

DESIGN OF SHALLOW FOUNDATIONS ON LOESS

BY

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DESIGN OF SHALLOW FOUNDATIONS ON LOESS

INTRODUCTION TO LOESS

Definition

"Loess is a wind-deposited sediment that is commonly unsatrified and unconsolidated and is composed dominantly of silt-size particles." (Ruhe, 1969)

Special characteristics commonly associated with loess

Open structure of loosely packed silt grains lightly cemented by clay

Collapsibility (dramatic compression at constant load when saturated)

Low density

Low moisture content

Low plasticity

Great thicknesses of unsaturated material

Ability to stand in high, steep cuts

Highly erodible

The above characteristics are associated with "classic" loess. Classic loess is best known because of its unusual properties. We will focus on classic loess because it has unique hazards and requires special treatment.

The classic properties are related to the open structure. (Figures A and B)

Variations

There are extensive deposits of loess that lack any or all of the above characteristics.

ORIGIN AND DISTRIBUTION OF LOESS

Origin

From Pleistocene glacial alluvium

"...the finely divided rock-powder silt of which loess is primarily composed was produced by interaction of several geological process, but mainly by abrasion resulting from movements of continental glaciers. With retreat of the continental glaciers, the silt was deposited along flood plains of rivers. This silt was then transported, sorted, and redeposited by wind action." (Gibbs and Holland, 1960)

Rivers that served as major sources included the Mississippi, Missouri, Illinois, Green, Platte, and Republican in the central United States. The sand hills of western Nebraska and eastern Colorado were also important sources.

Distribution

North America (Figure 1)

Nebraska (Figure 2)

Iowa (Figure 3)

China (Figure 3A)

Loess deposits cover about 11% of the land area of the world. In the United States, the figure is 17%, and in Iowa, 38%. (Turnbull, 1968, and Lutenegger, 1979). Loess deposits cover 6% of China. (Kie, 1988) There are important deposits in eastern Europe and Russia.

GEOLOGIC AGE AND ASSOCIATION

All loess I have heard about is of Pleistocene age. Principal North American deposits are associated with the Wisconsinan and Illinoian glaciations.

Wisconsin loess

Age

Ruhe (1969) dates Wisconsin loess in Iowa as pre-Cary, with the base ranging from 16,500 to 29,000 years and the top at 14,000 years.

Subgroups

Bignell

Peorian

Roxanna

The entire Wisconsinan deposit is commonly called Peorian. It is found at the ground surface throughout most of its area of occurrence, overlain only by glacial deposits of the Cary lobe and locally by alluvium.

Distribution

Figure 3 shows the distribution in Iowa.

Illinoian Loess

Age (Post-Yarmouth, pre-Sangamon)

Subgroups

The Loveland is stratified, but the subgroups are not commonly differentiated.

Paleosol

The Sangamon paleosol at the surface of the Loveland loess is strongly developed and a distinctive marker bed. It is often absent due to erosion. Where present, it can be a convenient bearing formation for belled piers.

Distribution

In Iowa, the Loveland is less extensive than the Wisconsin, extending only about 30 to 60 miles eastward of the Missouri River (Ruhe, 1969).

Most of the Loveland loess I have encountered is too dense to be collapse-susceptible. It can be normally consolidated if nearly saturated. Some deep older loesses in China have been shown to be collapse-susceptible, probably due to drier conditions.

Underlying deposits

When underlain by relatively impermeable clay till, the loess often includes a water table. Where underlain by aeolian sand, as in western Nebraska, it may be dry. Alluvium, residual soils, terraces, and bedrocks are also commonly found below loess in the midwest.

TYPICAL PROPERTIES OF LOESS

Variation of properties with distance from source

Thickness	(Figures 4 and 5)
Grain Size	(Figures 4 and 5)
Weathering Profiles	(Figure 6)

Range of properties of North American loess

Grain Size	(Figure 7)
Specific Gravity	2.57 to 2.79

Plasticity (Figures 8 and 9)

Permeability (Figure 10)

Vertical root holes often result in a higher vertical than horizontal permeability. Kie (1988) presents evidence that swelling of the clay particles may lead to a reduction in permeability with time.

Dry Density - 66 to 104pcf (Sheeler, 1968)

Other variables

Erodibility

Carbonate content and state of oxidation

Compressibility

Compressibility is the most important property for foundation design on loess.

Compression at natural water content (Figures 12B-12D)

Compression Index (C_c), commonly 0.15 to 0.5

Recompression Index (C_r), commonly 0.01 to 0.05

Apparent preconsolidation pressure (P_c)

Description: Although the loess may never have supported more overburden than presently exists, it often displays an apparent overconsolidation. This behavior can be observed both in laboratory consolidation tests and in the field.

Example (Figures 13 and 13A)

Range: a few hundred psf to 20,000 psf or more (Figure 15)

Kane of Iowa, Bally of Romania, and Milovic of Yugoslavia have separately studied the effect of water content on compressibility. (Figures 13B-14B)

For unsaturated loess, P_c appears to be related to moisture content, density, and clay content.

Lin and Wang (1988) have proposed a simple relationship between P_c and unconfined compressive strength. (Figure 14C)

Saturated loess is often normally consolidated, but not always. (Figure 14D)

For saturated loess, P_c is probably most strongly related to overburden, water table fluctuations and desiccation.

Consolidation after saturation (Figure 15)

After saturation, a collapse-susceptible loess exhibits a reduced apparent preconsolidation pressure, above which much greater compressions occur in the saturated state. (Figure 15)

Collapse on saturation

Description: An unsaturated soil supporting load at natural water content may become under-consolidated and undergo large compression at unchanged load when the moisture content is raised to near saturation. (Figure 16)

Some loess will collapse under its own weight when saturated. Ponding, canal construction, and irrigation have resulted in large ground settlements. (Figure 16A)

Some loess will collapse under a higher pressure, but not under overburden stress. (Figure 16B)

If the density of the soil is low enough that theoretical water content at saturation is greater than the liquid limit, collapse can be expected. (Figure 16C)

The minimum pressure at which collapse will occur is about the same as the "preconsolidation pressure" determined from a consolidation test on a saturated sample. (Figure 16D)

In general, loess with a low density and low water content can be expected to have a high collapse potential. (Figure 16E)

Consolidation upon gradual increase in water content

Evidence: Settlement of light buildings beginning several years after construction has been observed, usually associated with permanent fill loads. (Figures 17 and 17A) Example (Figures 17AA-17AE)

Rules of thumb

Avoid net fills of more than 3-4 feet.

If loess is moist, preloading with a surcharge may prevent delayed settlement. Example (Figure 17B and C)

Various factors can cause the moisture content to increase; not all such factors can be foreseen.

Conceptual model (Figure 17D)

The water content of a loess deposit has probably varied during its history. When the water content was at its highest, the loess became normally consolidated. A linear increase in density with depth may indicate a profile that has been normally consolidated. (Figure 17E)

At the present water content, the loess may be overconsolidated. Large compressions may occur if the loess is loaded to a higher pressure and the water content subsequently rises to its highest previous value.

The concept of a critical water content as proposed by Kane (Figure 13C) suggests that if the maximum past water content exceeded the critical water content, the soil will be stable even if the new water content exceeds the previous maximum, so long as the past overburden pressure is not exceeded.

Importance to Design

Fill-induced settlements that occur after building construction can be large, highly differential, and damaging. Correction can be very difficult. Avoiding such settlements is crucial to shallow foundation design.

Causes of Moisture Increases

Poor drainage, leaky pipes, and irrigation
(Figure 17F)

Grading (Figure 17G)

Example (Figures 17H-17K)

Shear Strength

Effective stress parameters (Figures 18, 18A)

According to Gibbs and Holland and Milovic, ϕ ranges from 28 to 38 degrees for silty loess, possibly lower for clayey loess.

C ranges from near zero for saturated silty loess to several ksf for dense, dry, clayey loess.

Consolidated-undrained parameters (Figure 19)

Pore pressures affect the friction angle of saturated loess. (Figure 19)

Kie (1988) indicates that ϕ increases with confining stress for unsaturated loess. (Figure 19A) For wet, low density loess, there may be a critical pressure at which strength decreases.

Undrained strength varies widely depending on water content, density, and clay content. (Figure 19B)

Modulus varies widely with density and water content. (Figure 19C) Milovic proposes the empirical relationship $E=100Qu$ for Yugoslav loess.

INVESTIGATIONS FOR FOUNDATION DESIGN

Geologic studies

Drilling

Flight augers

Hollow stem augers

Air rotary

Sampling

Special sample disturbance problems

Porous structure is subject to densification. Friction on sides of sample develops compressive stresses; when collapse pressure is exceeded, compaction begins.

Large-diameter samplers with substantial clearance ratios are better. (Figures 20 and 21) Block samples are best. (Figure 21)

A suggested order of increasing quality:

Split-spoon

Liner sampler

Thin-walled tubes

Dennison sampler

Hollow stem / continuous sampling system

Block samples

Cleaning the hole and removing the compacted zone before sampling are important.

High-quality samples can be extruded from the tube with little force.

Laboratory testing

Index properties

Water content

Density

Atterberg limits

Clay content

Strength

Unconfined compression (premature brittle failure may be a problem).

Triaxial compression

Penetrometer

Compressibility

Oedometer

Collapse-consolidation test

Penetrometer

"Thumb" consistency

Field Testing

Plate load tests (Figures 22 and 23)

Standard penetration test

Bore-hole shear

Marchetti dilatometer

Others

BEARING CAPACITY ANALYSIS

Drainage conditions

Drained behavior can be expected in unsaturated loess. Because the permeability is high, drainage usually occurs in saturated loess under normal rates of construction. Ultimate bearing capacity can be fairly high due to the high friction angle. (Figure 24)

Bearing capacity formulas

The bearing capacity factors proposed by Terzaghi for "local shear" may be appropriate for low density

loess, because much movement may be needed to mobilize the peak strength. (Figure 24)

Cases where bearing capacity may control

Shallow, narrow footing on wet loess

Heavy, settlement-tolerant structure that can be loaded rapidly

SETTLEMENT ANALYSIS

One-dimensional consolidation analysis

Classical consolidation analysis appears to predict settlement with reasonable accuracy where the soil is stressed well into virgin consolidation. A sufficient number of oedometer tests at natural water content on high quality samples is needed to evaluate stress history and compression index.

Recompression Index

For pressures in the recompression range, one-dimensional consolidation analysis based on recompression index from oedometer tests appears to overestimate settlement.

Elastic Analysis

Elastic analysis may be useful for estimating footing settlements at pressures in the recompression range, if the modulus can be accurately determined. Unconfined and triaxial compression tests appear to underestimate modulus (overestimate settlement). Milovic's results suggest this may be due largely to sample disturbance. Milovic also shows that loess is anisotropic and proposed special influence factors for settlement predictions.

Elastic analysis may form a basis for extending the results of footing settlement measurements or plate load tests to larger foundations.

Moisture Changes

Settlement resulting from saturation of collapse-susceptible loess can be estimated with limited accuracy from collapse-consolidation tests.

There is presently no accepted method for predicting moisture increases short of saturation and the resulting settlement.

PRESUMPTIVE BEARING CAPACITIES

Correlation with SPT per Riggs. (Figure 25) This correlation is for dense, moist, plastic loess.

Correlation with consistency

Resistance to penetration by the fingers has been correlated with unconfined compressive strength for clays. For loess it may be related to the apparent preconsolidation pressure. The unconfined strengths commonly associated with consistency may be reasonable allowable bearing pressures. (Figure 26)

Lin and Wang's correlation (Figure 16C) suggests that settlements will be small for bearing pressures approximately equal to the unconfined strength.

RISK REDUCTION

Reduced Bearing Pressures

Reduce likelihood of exceeding preconsolidation pressure under present or future moisture conditions.

Footings lowered to better soil

Structural fill rafts or blankets (Figure 27)

Provide a layer with high strength and low compressibility in the highly-stressed zone beneath the footing.

Provide a cap with low permeability to reduce the infiltration of water from rain, irrigation, or accidental sources.

Precompression

Accelerate settlement induced by fill loads

Reduce footing settlement by precompressing the soil under pressures higher than will be imposed by the footing.

Precompression is ineffective if soil is so dry that it does not compress significantly under the surcharge.

Structural details

Grade beam reinforcement of foundation wall can help distribute movements. Control joints in walls reduce cracking.

Water control

Site details can greatly reduce infiltration of water than can lead to settlement. Examples:

Conduct roof drains to storm sewers

Shape site for positive drainage

Avoid planters without water-tight bottoms

Test utilities

Soil Improvement

Replacement, compaction, and precompression are widely used in the U.S.A. Many other methods have been tried in eastern Europe, some with considerable success. Evstatiev (1988, Figure 28) gives a summary.

SELECTION OF A FOUNDATION SYSTEM FOR LIGHTLY LOADED STRUCTURES ON LOW DENSITY LOESS

Will there be net fill loads?

Are there normally consolidated layers at depth?

Consider preloading

Are low density soils moist?

Consider preloading

If soils are dry, may they moisten with time?

Consider redesign to eliminate fill

Is risk of collapse-induced settlement excessive? (High collapse index, low moisture, critical structure, poor drainage, water sources)

Consider structural fill layer

Under footings

Under entire structure

Select bearing pressure that is lower than the apparent preconsolidation pressure to limit settlement.

Is structure unusually settlement-sensitive?

Estimate settlements based on elastic or recompression analysis

Reduce bearing pressure or use structural fill if necessary to reduce settlement

In all cases, include proper water control features in the design.

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ENGINEERING GEOLOGY

Scope of the journal

Engineering Geology is an international medium for the publication of original studies and comprehensive reviews in the field of Geotechnical Engineering and Rock Mechanics. The editors will endeavour to maintain a high scientific level and it is hoped that with its international coverage the journal will contribute to the sound development of this field.

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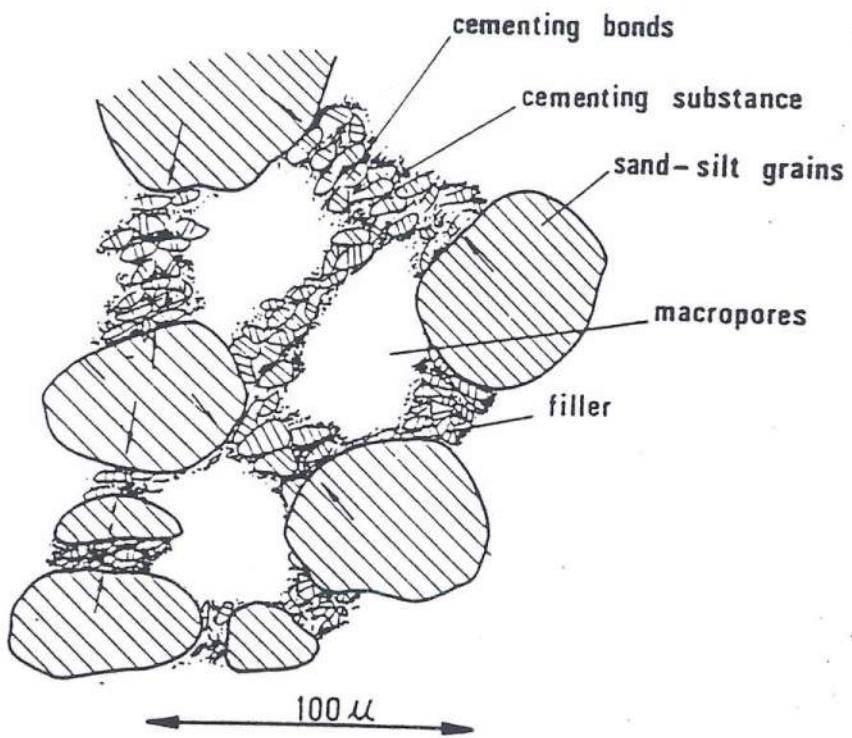
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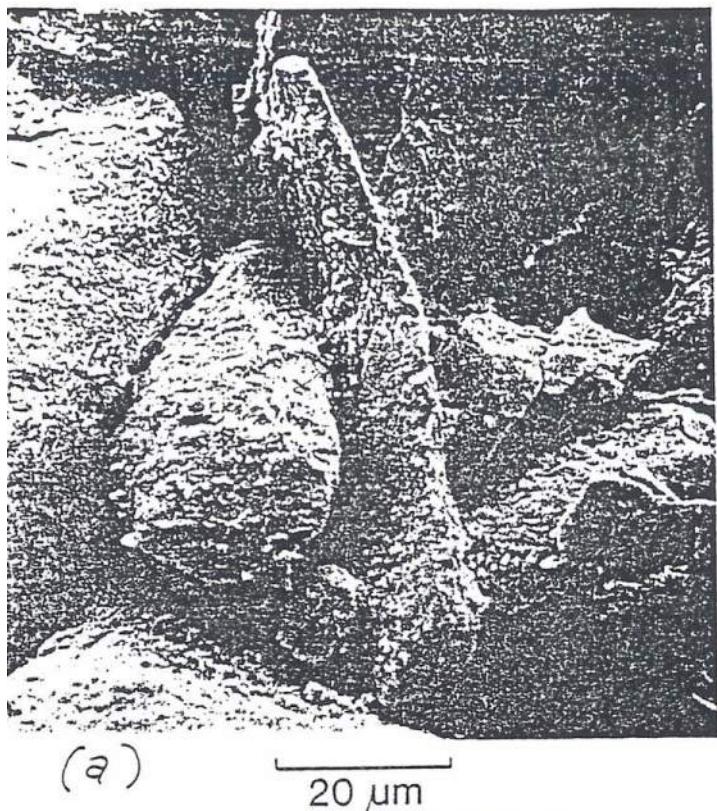
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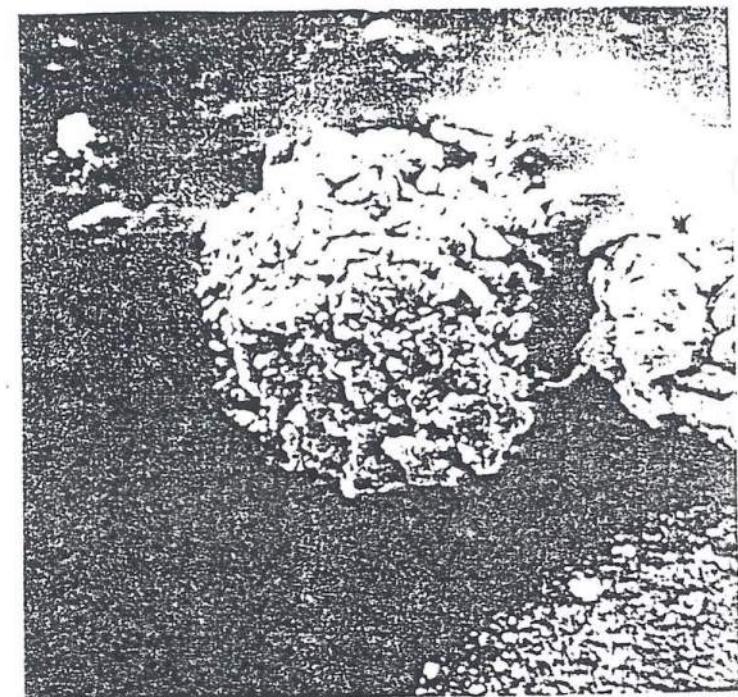
MICRO STRUCTURE OF LOESS

