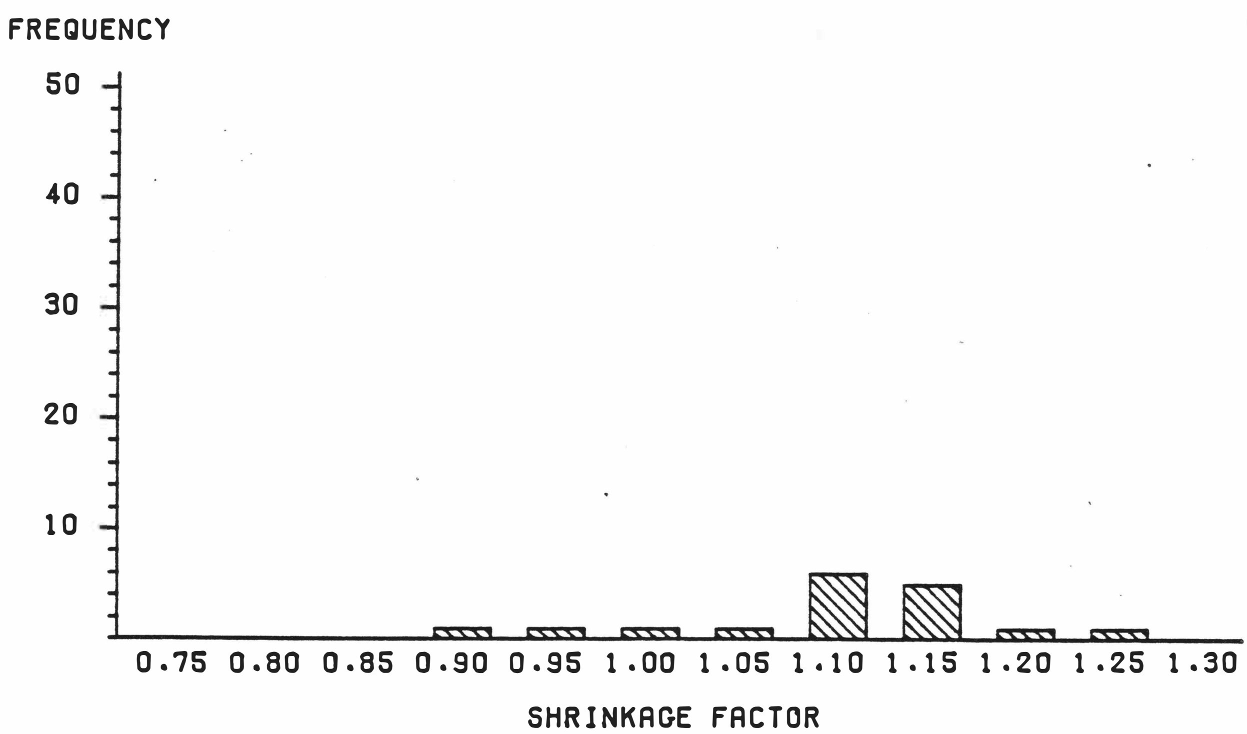


Unified Classification (Continued)