FROM TAN TJONG KIE, 1988



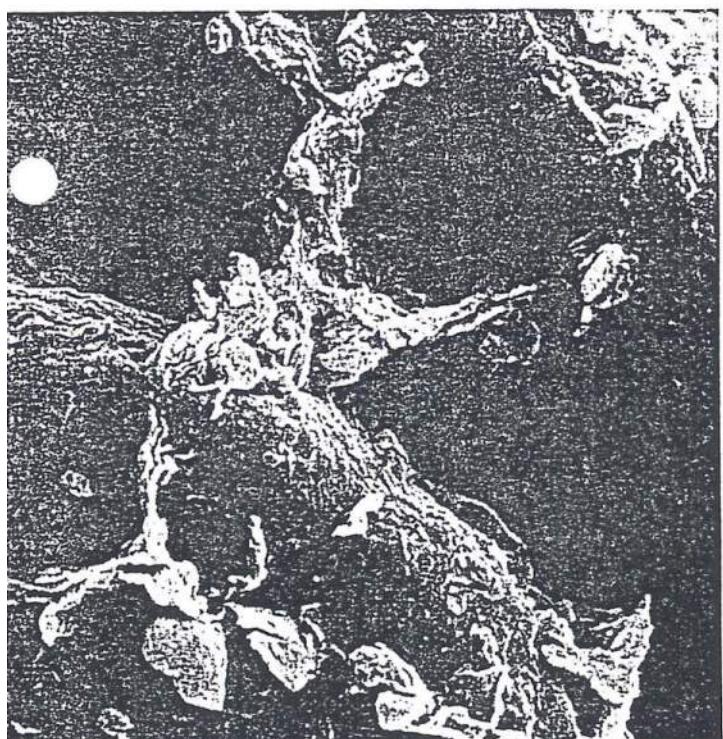
(a)

20 μ m



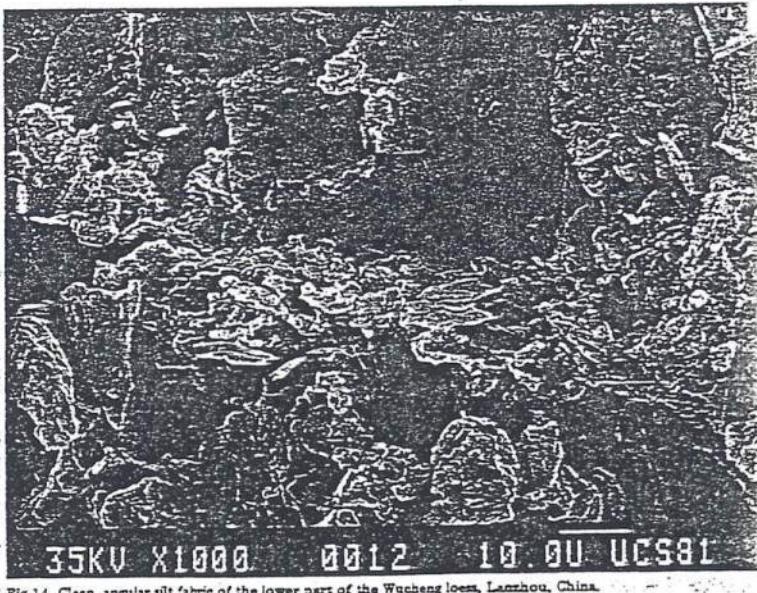
(c)

30 μ m



(b)

10 μ m



(d)

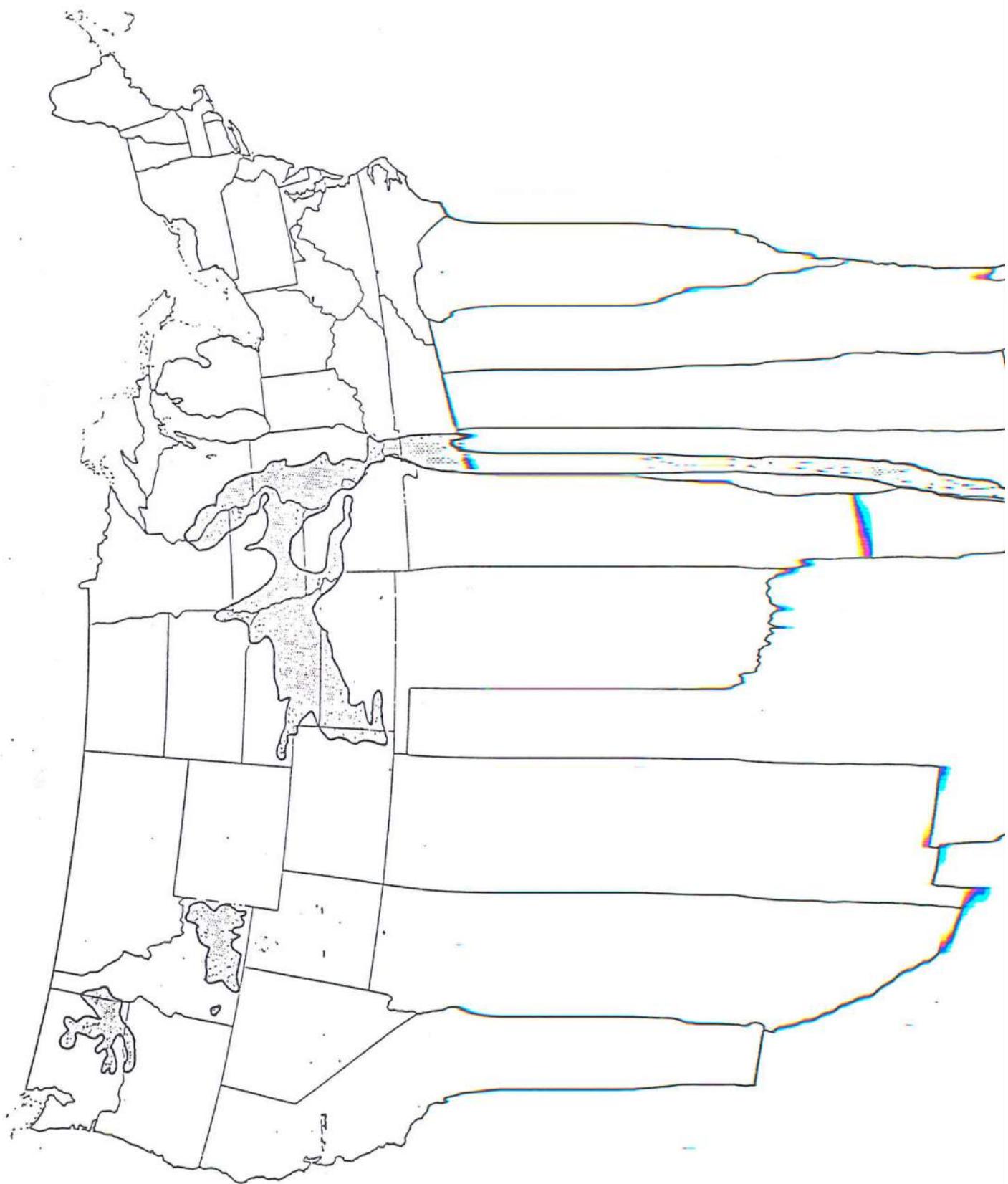
ELECTRON MICRO GRAPHS OF LOESS STRUCTURE

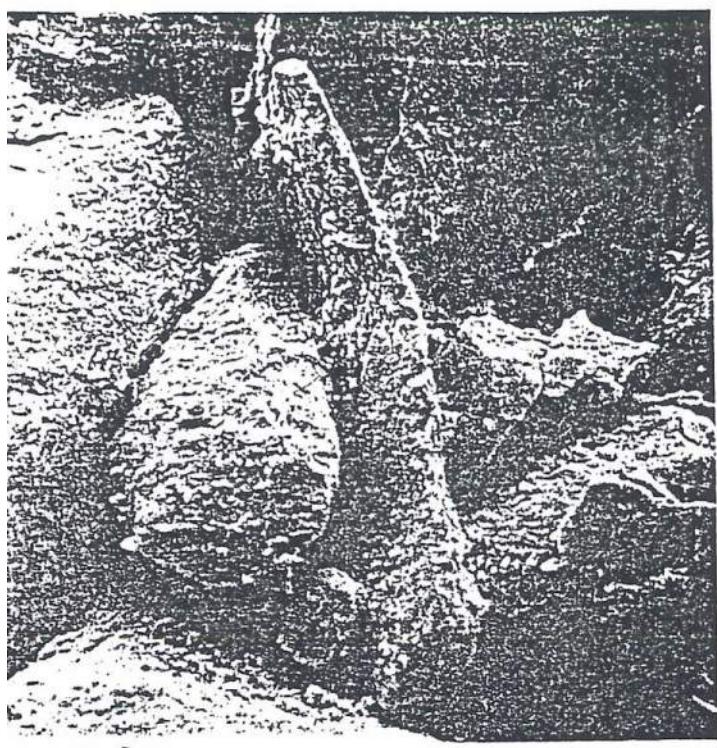
(a) Clay-coated silt grains
(b) Clay bridge

(c) silt-size aggregate of clay
(d) clean, angular silt fabric

FROM DERBYSHIRE AND MELLORS, 1988

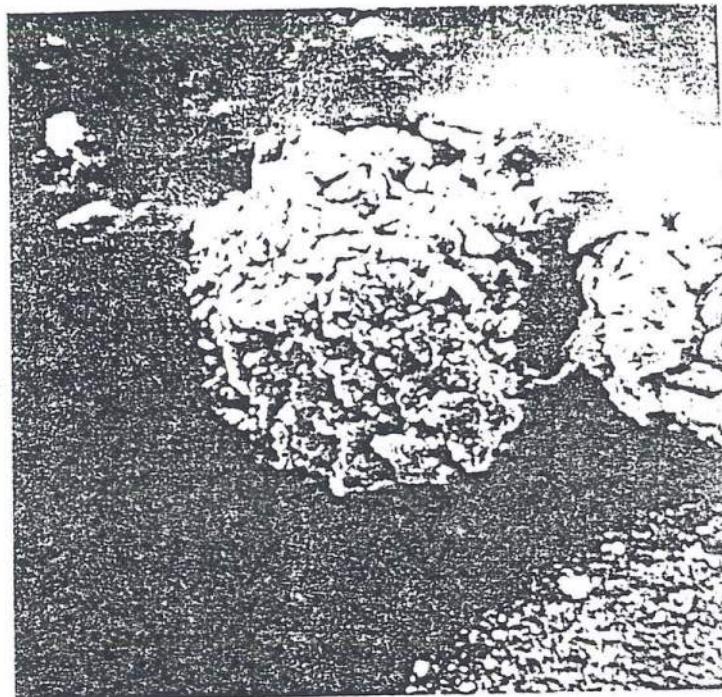
FIGURE B



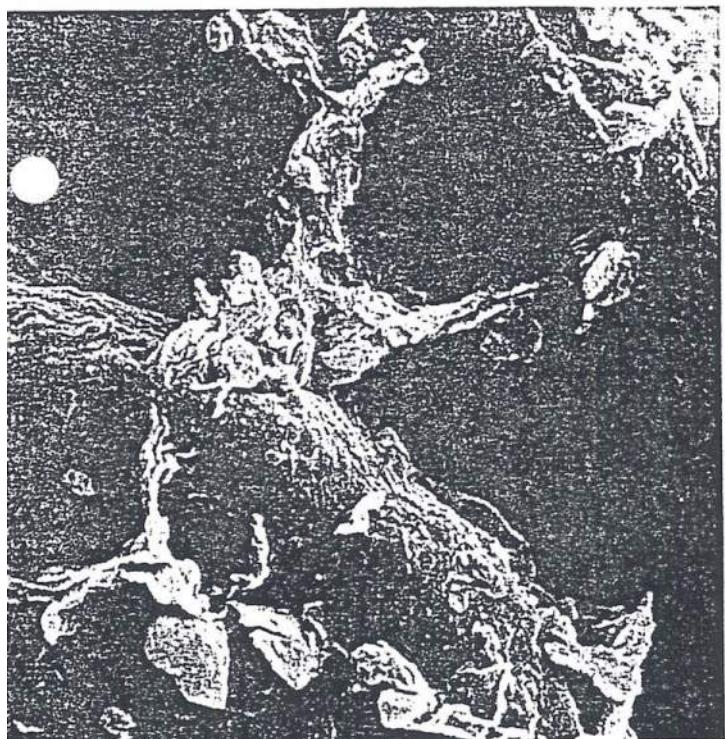


(a)

20 μm

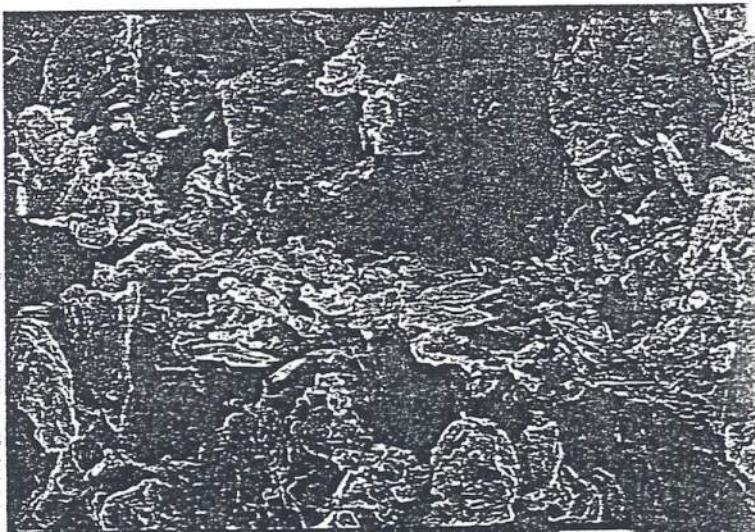


(c)



(b)

10 μm



(d)