CLASS=ML-CL

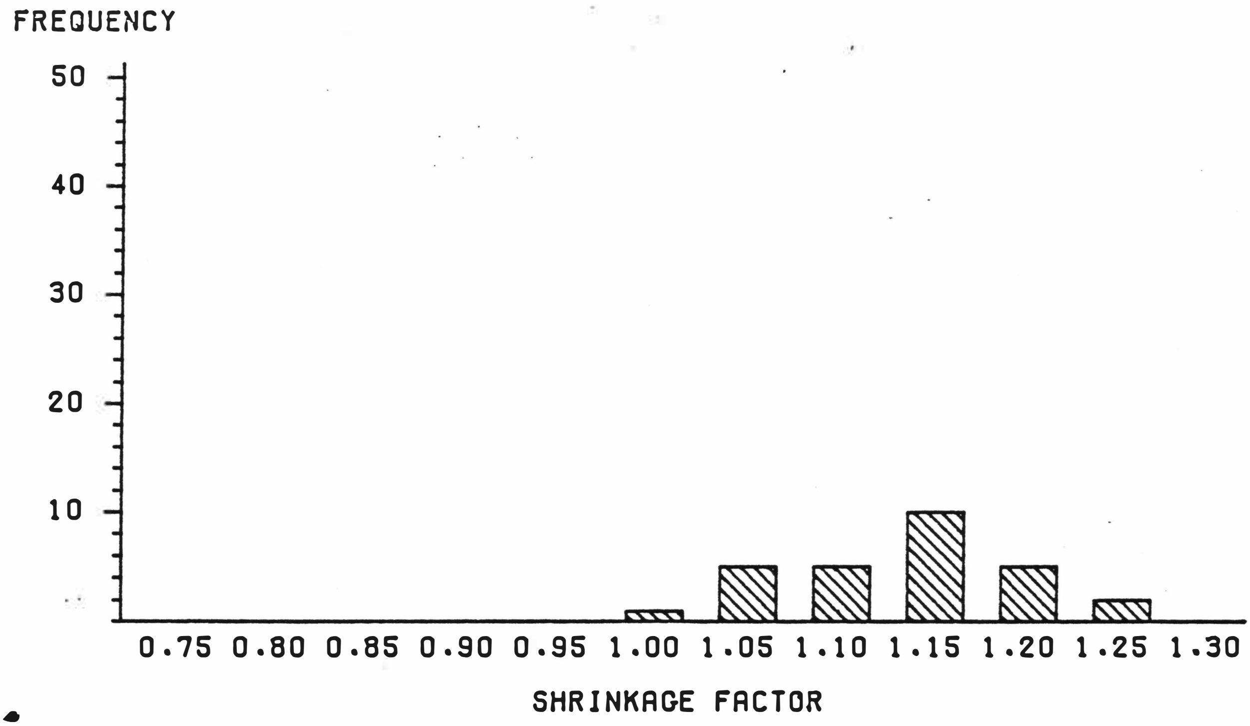


CLASS=SC

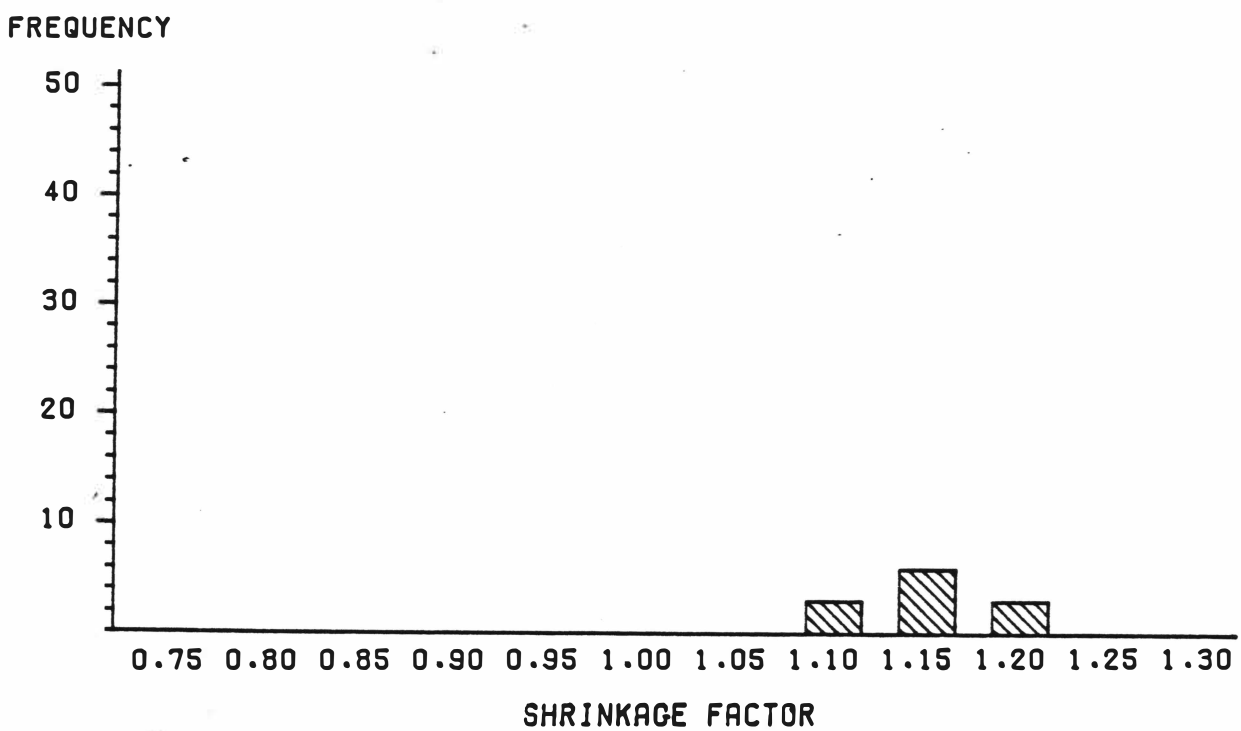


Unified Classification (Continued)

CLASS=SM

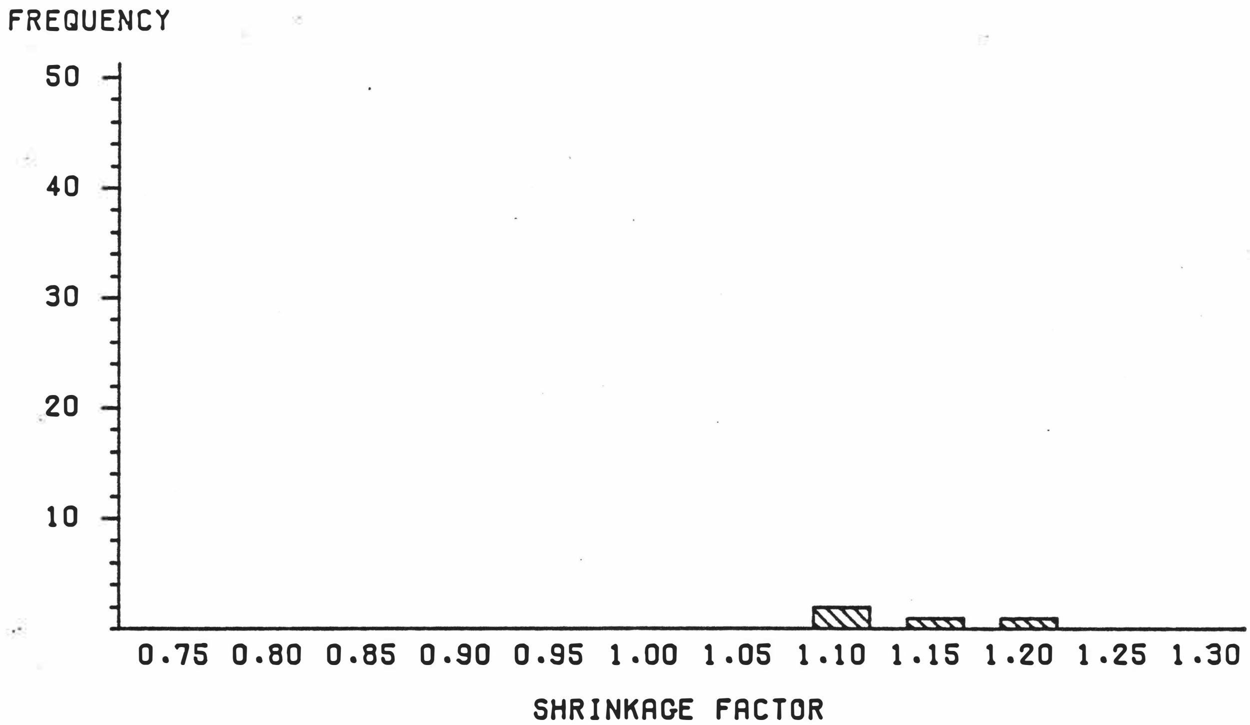


CLASS=SM-SC



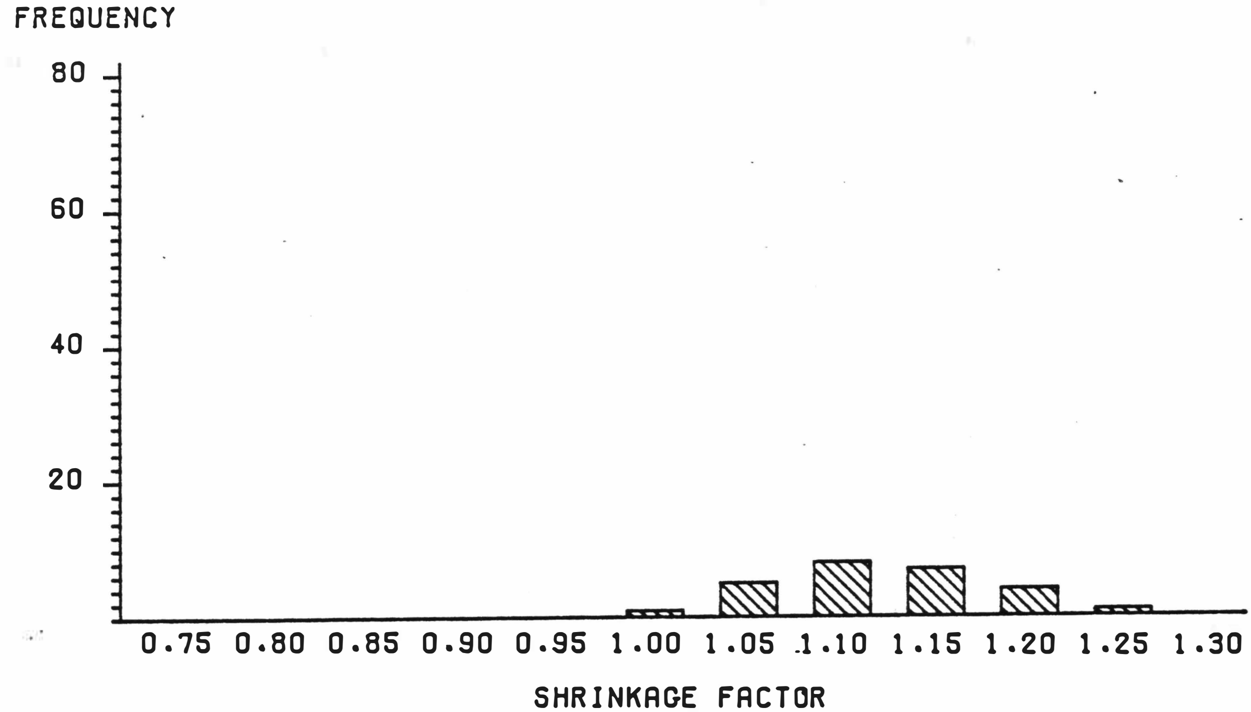
Unified Classification (Continued)