ELECTRON MICRO GRAPHS OF LOESS STRUCTURE

(a) Clay-coated silt grains
(b) Clay bridge

(c) silt-size aggregate of clay
(d) clean, angular silt fabric

FROM DERBYSHIRE AND MELLORS, 1988

FIGURE B

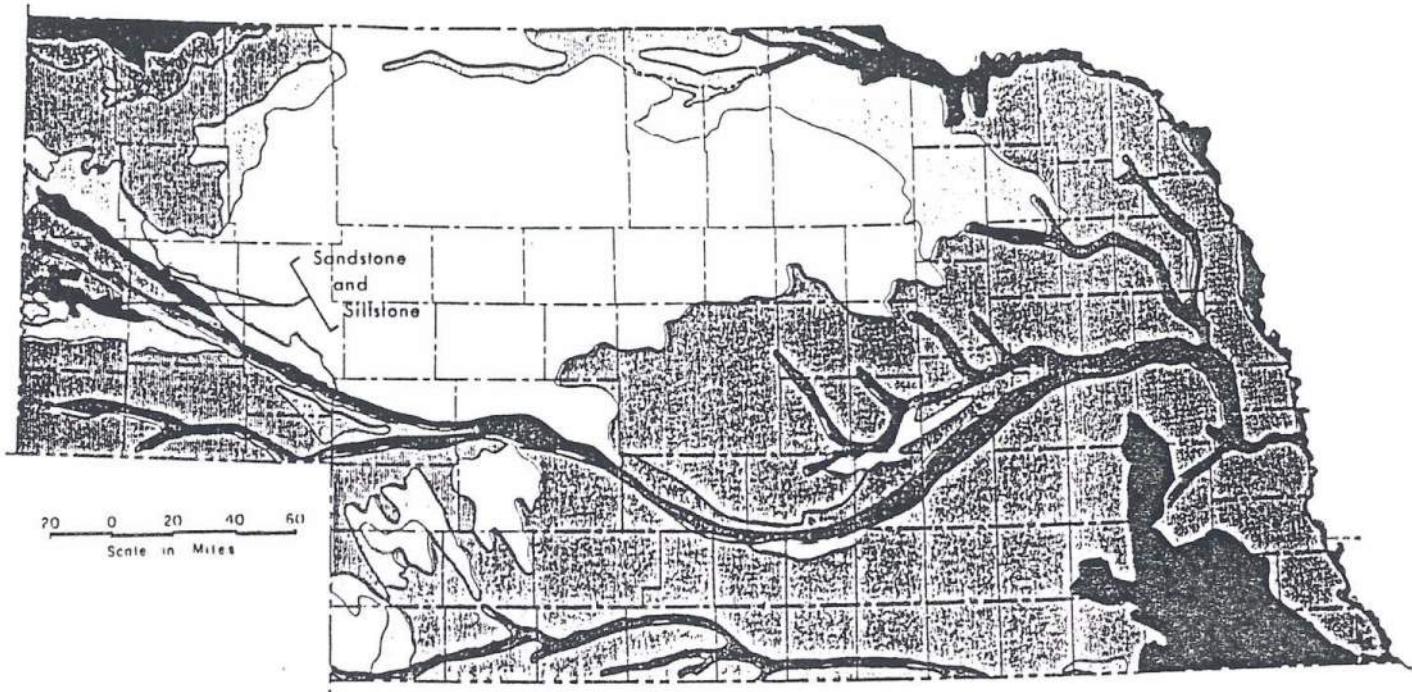
FIGURE 1



OUTLINE OF MAJOR LOESS DEPOSITS IN THE UNITED STATES

FIGURE 1

FROM GIBBS AND HOLLAND, 1960

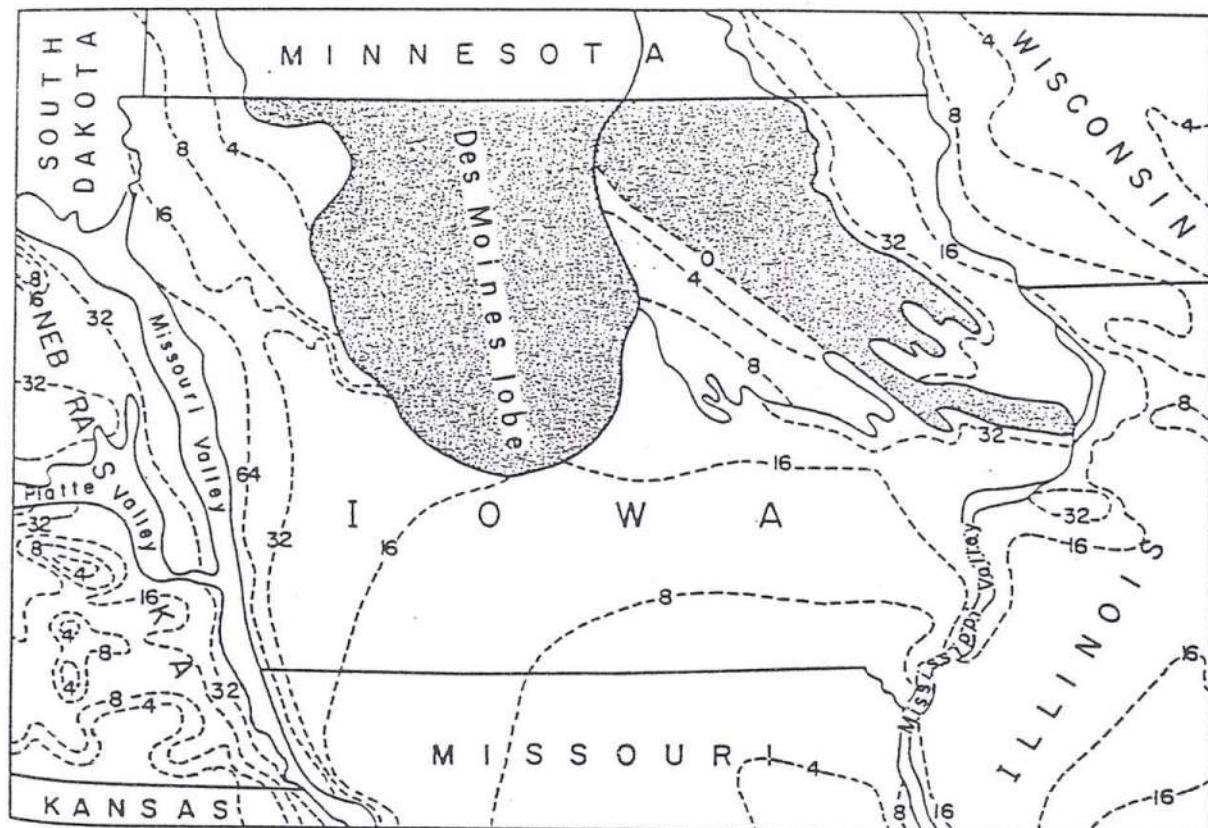


SOIL PARENT MATERIALS

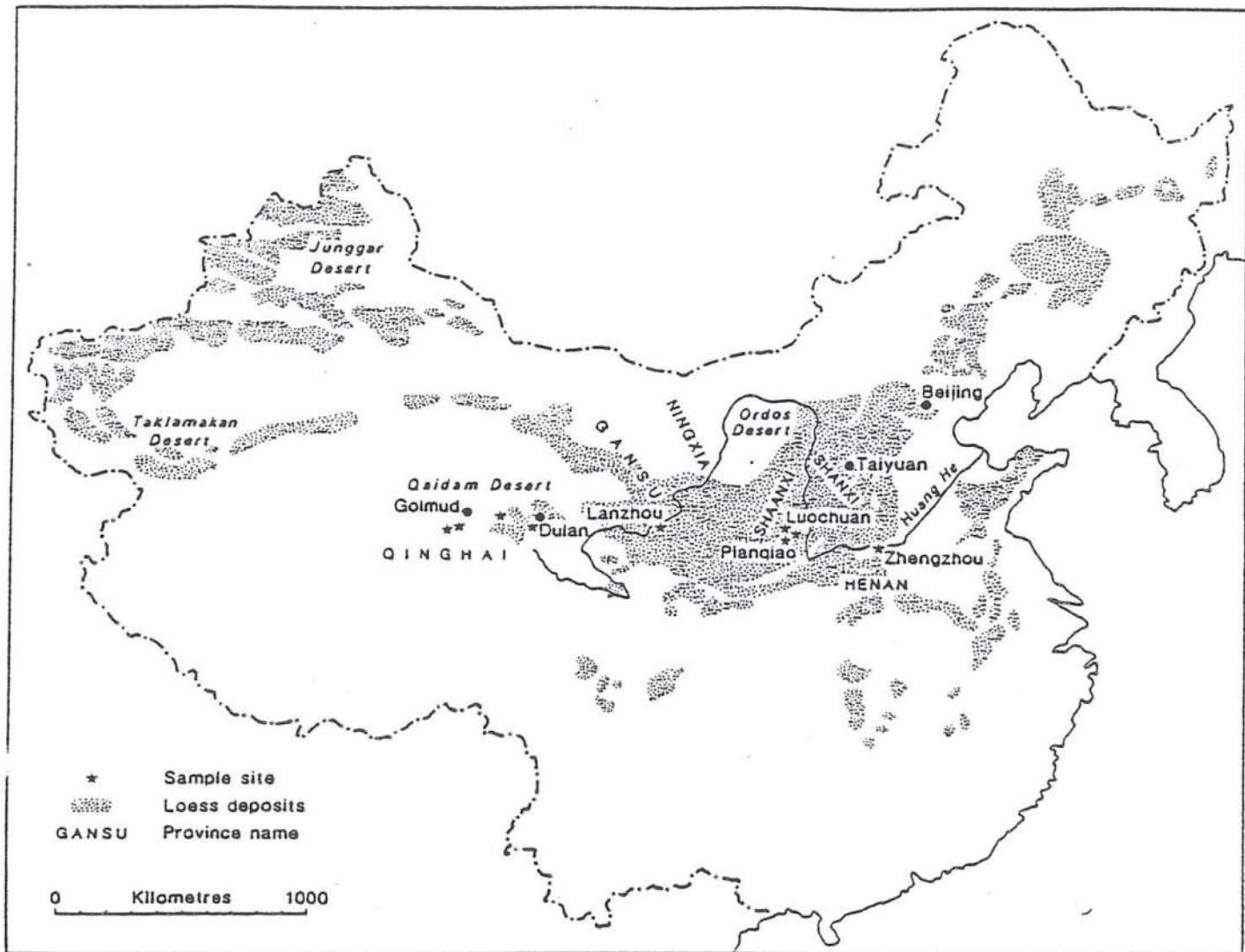
	SHALE		SAND AND SILT		ALLUVIUM		LOESS AND DRIFT
	SANDSTONE		SAND		LOESS		LOESS AND ALLUVIUM

FROM ELDER, 1969

FIG. 2.2. Loess thickness in Iowa. Contours in feet. Note decrease in thickness away from the Missouri River Valley and around the periphery of the Iowan erosion surface in northeast Iowa (cf. pl. 1). Shaded areas are essentially loess-free. (Modified from Thorp and Smith, 1952.)



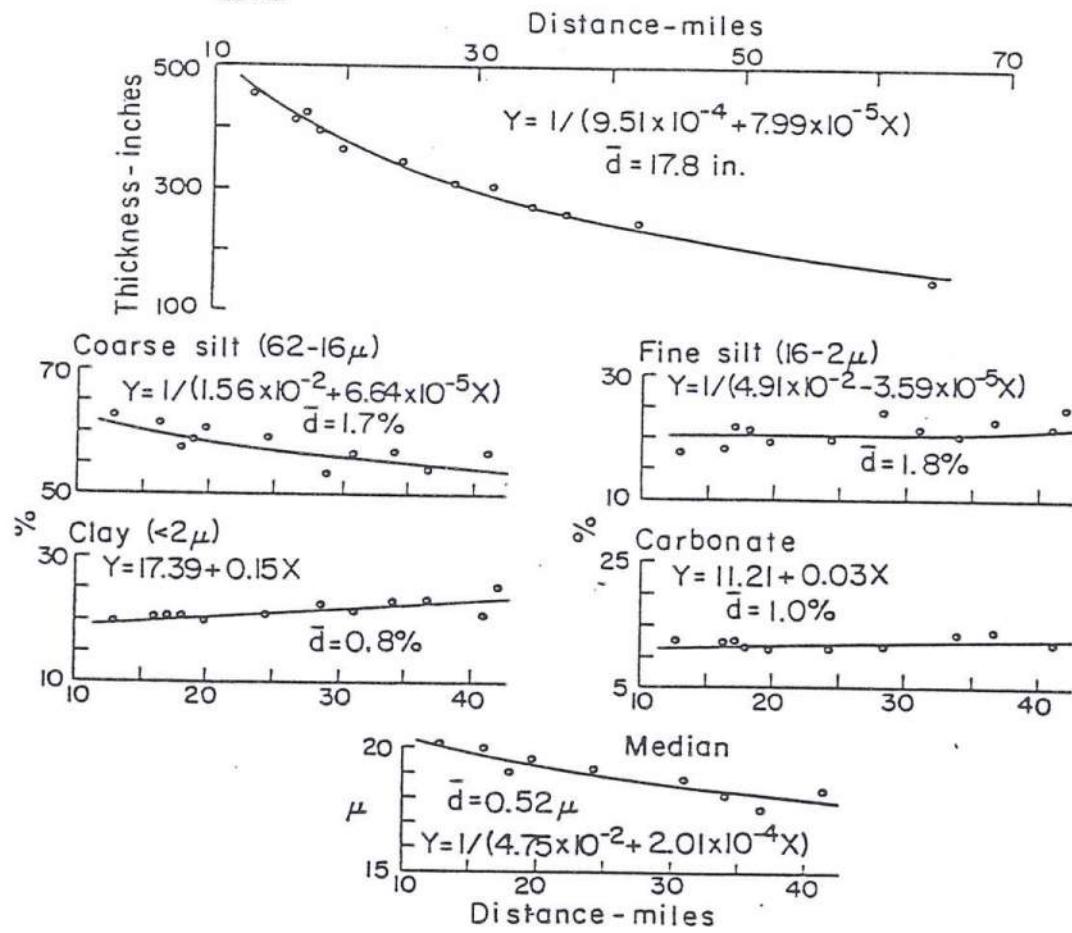
FROM RUHE, 1969



DISTRIBUTION OF LOESS IN CHINA

FROM DERBYSHIRE AND MELLORS, 1988

FIG. 2.3. Relations of loess thickness, particle size, and carbonate content of Wisconsin loess at primary- and secondary-divide ridge crests along the Rock Island Railroad from Bentley to Adair, Iowa.



FROM RUHE, 1969

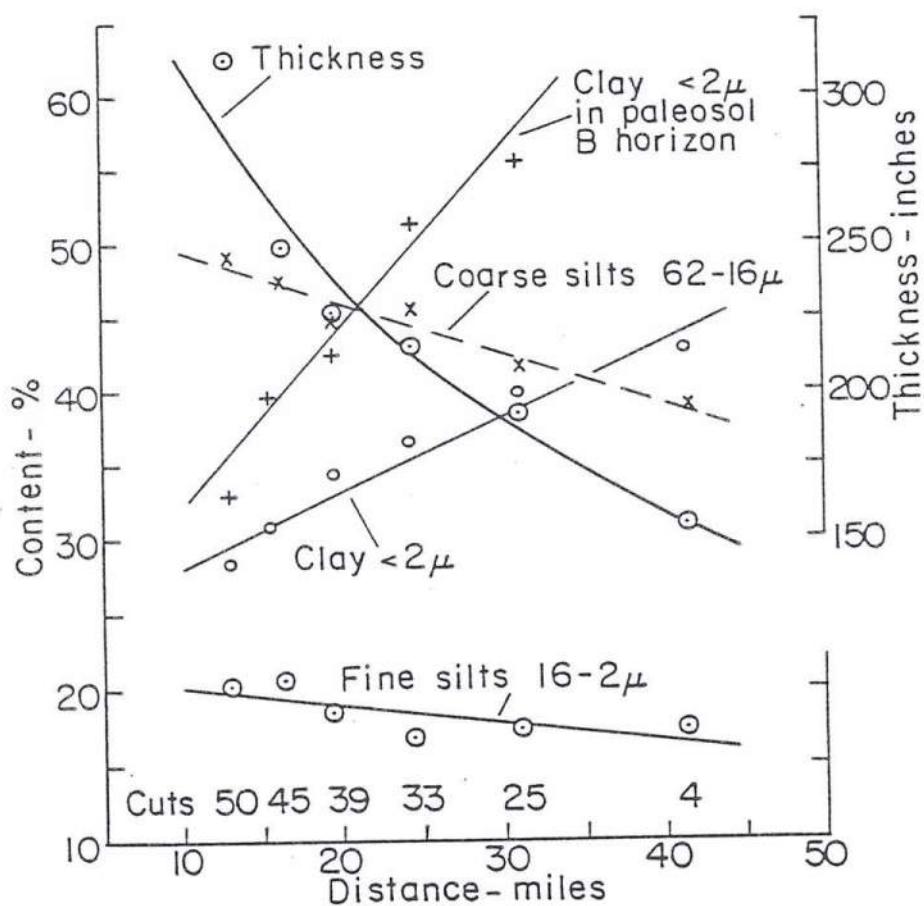


FIG. 3.1. Relations of thickness and coarse silt, fine silt, and clay content of Loveland loess to distance along traverse from Bentley to Atlantic in southwestern Iowa. Missouri River Valley source is 13 miles west (left on diagram) of cut 50. Amount of clay in B horizon of Sangamon paleosol increases eastward from cut 50 to cut 25.