CLASS=SP

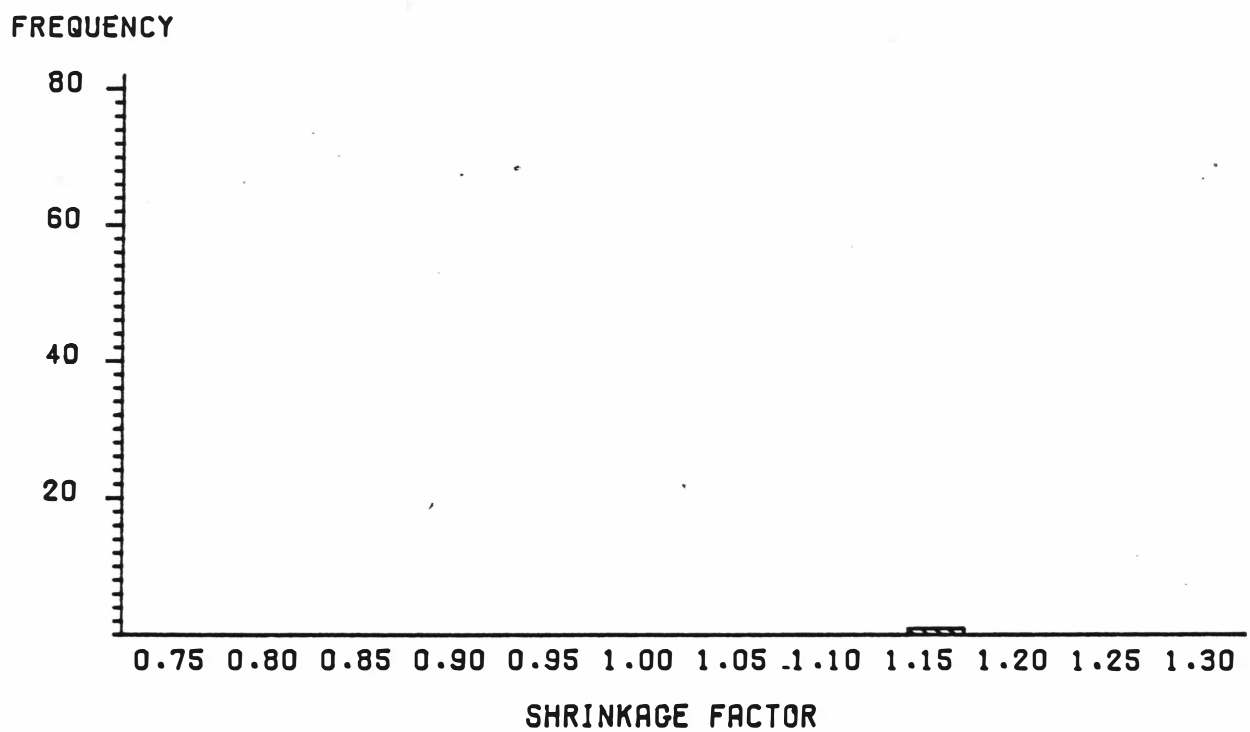


AASHTO Classification

CLASS=A-2-4

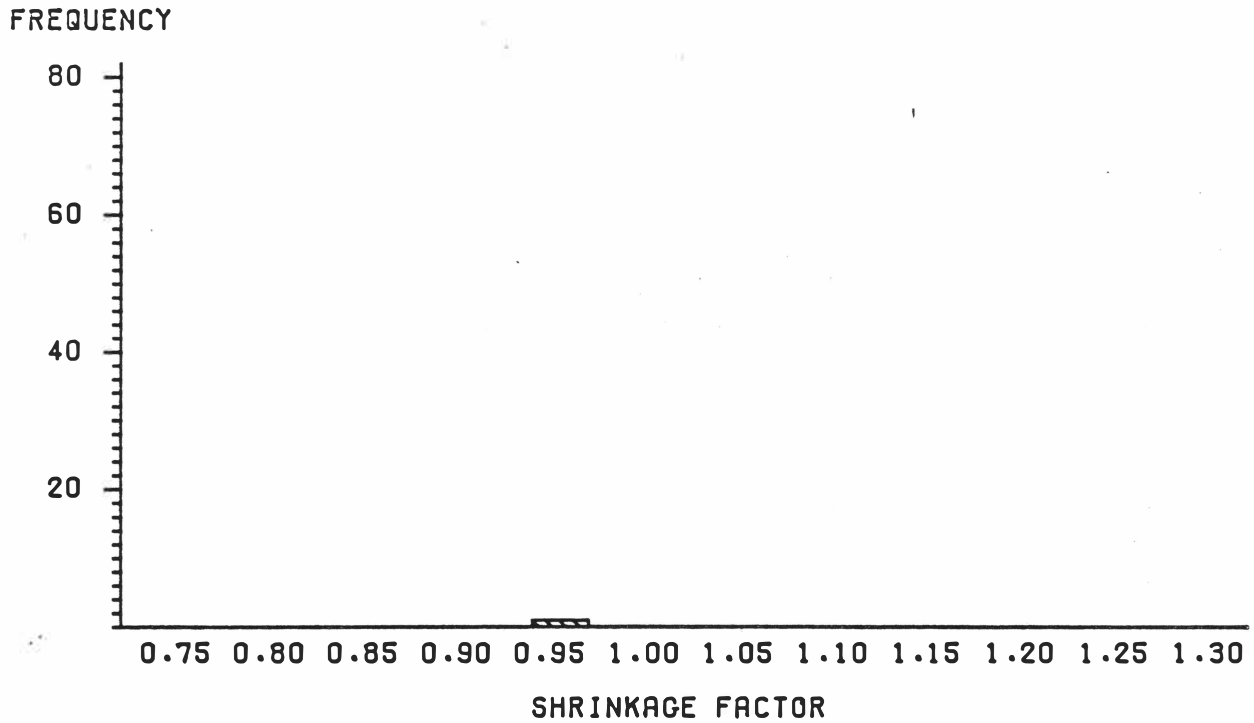


CLASS=A-2-6

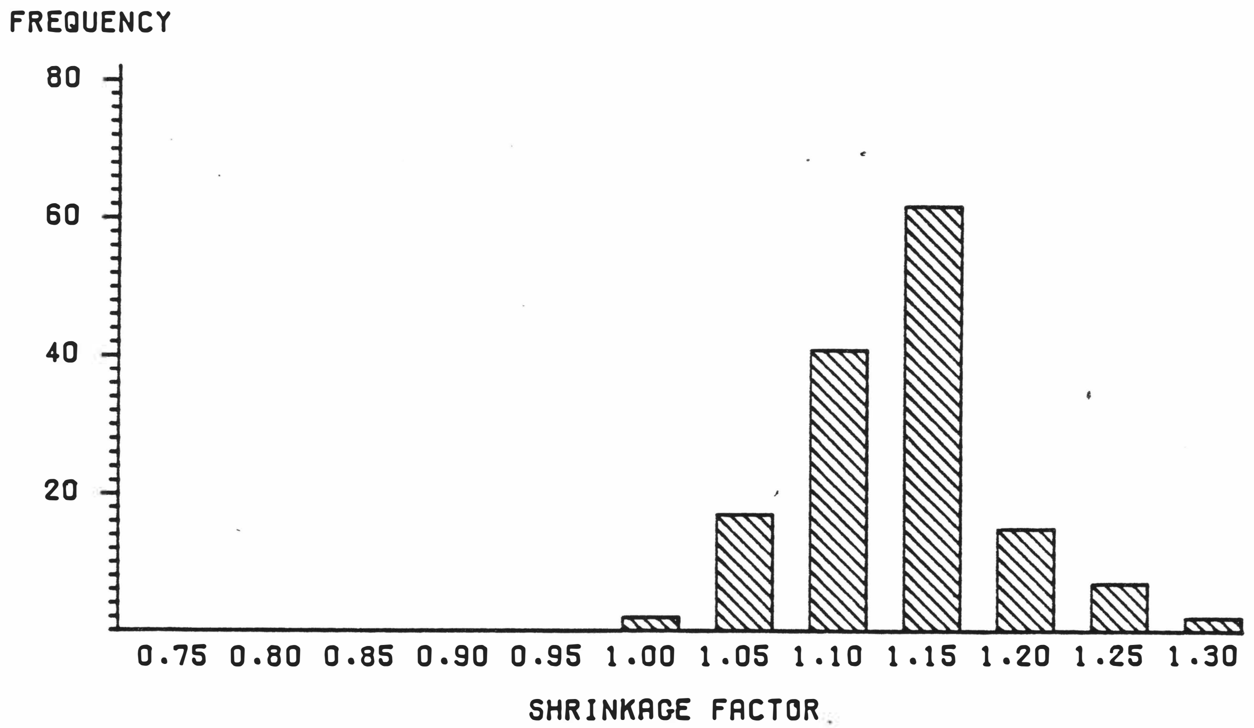


AASHTO Classification (Continued)

CLASS=A-2-7

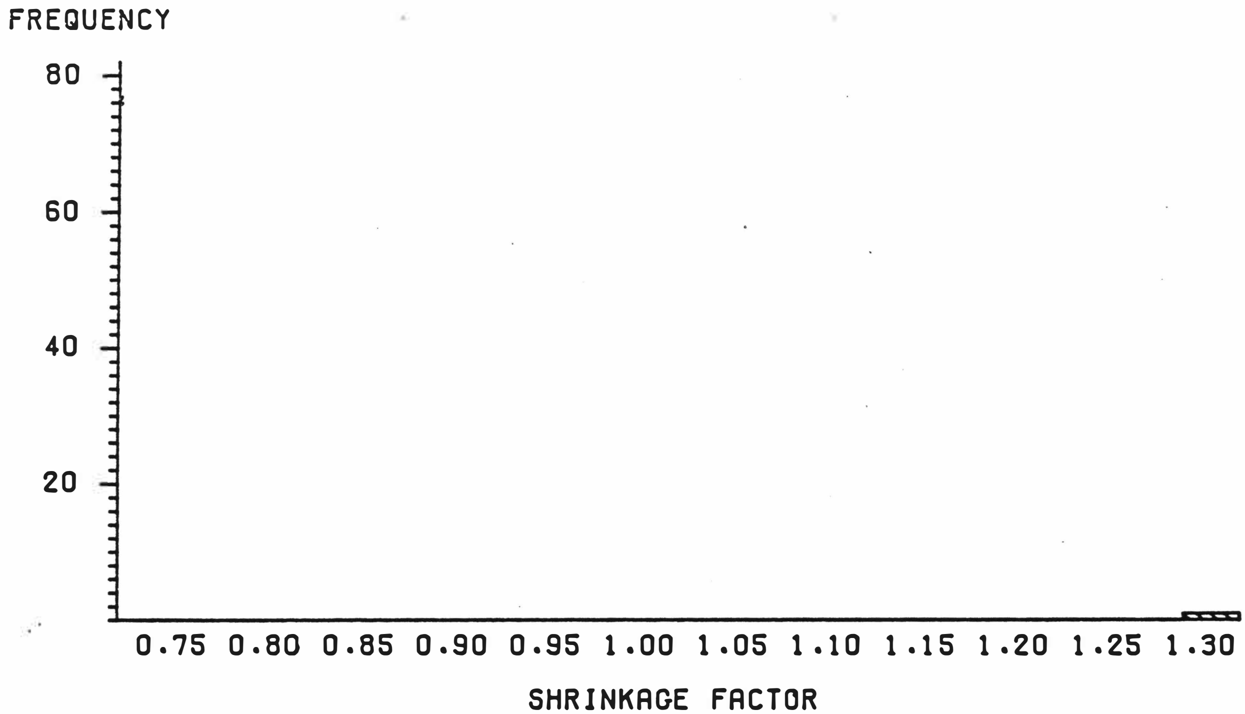


CLASS=A-4



AASHTO Classification (Continued)