FROM RUHE, 1969

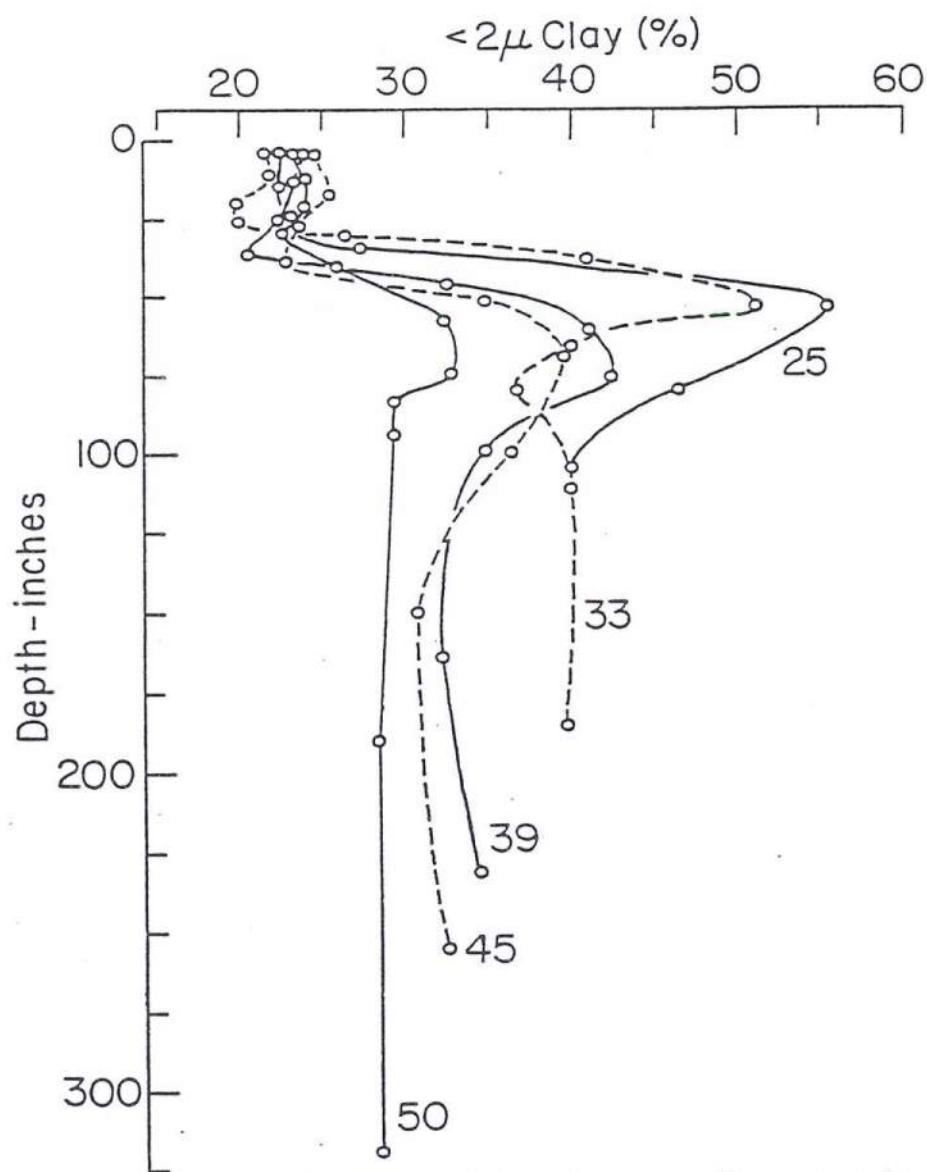
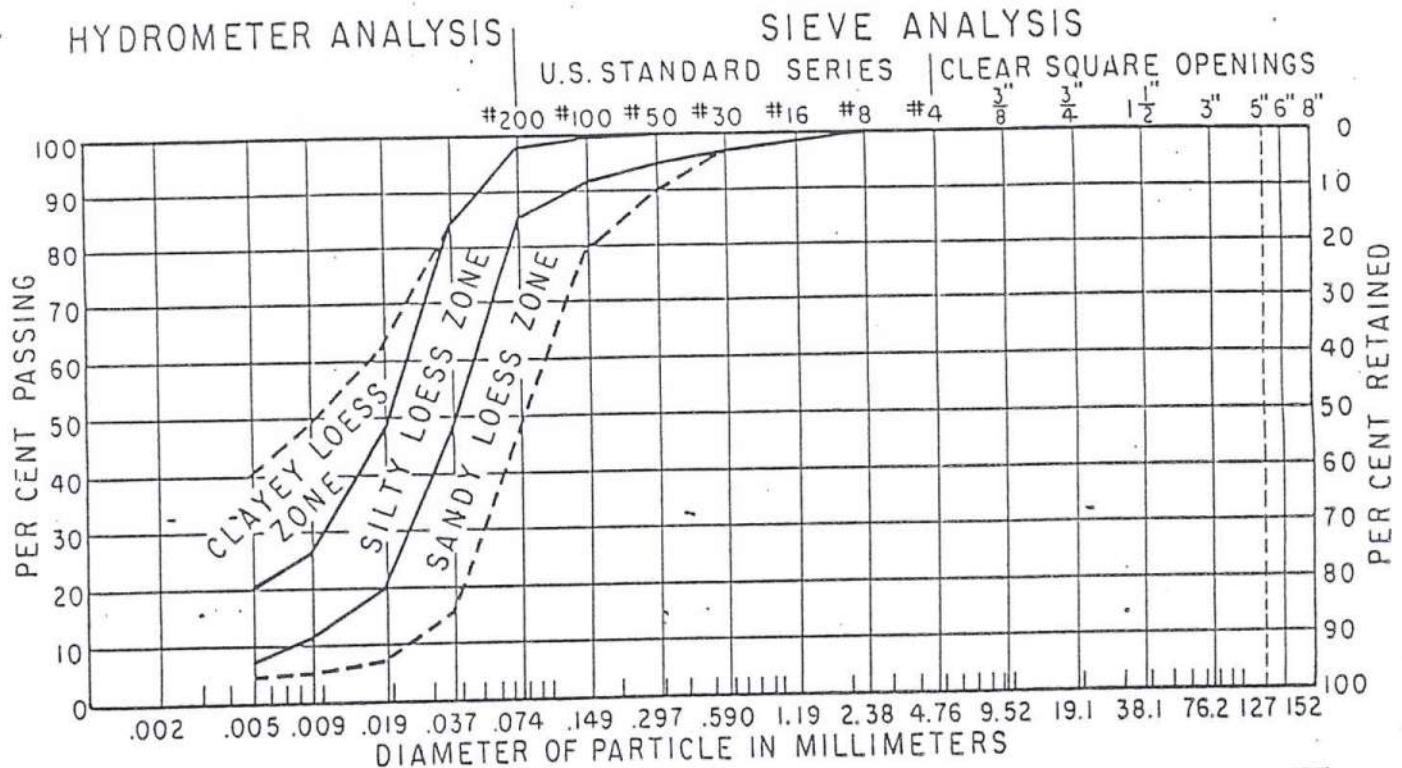


FIG. 3.2. Clay content of the B horizons of Sangamon paleosol from west (cut 50) to east (cut 25) along Bentley to Atlantic traverse in southwestern Iowa.

FROM RUHE, 1969

FIGURE 6

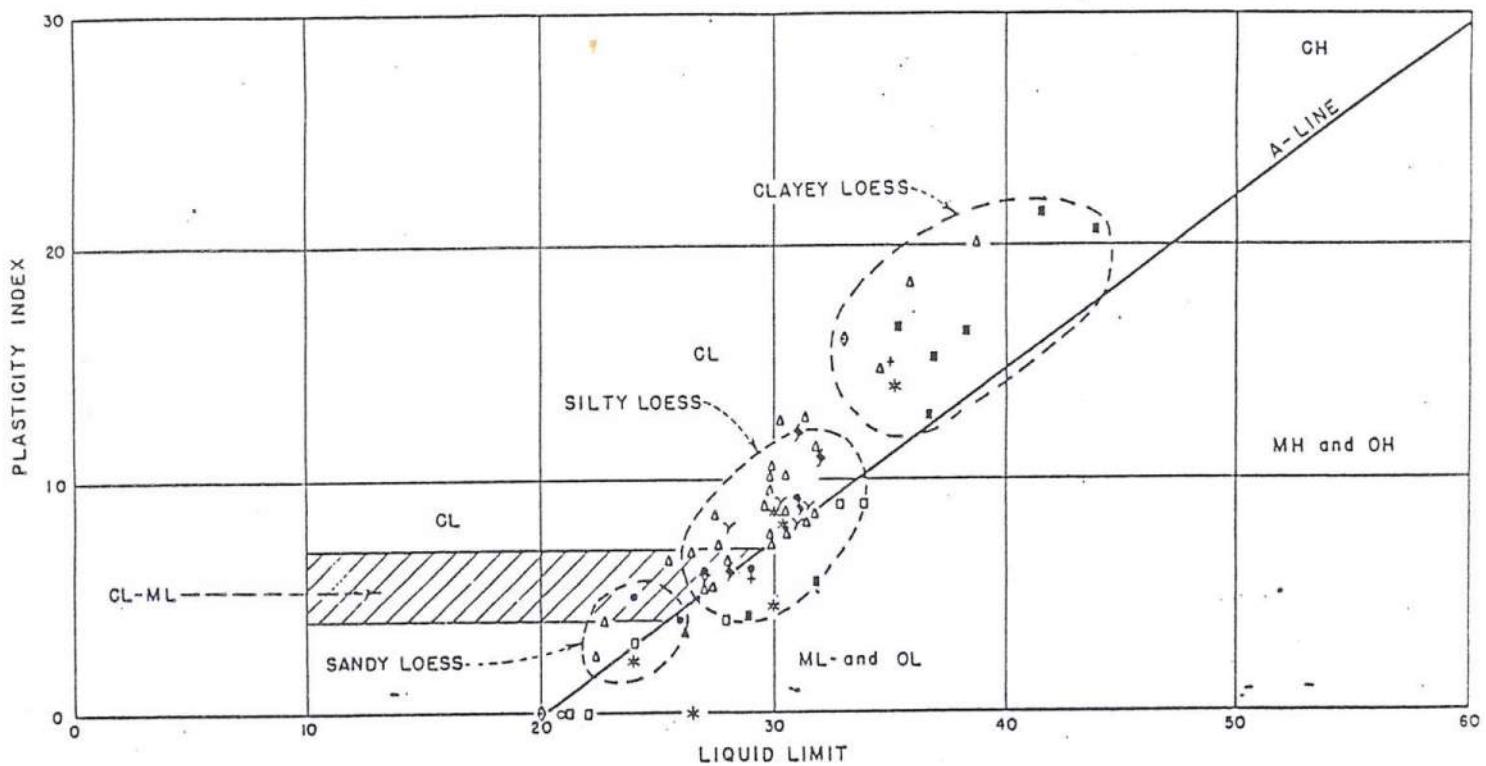


Gradation data was obtained on 148 samples from projects in the Missouri River Basin area. The curves generally take the direction shown by the boundary lines

For all samples tested,
76% were in the silty loess zone
18% were in the clayey loess zone
6% were in the sandy loess zone

TRENDS OF GRADATION CURVES FOR LOESS
FIGURE 5

FROM GIBBS AND HOLLAND, 1960.



Consistency limits data were obtained for samples from the following structures:

- | | | |
|---------------------------------------|---|-----------------|
| • Trenton Dam and Railroad Relocation | + | Cushing Dam |
| ▲ Bonney Dam | ○ | Milburn Dam |
| * Davis Creek Dam | ■ | Amherst Dam |
| △ Ashton pile test area | ↳ | Courtland Canal |
| □ Rockville Dam | ◊ | Cambridge Canal |
| Υ Medicine Creek Dam | | |

TRENDS OF PLASTICITY CHARACTERISTICS OF LOESS
FIGURE 6
FROM GIBBS AND HOLLAND, 1960

FIGURE 8

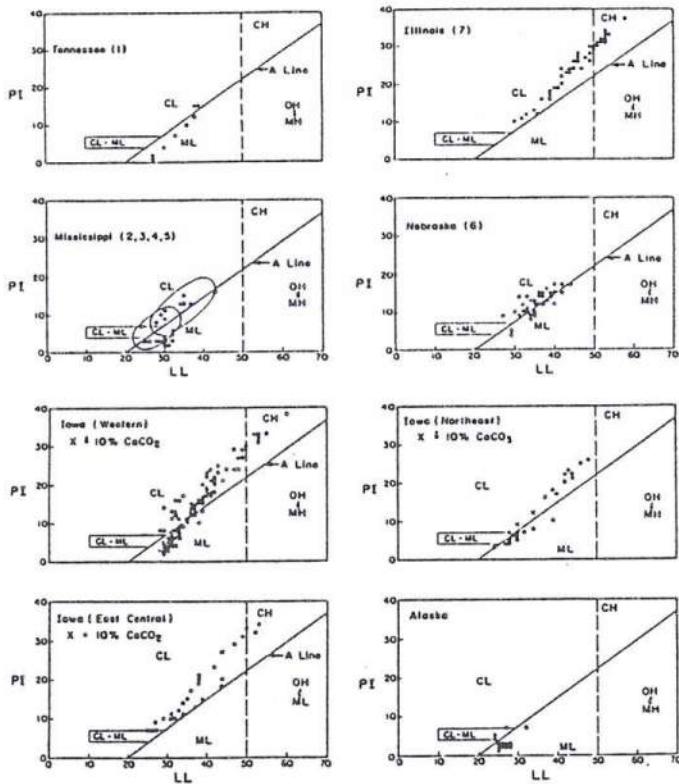


Figure 2. Plasticity data of loess in the United States.