CLASS=A-5



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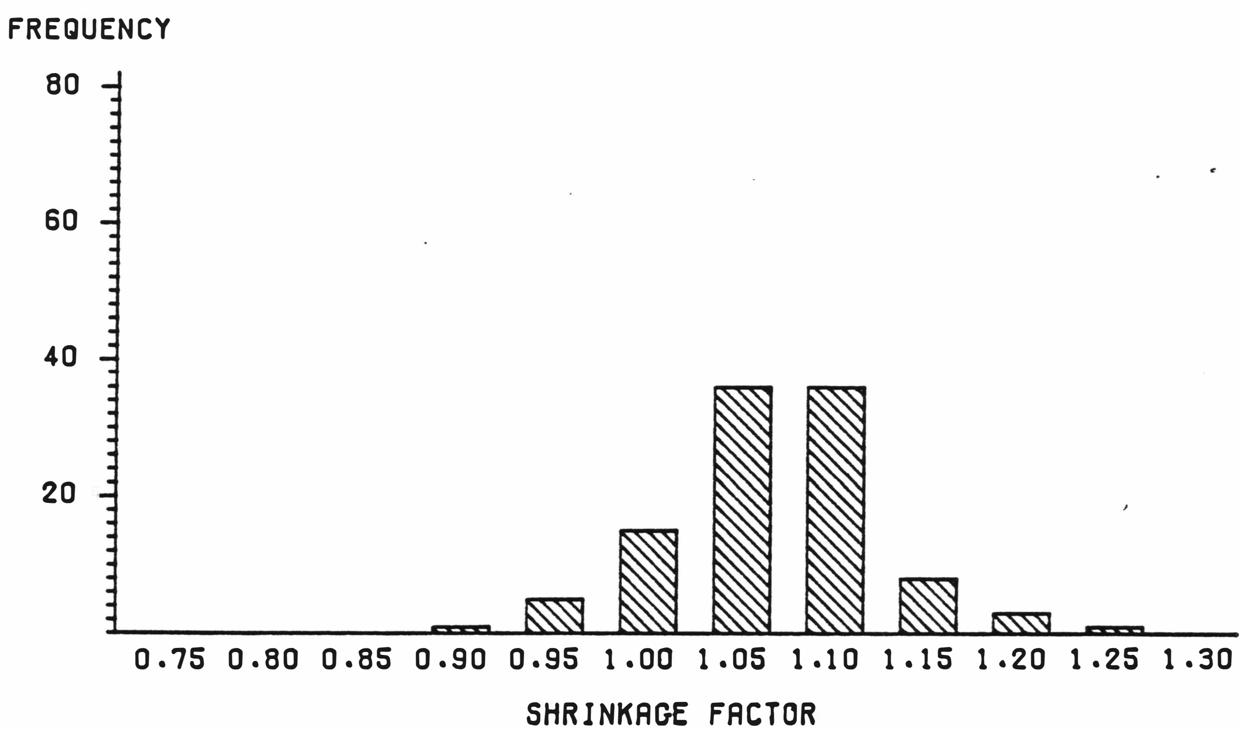
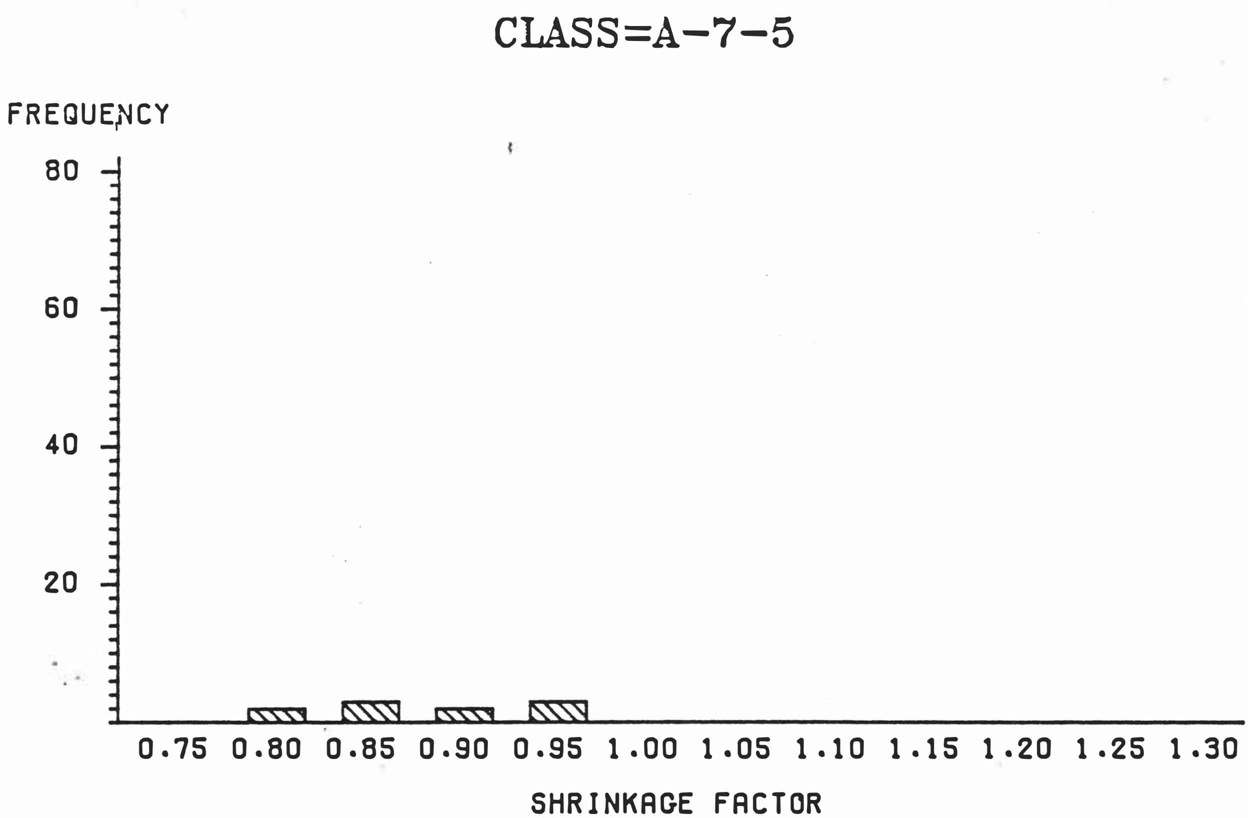
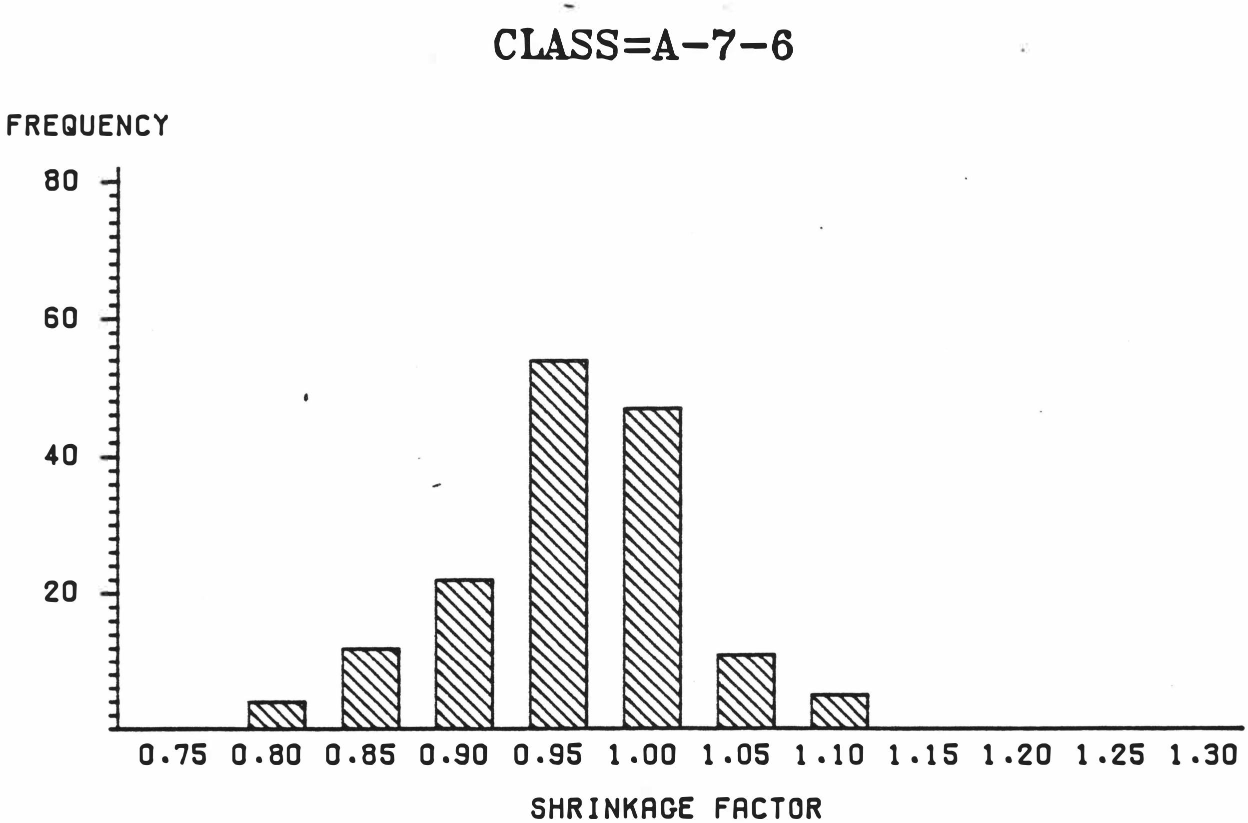


AASHTO Classification (Continued)





SHRINKAGE FACTORS

Summary Statistics for USDA Soil Classification

USDA Class	Horizon	Number of Observations	Mean	Standard Deviation	Minimum Value	Maximum Value
C		59	0.96	0.09	0.79	1.17
C	A	8	1.03	0.08	0.90	1.15
C	B	44	0.94	0.09	0.79	1.17
C	C	7	1.01	0.05	0.95	1.09
CL		51	1.01	0.09	0.80	1.24
CL	A	7	1.04	0.11	0.93	1.24
CL	B	34	1.01	0.08	0.80	1.17
CL	C	9	0.99	0.09	0.85	1.12
CL	C/R	1	0.94	.	0.94	0.94
L		28	1.11	0.07	0.96	1.28
L	A	17	1.10	0.06	0.96	1.17
L	B	7	1.12	0.09	1.03	1.25
L	C	3	1.19	0.09	1.12	1.28
L	C/R	1	1.14	.	1.14	1.14
LS		11	1.14	0.07	0.98	1.22
LS	A	5	1.17	0.05	1.10	1.22
LS	B	4	1.09	0.08	0.98	1.15
LS	C	2	1.15	0.01	1.15	1.15
S		6	1.11	0.04	1.05	1.18
S	A	1	1.11	.	1.11	1.11
S	B	2	1.13	0.07	1.09	1.18
S	C	3	1.10	0.04	1.05	1.13
SC		1	1.09	.	1.09	1.09
SC	B	1	1.09	.	1.09	1.09
SCL		13	1.11	0.06	1.03	1.20
SCL	B	13	1.11	0.06	1.03	1.20
SIC		39	0.96	0.07	0.83	1.10
SIC	A	4	0.94	0.11	0.86	1.09
SIC	B	33	0.96	0.07	0.83	1.08
SIC	C	2	1.04	0.09	0.98	1.10
SICL		65	1.02	0.08	0.84	1.19
SICL	A	12	1.01	0.07	0.91	1.14
SICL	B	42	1.01	0.09	0.84	1.19
SICL	C	11	1.04	0.08	0.91	1.15
SIL		122	1.09	0.07	0.90	1.29
SIL	A	97	1.10	0.07	0.90	1.26
SIL	B	20	1.09	0.09	0.90	1.29
SIL	C	5	1.07	0.06	1.01	1.16
SL		43	1.14	0.07	0.92	1.29
SL	A	18	1.11	0.07	0.92	1.20
SL	A/C	1	1.18	.	1.18	1.18
SL	B	12	1.16	0.07	1.05	1.29
SL	C	12	1.15	0.08	1.03	1.27

SHRINKAGE FACTORS

Summary Statistics for Unified Soil Classification

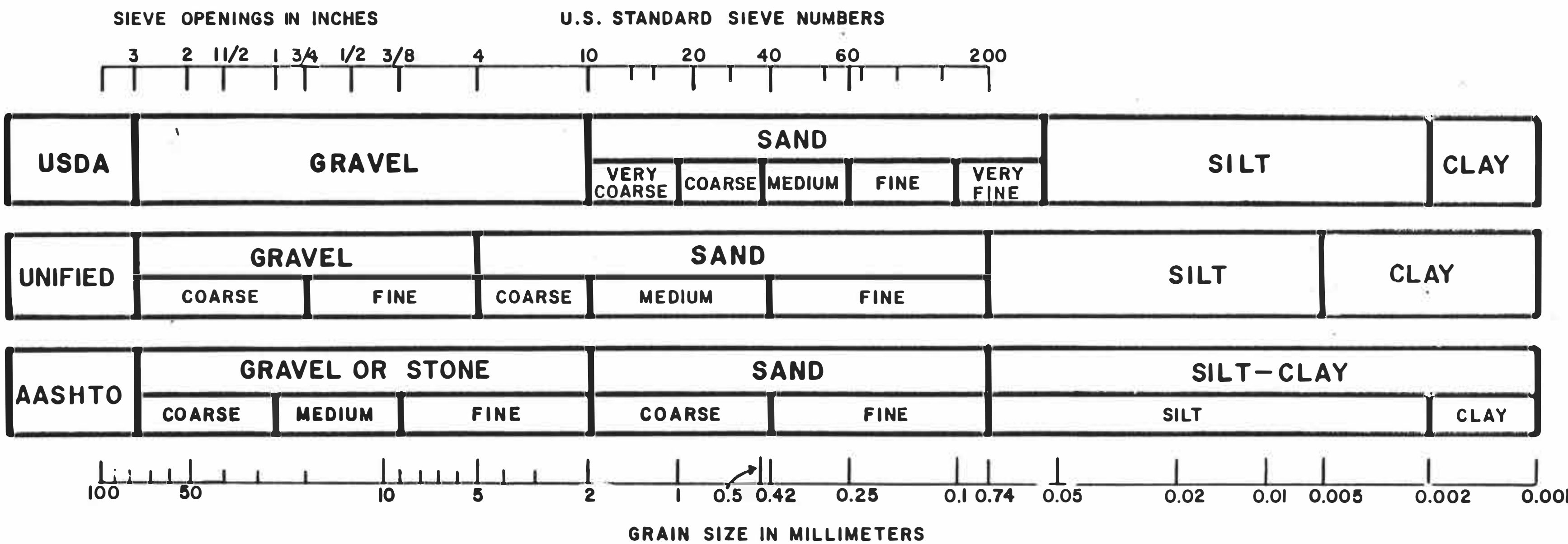
Unified Class	Horizon	Number of Observations	Mean	Standard Deviation	Minimum Value	Maximum Value
CH		56	0.90	0.06	0.79	1.05
CH	A	3	0.89	0.04	0.86	0.93
CH	B	49	0.90	0.05	0.79	0.99
CH	C	4	0.97	0.06	0.91	1.05
CL		224	1.04	0.07	0.88	1.29
CL	A	72	1.05	0.07	0.91	1.18
CL	B	121	1.03	0.07	0.88	1.29
CL	C	30	1.05	0.07	0.95	1.19
CL	C/R	1	0.94	.	0.94	0.94
MH		4	0.87	0.06	0.80	0.96
MH	B	4	0.87	0.06	0.80	0.96
ML		68	1.10	0.09	0.85	1.29
ML	A	52	1.11	0.07	0.90	1.22
ML	B	7	1.11	0.09	1.03	1.29
ML	C	9	1.09	0.15	0.85	1.28
ML-CL		31	1.15	0.05	1.06	1.26
ML-CL	A	23	1.14	0.05	1.06	1.26
ML-CL	B	6	1.16	0.05	1.10	1.23
ML-CL	C	1	1.13	.	1.13	1.13
ML-CL	C/R	1	1.14	.	1.14	1.14
SC		17	1.10	0.09	0.90	1.27
SC	A	5	1.04	0.10	0.90	1.13
SC	B	11	1.11	0.07	0.95	1.20
SC	C	1	1.27	.	1.27	1.27
SM		28	1.14	0.06	0.98	1.23
SM	A	14	1.15	0.05	1.06	1.22
SM	A/C	1	1.18	.	1.18	1.18
SM	B	7	1.12	0.08	0.98	1.23
SM	C	6	1.13	0.07	1.05	1.23
SM-SC		12	1.15	0.03	1.11	1.20
SM-SC	A	2	1.14	0.04	1.11	1.17
SM-SC	B	7	1.16	0.03	1.12	1.20
SM-SC	C	3	1.14	0.02	1.12	1.16
SP		4	1.12	0.05	1.08	1.18
SP	B	3	1.11	0.05	1.08	1.18
SP	C	1	1.13	.	1.13	1.13