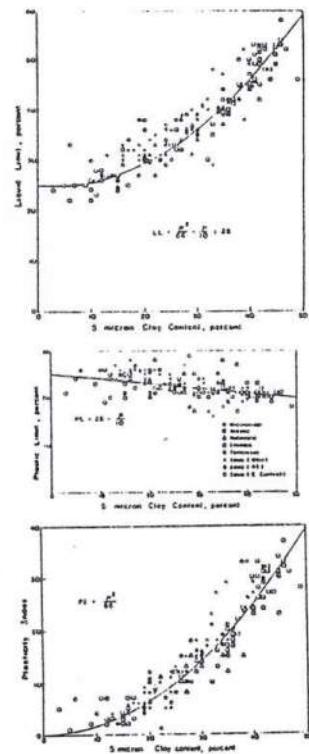
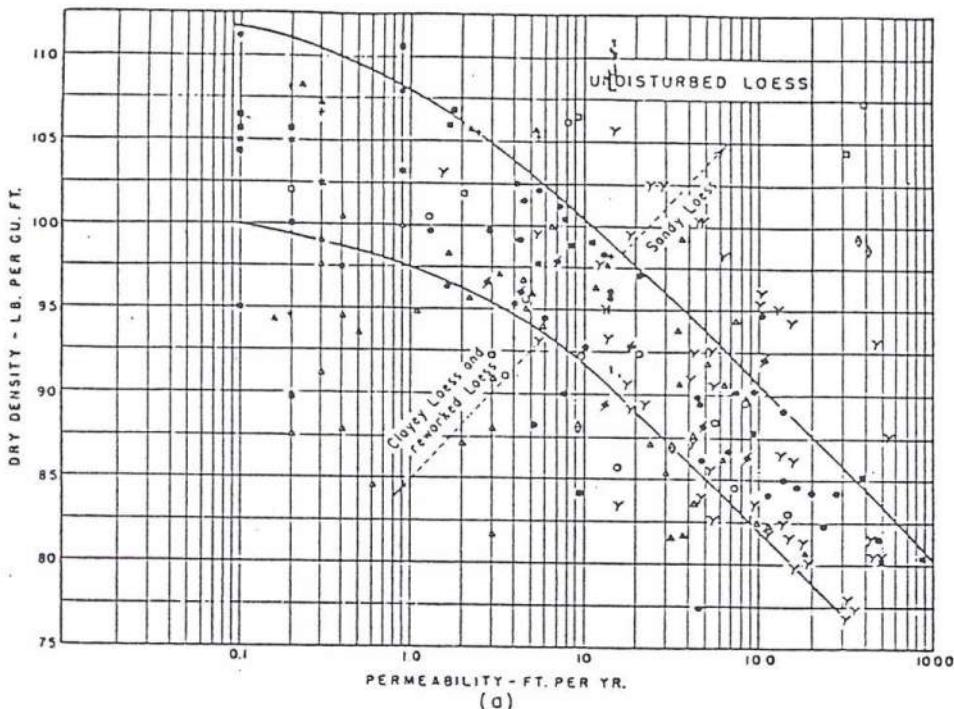
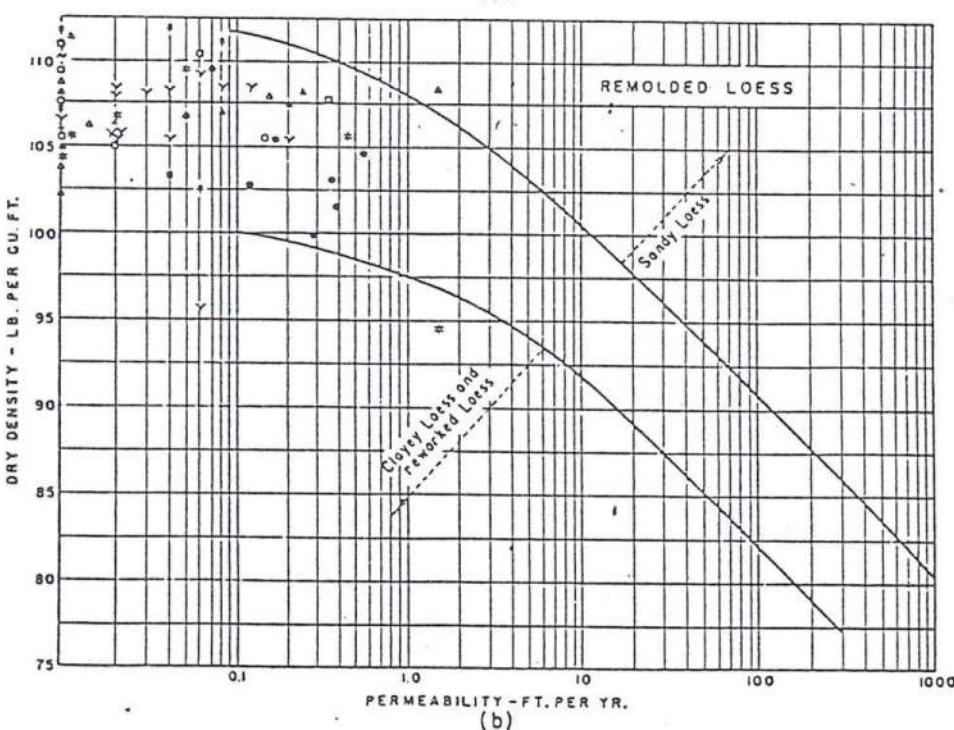


Figure 3. Plasticity data as a function of five-micron clay content for loess in the United States. The symbol μ represents five-micron clay content in the equations.

FROM SHEELER, 1968



(a)



(b)

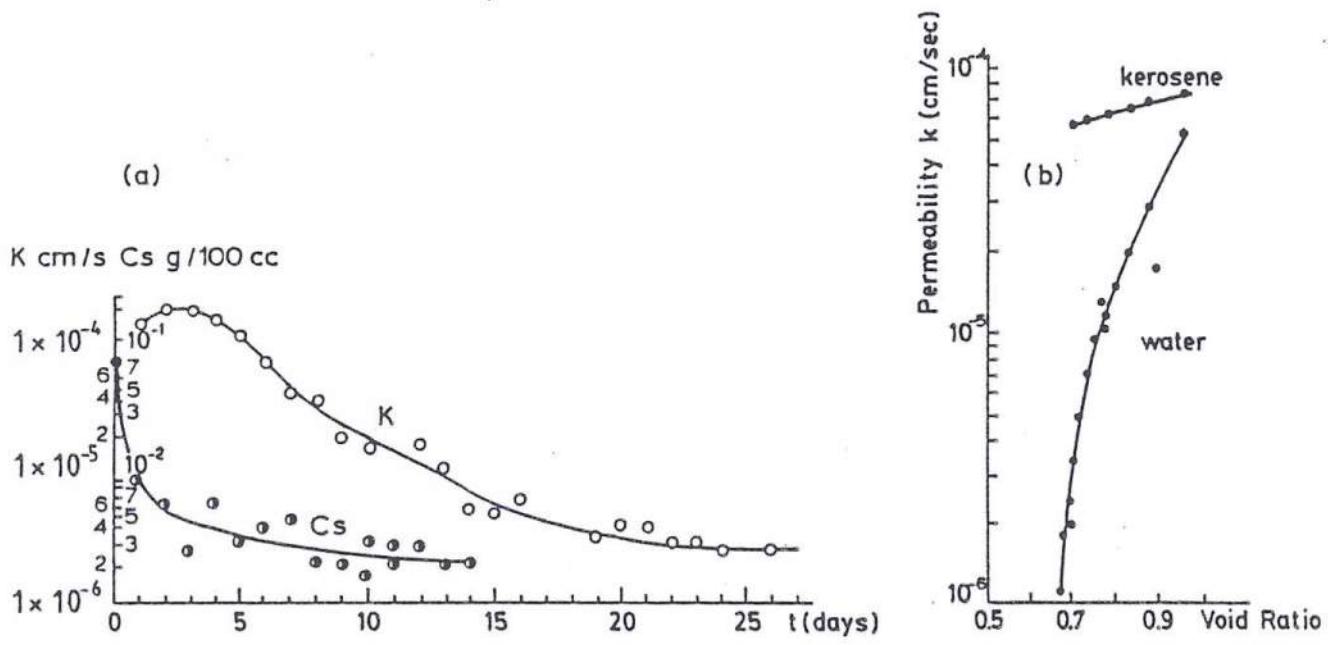
EXPLANATION

- | | |
|---------------------------------------|-------------------|
| • Trenton Dam and Railroad Relocation | ○ Milburn Dam |
| ▲ Bonny Dam | ■ Amherst Dam |
| ■ Davis Creek Dam | ◆ Courtland Canal |
| △ Ashton pile test area | ◊ Cambridge Canal |
| □ Rockville Dam | † Enders Dam |
| Υ Medicine Creek Dam | ~ Erickson Dam |
| + Cushing Dam | |

TRENDS OF PERMEABILITY FOR LOESS
FIGURE 7

FROM GIBBS AND HOLLAND, 1960

FIGURE 10

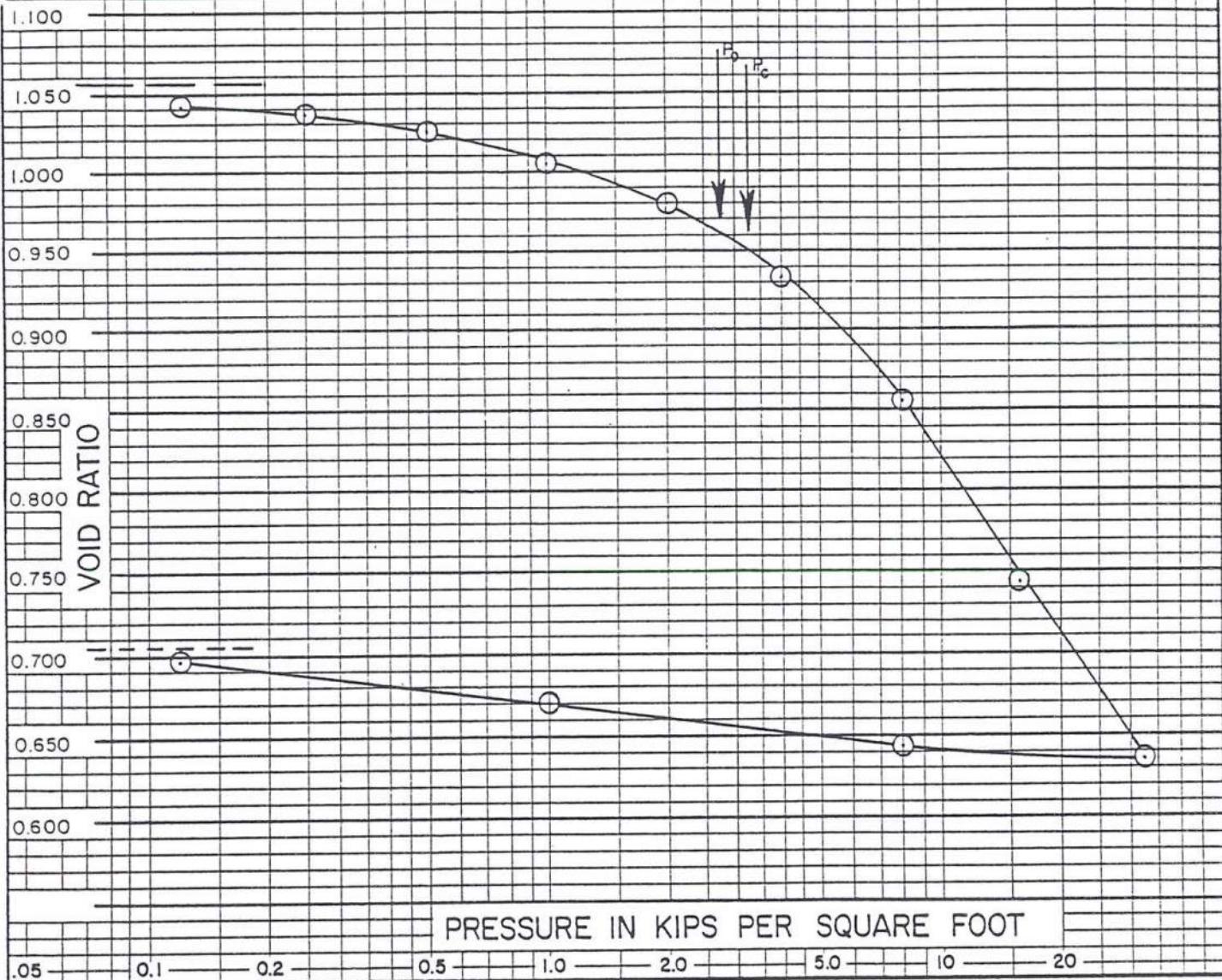


(a). Long term permeability tests with simultaneous determination of the amounts of dissolved salts. (b). Permeability tests of 24 hours duration with water and kerosene as percolating liquids.

CHANGE IN PERMEABILITY WITH TIME

FROM TAN TJONG KIE, 1988

PRESSURE-VOID RATIO CURVE

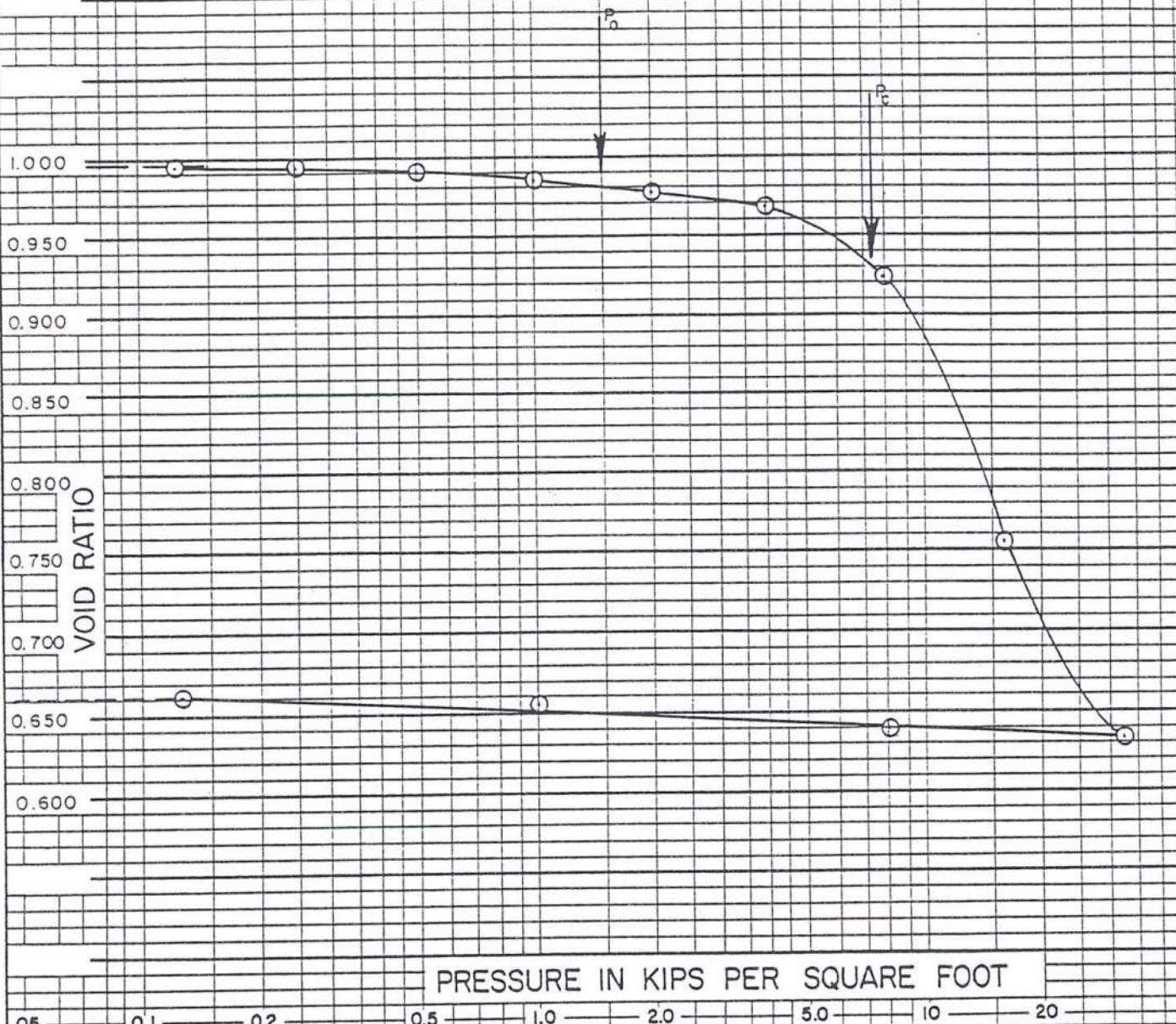


PROPERTIES OF CONSOLIDATION SPECIMEN

DIAMETER OF SPECIMEN, in.	2.50	INITIAL VOID RATIO, SHOWN THUS	— — —	1.057
INITIAL THICKNESS OF SPECIMEN, in.	1.00	FINAL VOID RATIO, SHOWN THUS	— — — —	0.705
INITIAL WATER CONTENT, %	33.5	PROBABLE PRECONSOLIDATION STRESS, ksf SHOWN THUS	↑ P_c	3.2
FINAL WATER CONTENT, %	24.7	EXISTING OVERBURDEN STRESS, ksf SHOWN THUS	↑ P_o	2.7
INITIAL DEGREE SATURATION, %	90.8	COMPRESSION INDEX, C_c		0.380
FINAL DEGREE SATURATION, %	100	REBOUND INDEX, C_r		0.026
INITIAL DRY DENSITY,pcf	86.8	NEW GRAIN ELEVATOR - SHELBY, NEBRASKA		
UNIFIED CLASSIFICATION	CL			
LIQUID LIMIT, %	31	WOODWARD - CLYDE CONSULTANTS CONSULTING ENGINEERS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS CENTRAL REGION		
PLASTIC LIMIT, %	19			
PLASTICITY INDEX, %	12	DRAWN BY: DH CHECKED BY: CNE		
LIQUIDITY INDEX	1.25	CONSOLIDATION TEST BORING NO.: 3 DEPTH: 25'		
INDICATED SPECIFIC GRAVITY	2.86			