SHRINKAGE FACTORS

Summary Statistics for AASHTO Soil Classification

AASHTO Class	Horizon	Number of Observations	Mean	Standard Deviation	Minimum Value	Maximum Value
A-2-4		26	1.12	0.06	0.98	1.23
A-2-4	A	10	1.13	0.05	1.06	1.22
A-2-4	B	9	1.12	0.08	0.98	1.23
A-2-4	C	7	1.11	0.05	1.05	1.18
A-2-6		1	1.15	.	1.15	1.15
A-2-6	B	1	1.15	.	1.15	1.15
A-2-7		1	0.95	.	0.95	0.95
A-2-7	B	1	0.95	.	0.95	0.95
A-4		146	1.13	0.05	1.00	1.29
A-4	A	96	1.13	0.05	1.00	1.26
A-4	A/C	1	1.18	.	1.18	1.18
A-4	B	35	1.15	0.06	1.03	1.29
A-4	C	13	1.15	0.07	1.03	1.27
A-4	C/R	1	1.14	.	1.14	1.14
A-5		1	1.28	.	1.28	1.28
A-5	C	1	1.28	.	1.28	1.28
A-6		105	1.07	0.06	0.90	1.25
A-6	A	43	1.05	0.06	0.90	1.18
A-6	B	47	1.08	0.05	0.99	1.25
A-6	C	14	1.08	0.05	0.98	1.19
A-6	C/R	1	0.94	.	0.94	0.94
A-7-5		10	0.88	0.06	0.79	0.96
A-7-5	A	3	0.94	0.02	0.92	0.96
A-7-5	B	6	0.86	0.06	0.79	0.96
A-7-5	C	1	0.85	.	0.85	0.85
A-7-6		155	0.96	0.06	0.81	1.12
A-7-6	A	20	0.96	0.06	0.86	1.10
A-7-6	B	116	0.95	0.06	0.81	1.12
A-7-6	C	19	0.99	0.05	0.89	1.09

COMPARISON OF PARTICLE SIZE SCALES



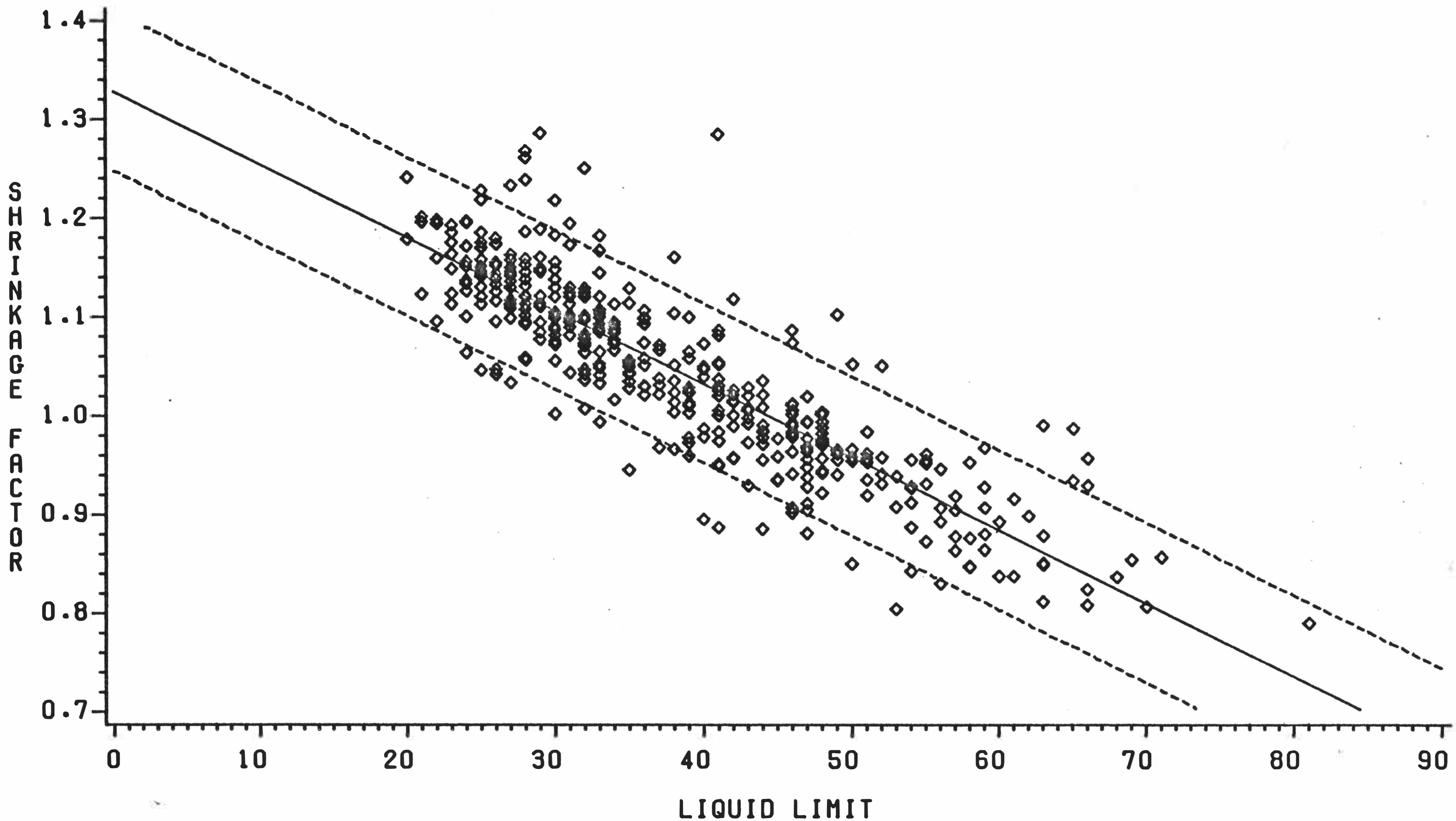
APPENDIX B

SHRINKAGE AND COMMON LABORATORY TESTS

This appendix demonstrates the reliability of liquid limit, plasticity index, and clay content tests AASHTO T89, T90, and T88 respectively, to predict shrinkage factors.

Figure B-1.