FIGURE 12B

PRESSURE-VOID RATIO CURVE



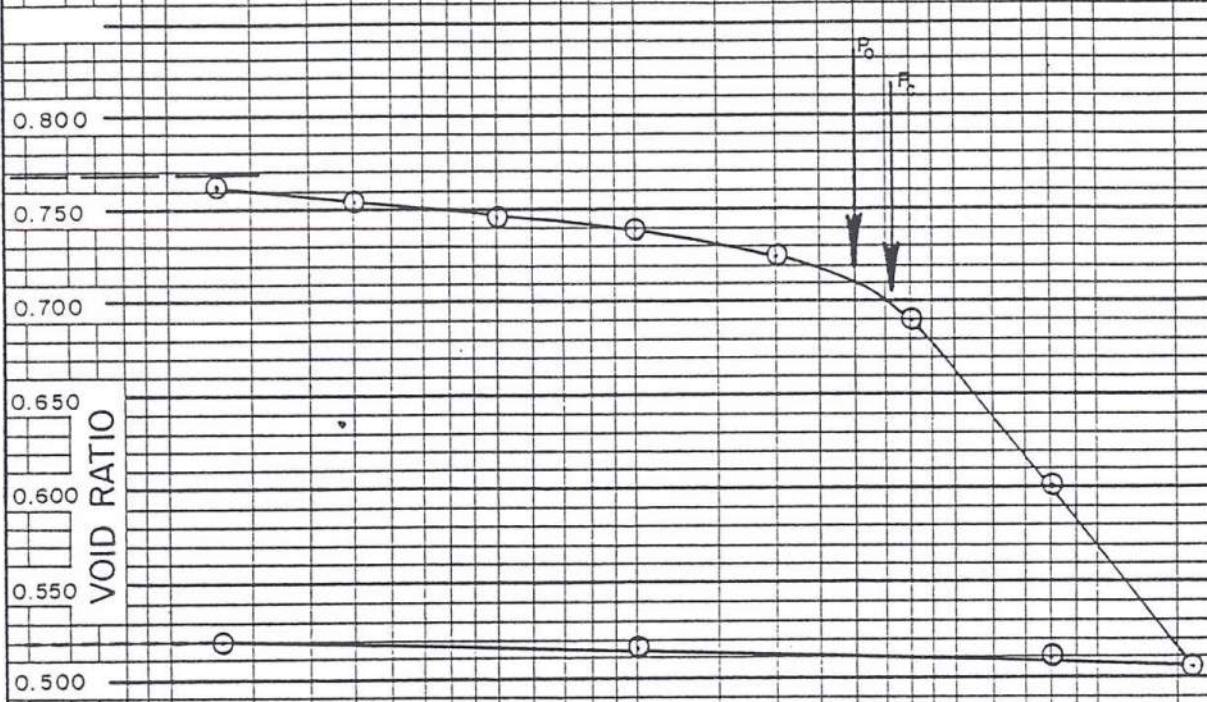
PRESSURE IN KIPS PER SQUARE FOOT

.05 0.1 0.2 0.5 1.0 2.0 5.0 10 20

PROPERTIES OF CONSOLIDATION SPECIMEN

DIAMETER OF SPECIMEN, in.	2.50	INITIAL VOID RATIO, SHOWN THUS	-----	0.997
INITIAL THICKNESS OF SPECIMEN, in	1.00	FINAL VOID RATIO, SHOWN THUS	-----	0.661
INITIAL WATER CONTENT, %	24.4	PROBABLE PRECONSOLIDATION STRESS, ksf SHOWN THUS	P _c	7.4
FINAL WATER CONTENT, %	22.0	EXISTING OVERBURDEN STRESS, ksf SHOWN THUS	P ₀	1.5
INITIAL DEGREE SATURATION, %	65.1	COMPRESSION INDEX, C _c		0.646
FINAL DEGREE SATURATION, %	88.4	REBOUND INDEX, C _r		0.011
INITIAL DRY DENSITY,pcf	82.8	NEW GRAIN ELEVATOR - HASTINGS, NEBRASKA		
UNIFIED CLASSIFICATION	CL-ML			
LIQUID LIMIT, %	31	WOODWARD - CLYDE CONSULTANTS		
PLASTIC LIMIT, %	22	CONSULTING ENGINEERS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS		
PLASTICITY INDEX, %	9	CENTRAL REGION		
LIQUIDITY INDEX	-0.27	DRAWN BY: DH CHECKED BY: CNE		
INDICATED SPECIFIC GRAVITY	2.65	CONSOLIDATION TEST BORING NO.: I DEPTH: 15.1'		
		FIGURE 12C		

PRESSURE-VOID RATIO CURVE



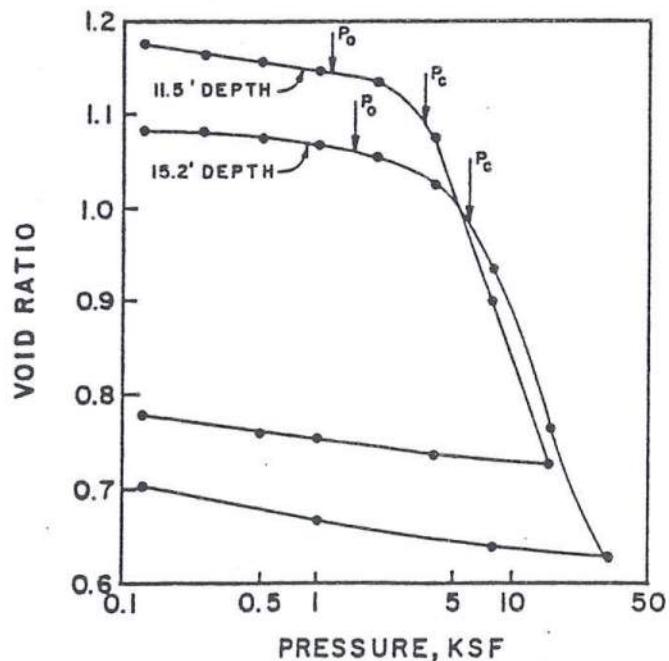
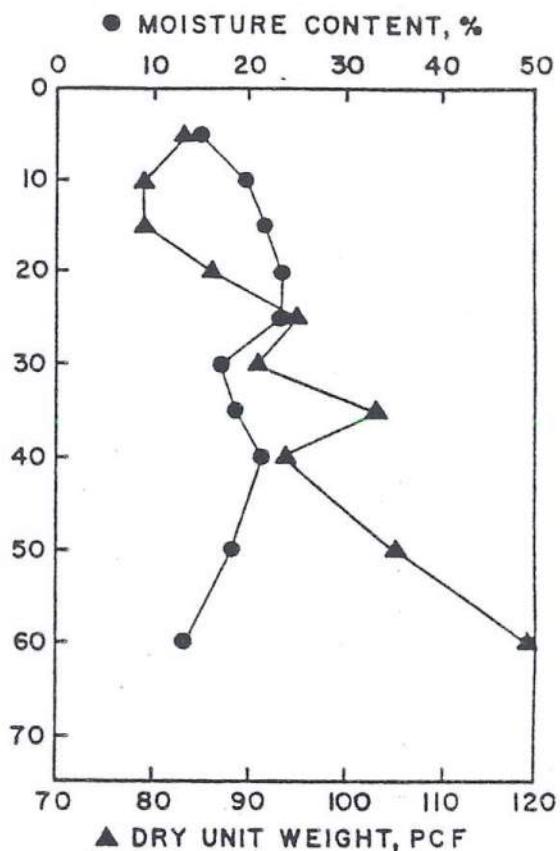
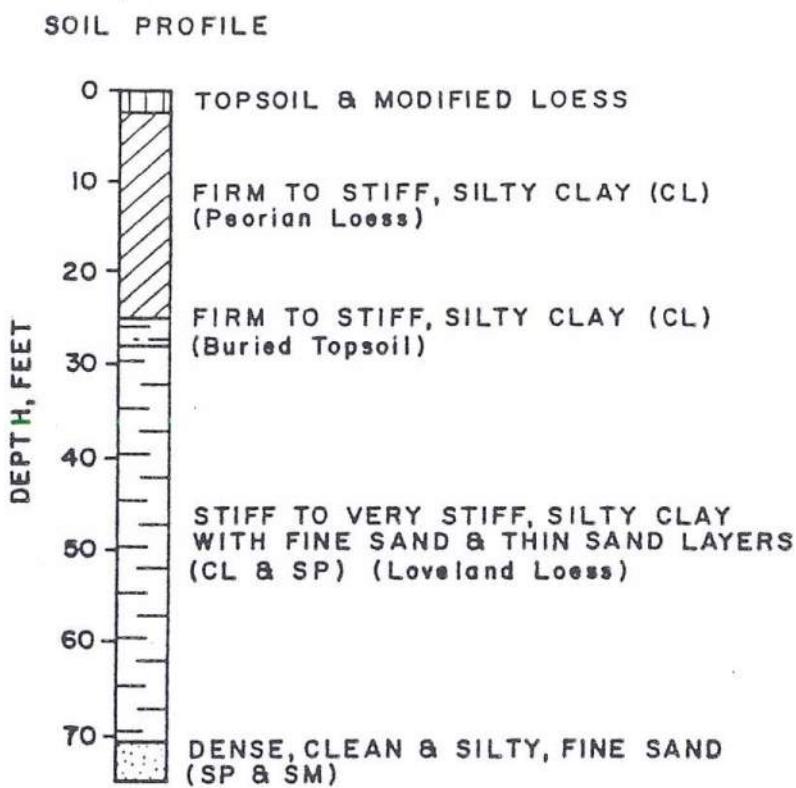
PRESSURE IN KIPS PER SQUARE FOOT

.05 0.1 0.2 0.5 1.0 2.0 5.0 10 20

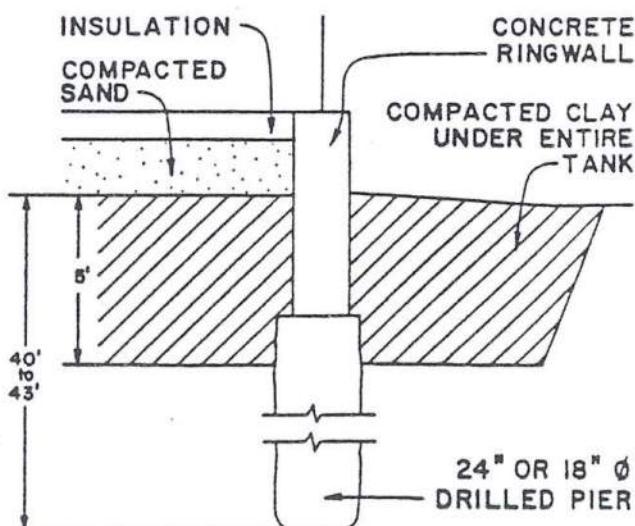
PROPERTIES OF CONSOLIDATION SPECIMEN

DIAMETER OF SPECIMEN, in.	2.50	INITIAL VOID RATIO, SHOWN THUS	0.758
INITIAL THICKNESS OF SPECIMEN, in	1.00	FINAL VOID RATIO, SHOWN THUS	0.520
INITIAL WATER CONTENT, %	14.4	PROBABLE PRECONSOLIDATION STRESS, ksf SHOWN THUS	1 P_c
FINAL WATER CONTENT, %	12.5	EXISTING OVERBURDEN STRESS, ksf SHOWN THUS	1 P_o
INITIAL DEGREE SATURATION, %	49.6	COMPRESSION INDEX, C_c	0.313
FINAL DEGREE SATURATION, %	63.9	REBOUND INDEX, C_r	0.009
INITIAL DRY DENSITY, pcf	93.6	NEW GRAIN ELEVATOR - HASTINGS, NEBRASKA	
UNIFIED CLASSIFICATION	CL	WOODWARD - CLYDE CONSULTANTS CONSULTING ENGINEERS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS CENTRAL REGION	
LIQUID LIMIT, %	24	DRAWN BY: DH CHECKED BY: CNE	
PLASTIC LIMIT, %	14	CONSOLIDATION TEST BORING NO.: I DEPTH: 29.2'	
PLASTICITY INDEX, %	10		
LIQUIDITY INDEX	0.04		
INDICATED SPECIFIC GRAVITY	2.65		

FIGURE 12D

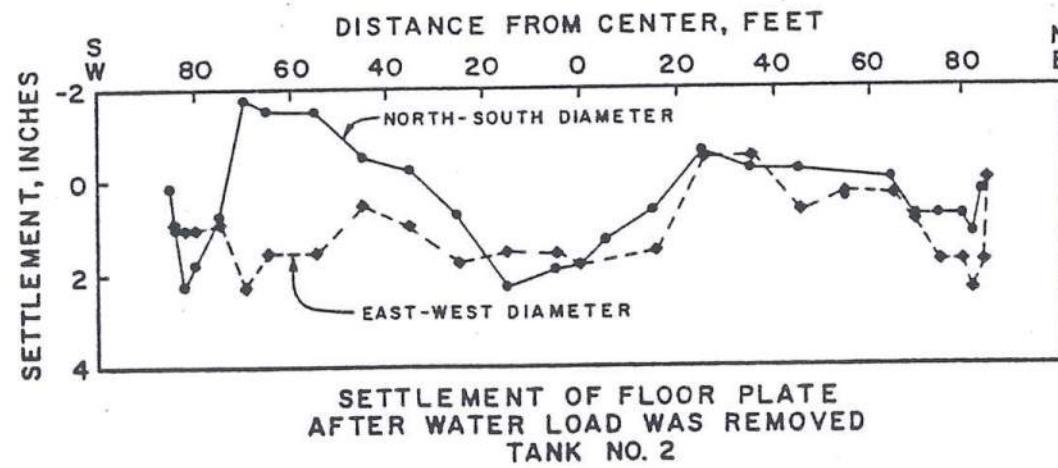
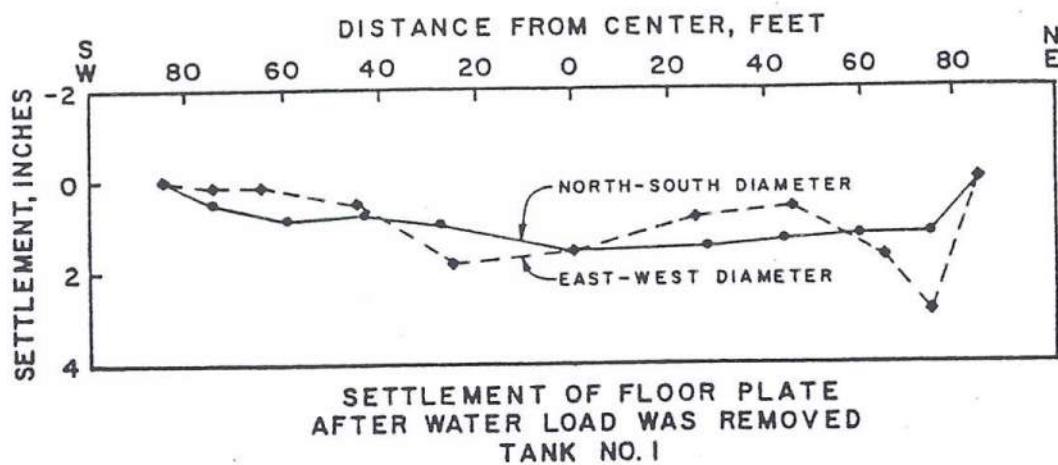


CONSOLIDATION CHARACTERISTICS



FOUNDATION SECTION

CASE NO. 5



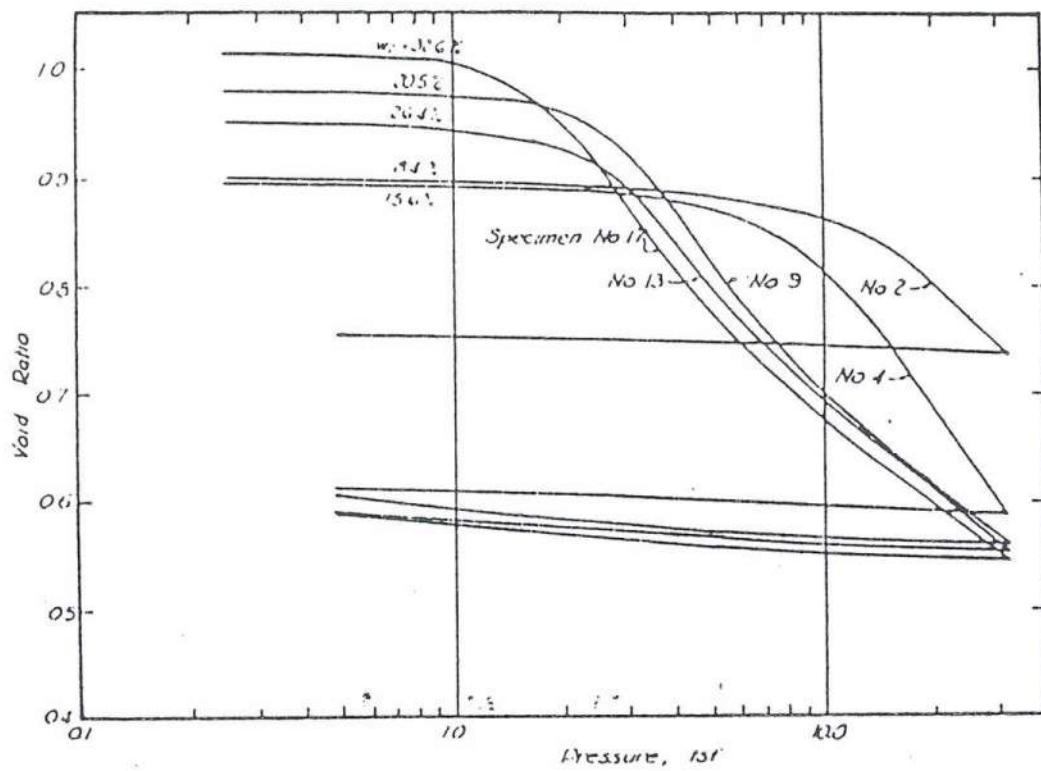


Figure 5. Typical void ratio-log pressure relationships, Hawkeye loess.

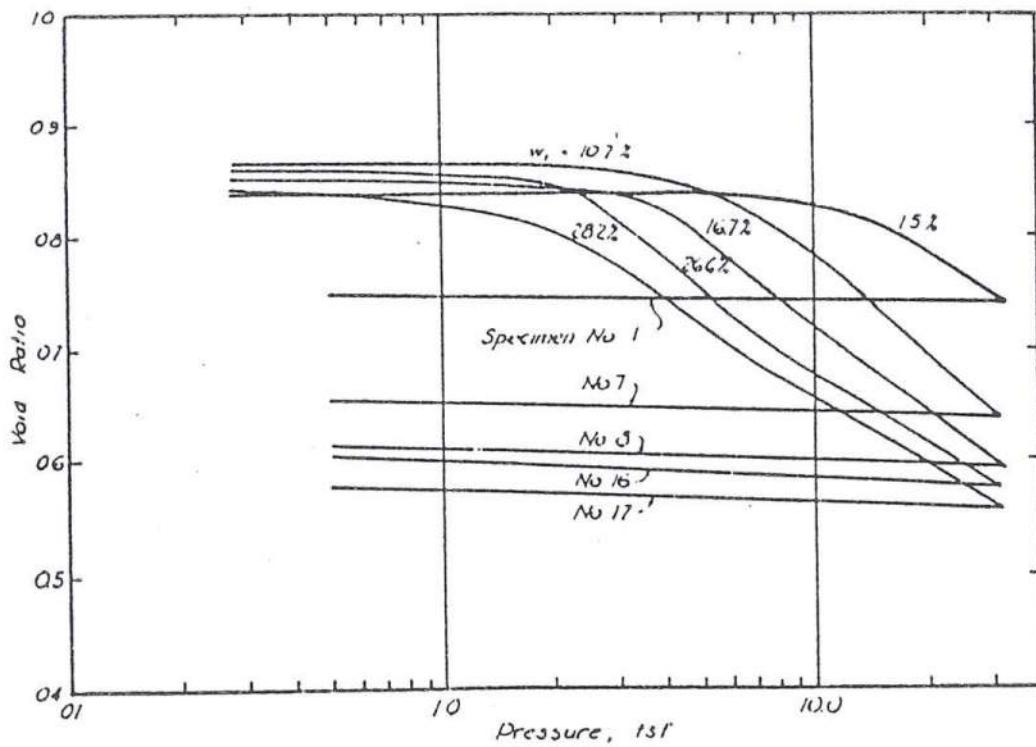


Figure 6. Typical void ratio-log pressure relationships, Oakdale loess.

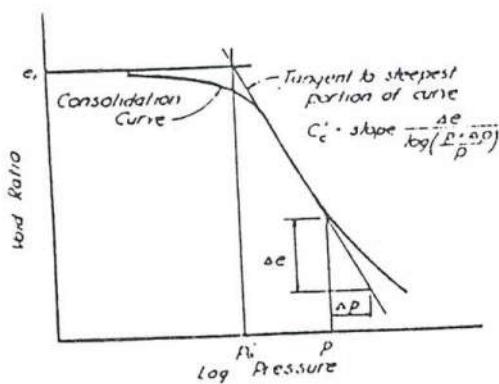


Figure 7. Definitions of parameters P_0' and C_c' .

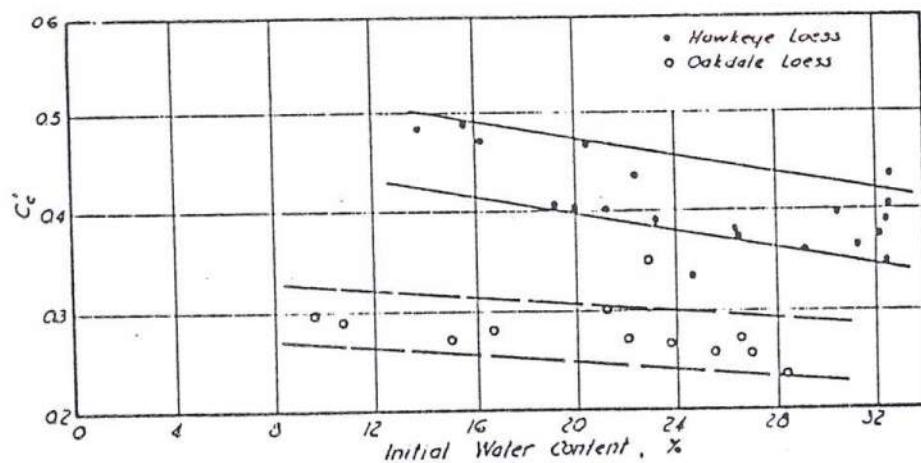
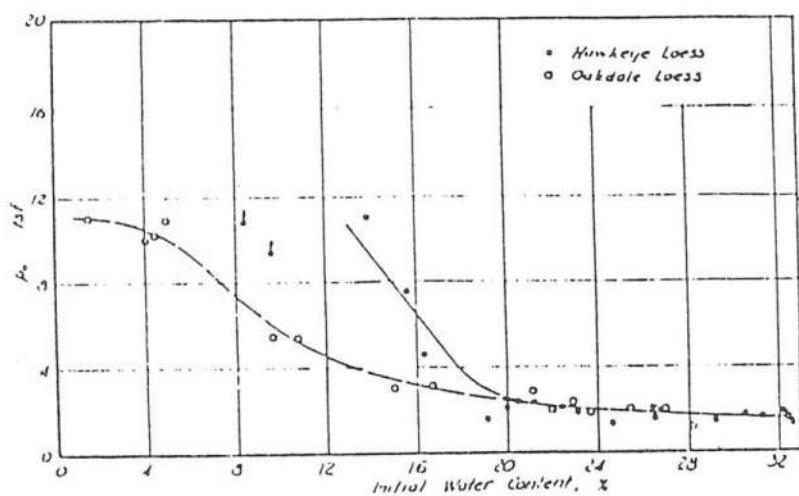
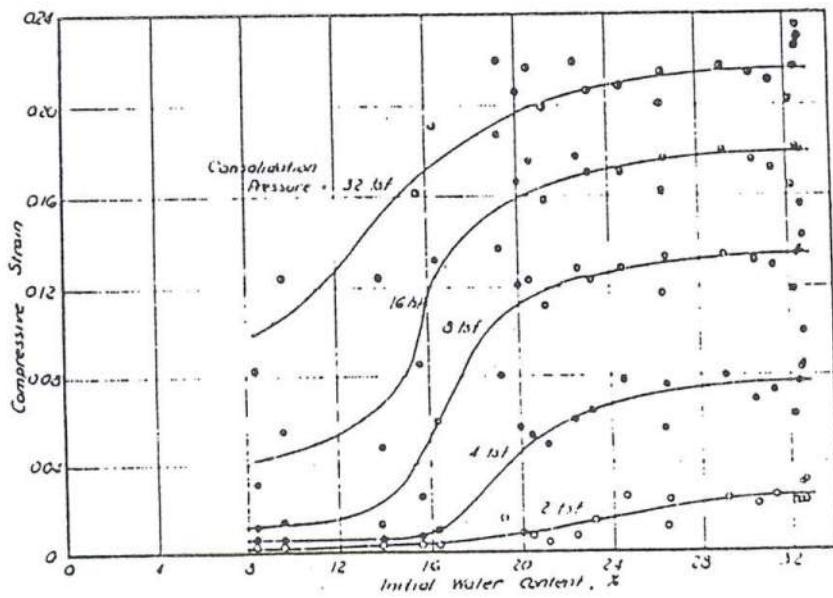
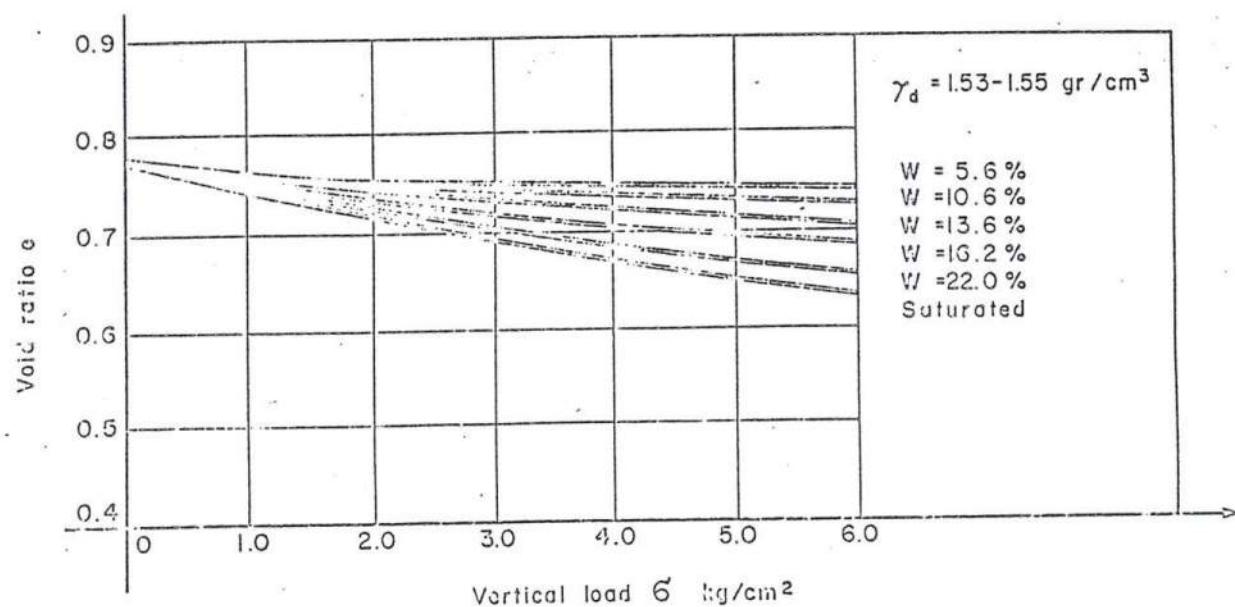
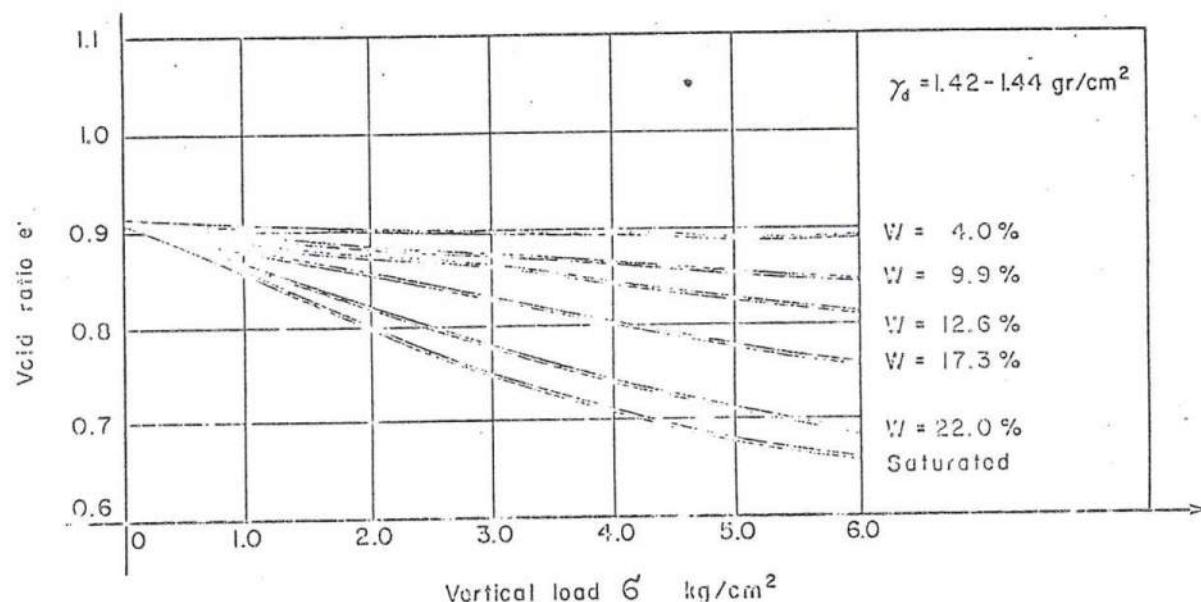
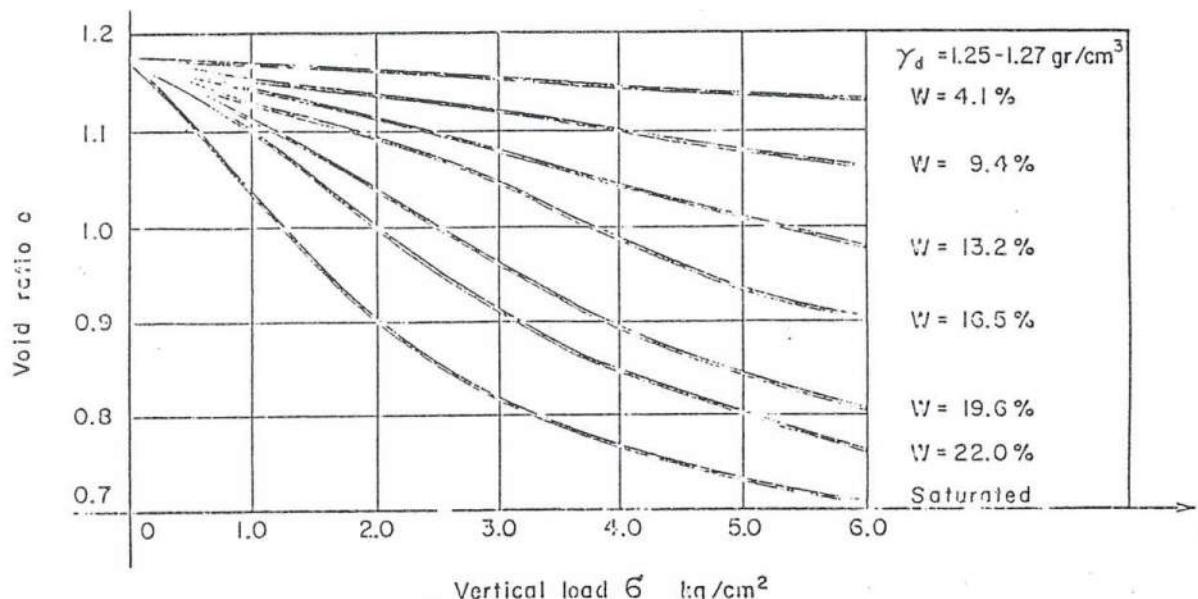