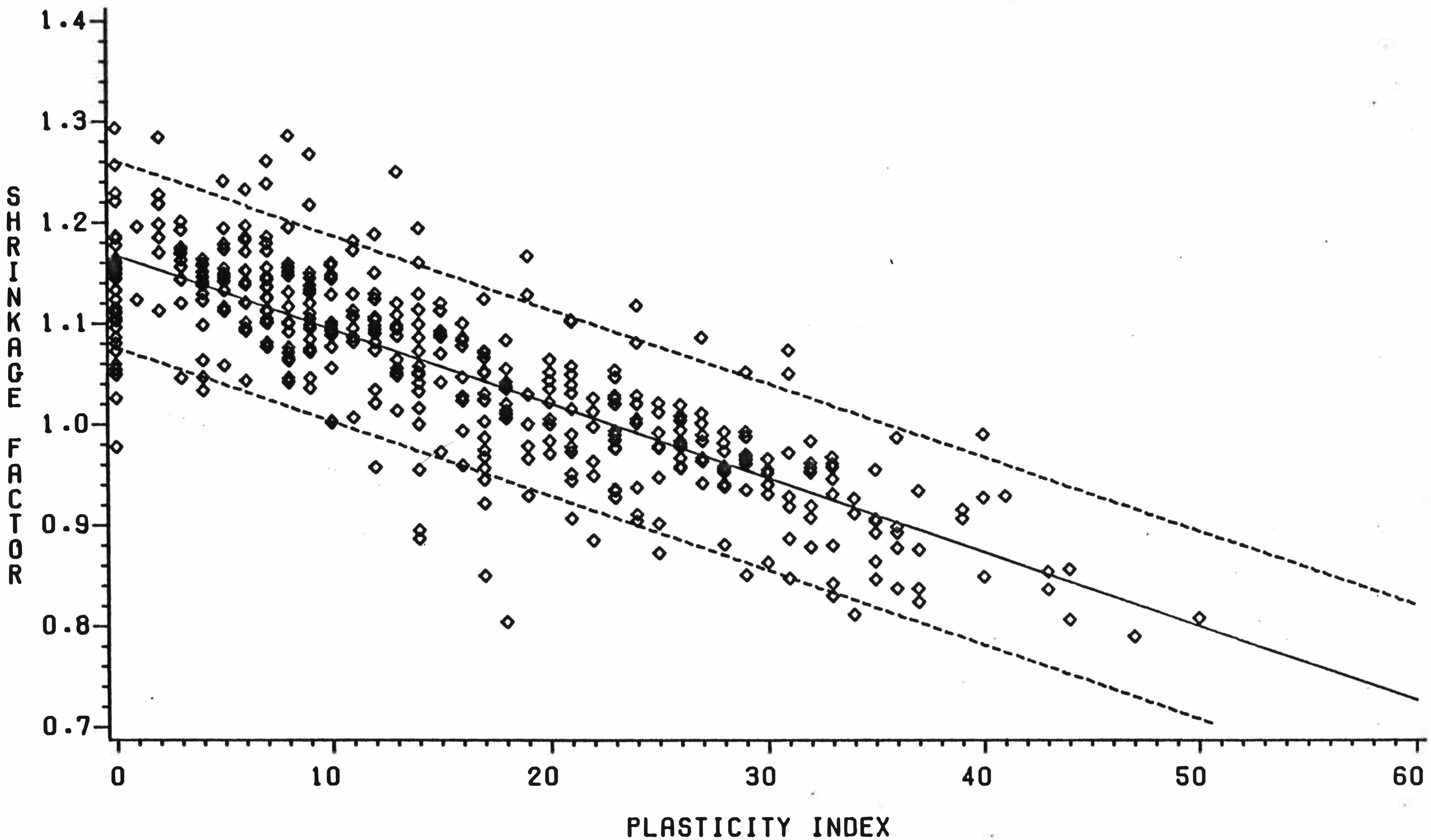
Relationship of Shrinkage Factor and Liquid Limit



SF = 1.328 − 0.007 LL

Figure B–2.

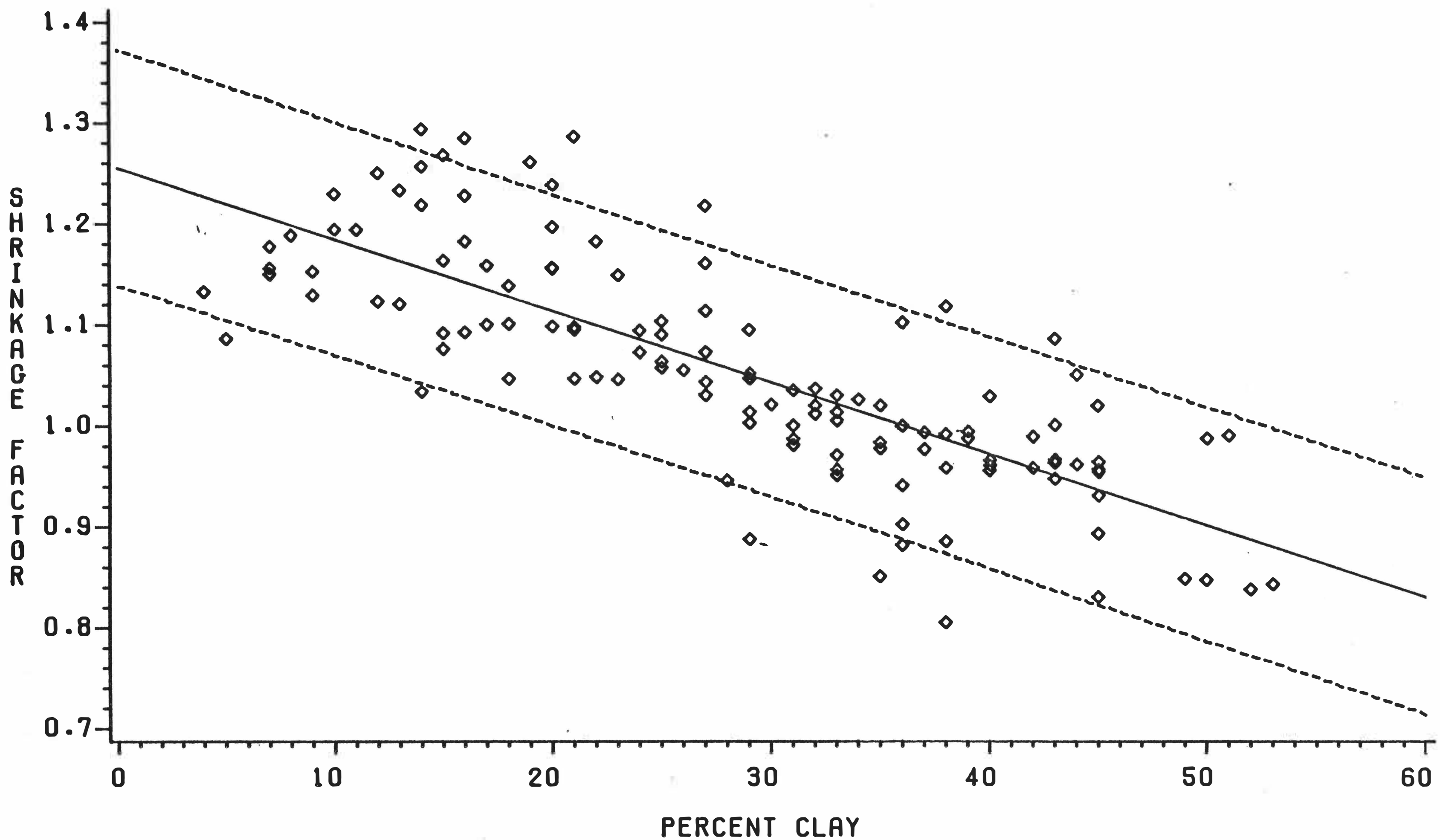
Relationship of Shrinkage Factor and Plasticity Index



SF = 1.167 – 0.007 PI

Figure B-3

Relationship of Shrinkage Factor and Clay Content



SF = 1.255 − 0.007 CLAY