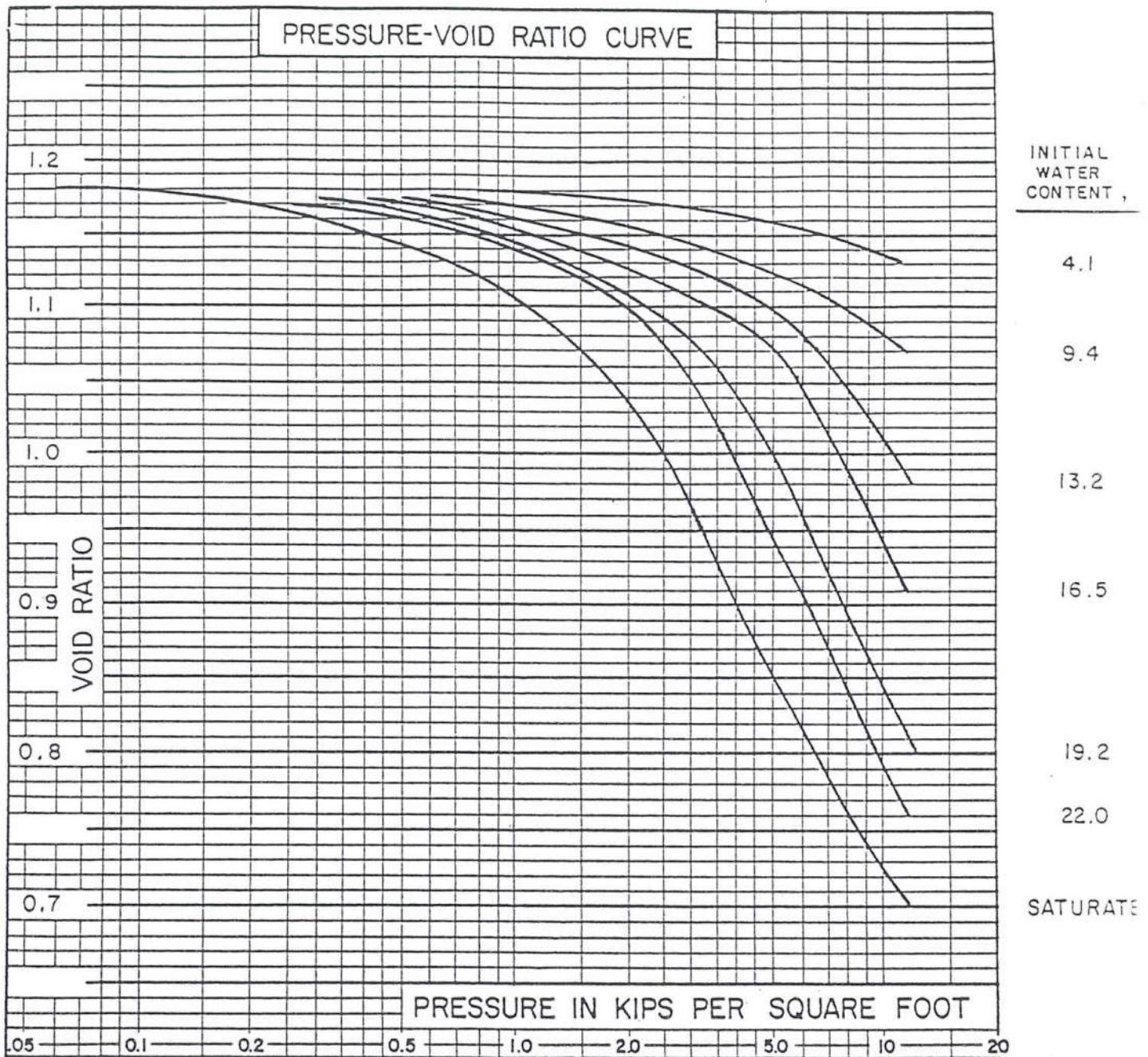
Figure 9. Variation of C_c' with initial water content.



FROM KANE, 1969.

FIGURE 13C



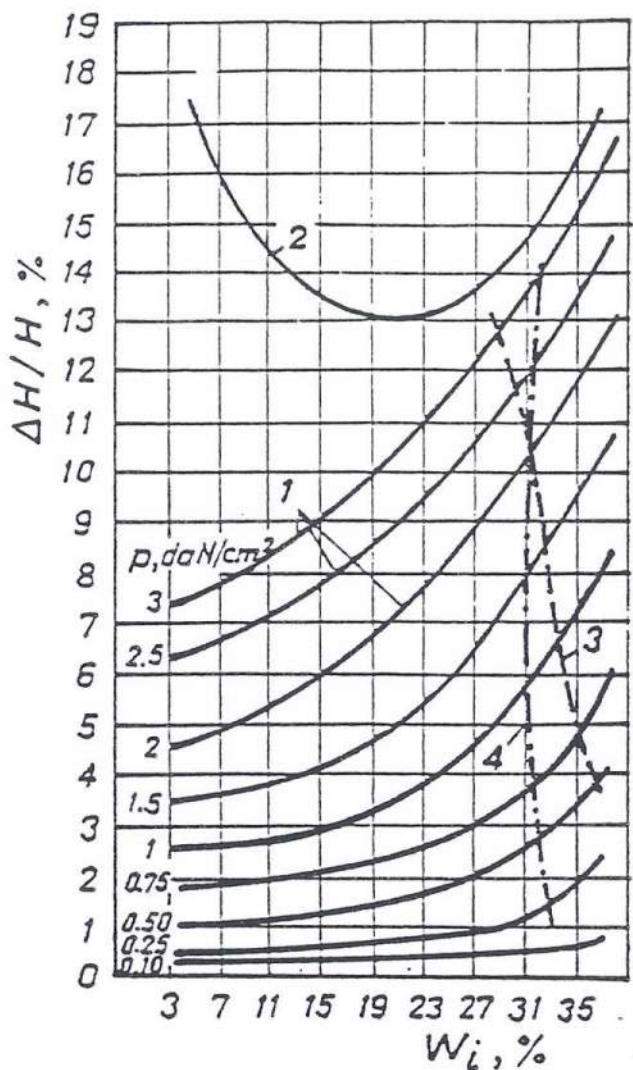


COMPRESSION OF LOESS AT
DIFFERENT WATER CONTENTS

INITIAL DRY UNIT WEIGHT = 78 LB./FT.³

REPLOTTED FROM MILOVIC

FIGURE 14A

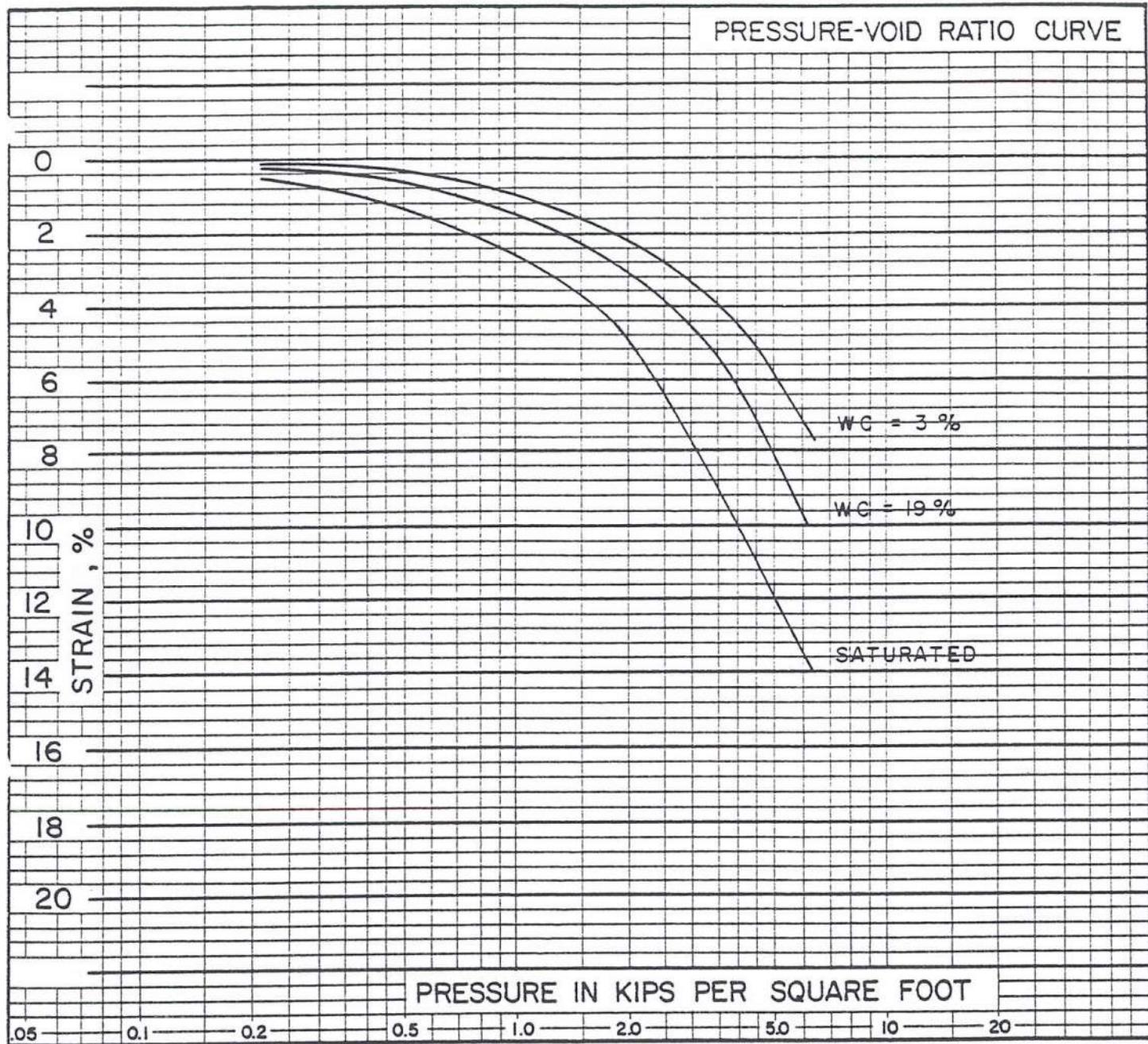


Oedometer settlements of undisturbed loess samples: (1) settlements of samples with different initial moisture content, unchanged during loading; (2) final settlement of samples after flooding at 3 daN/cm²; (3) saturation due to compression; (4) settlements of samples flooded before loading.

RELATIONSHIP BETWEEN COMPRESSIBILITY AND MOISTURE CONTENT

FROM BALLY, 1988

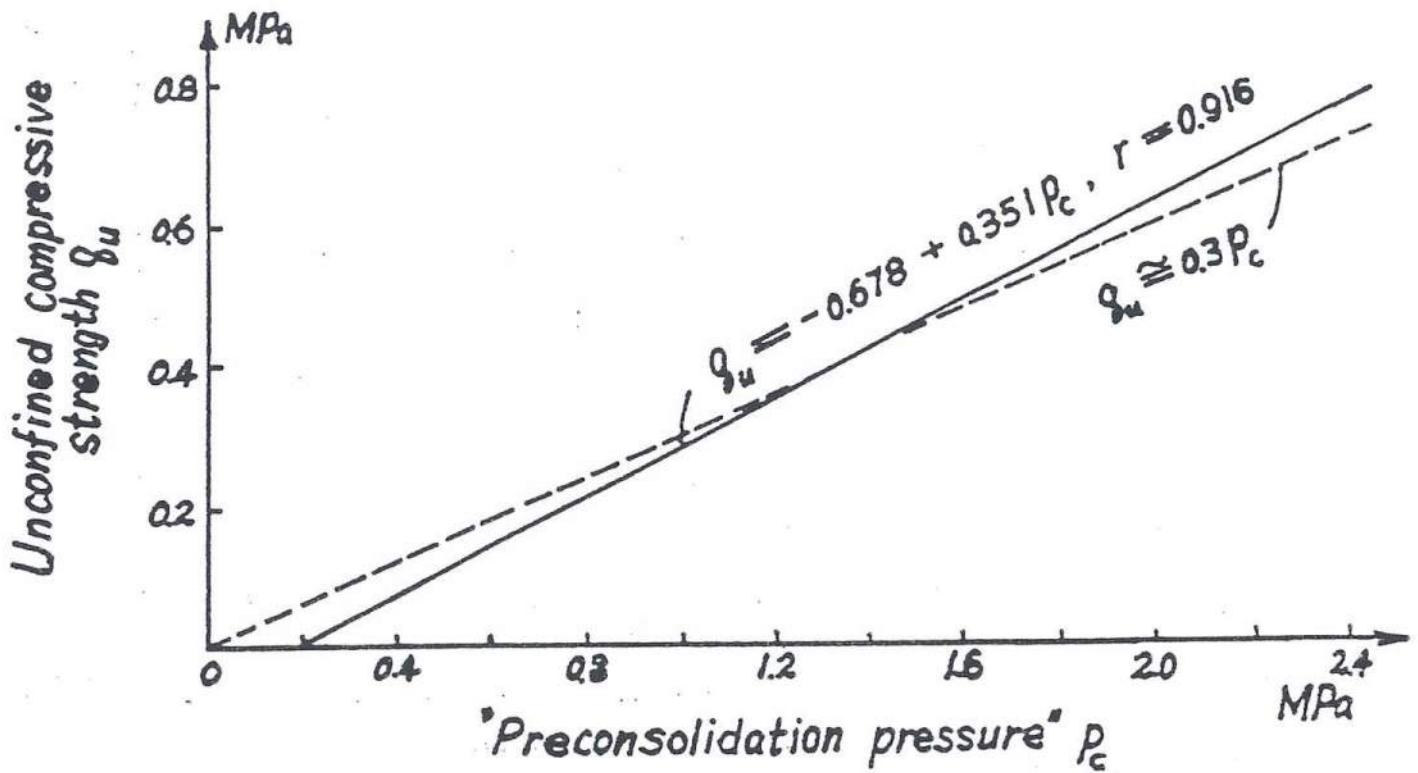
FIGURE 14B



CONSOLIDATION OF LOESS
AT DIFFERENT MOISTURE CONTENTS

REPLOTTED FROM BALLY, 1988

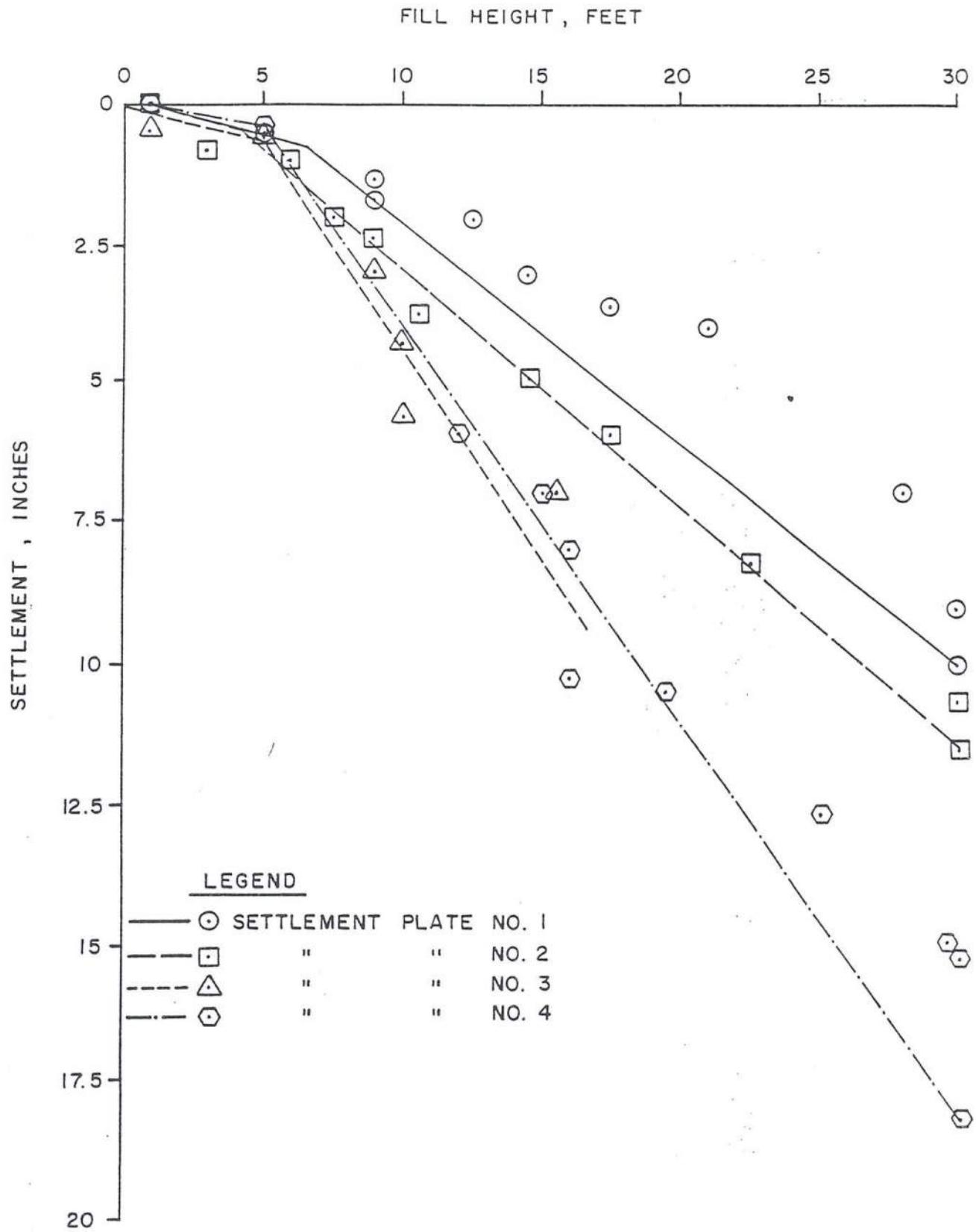
FIGURE 14BB



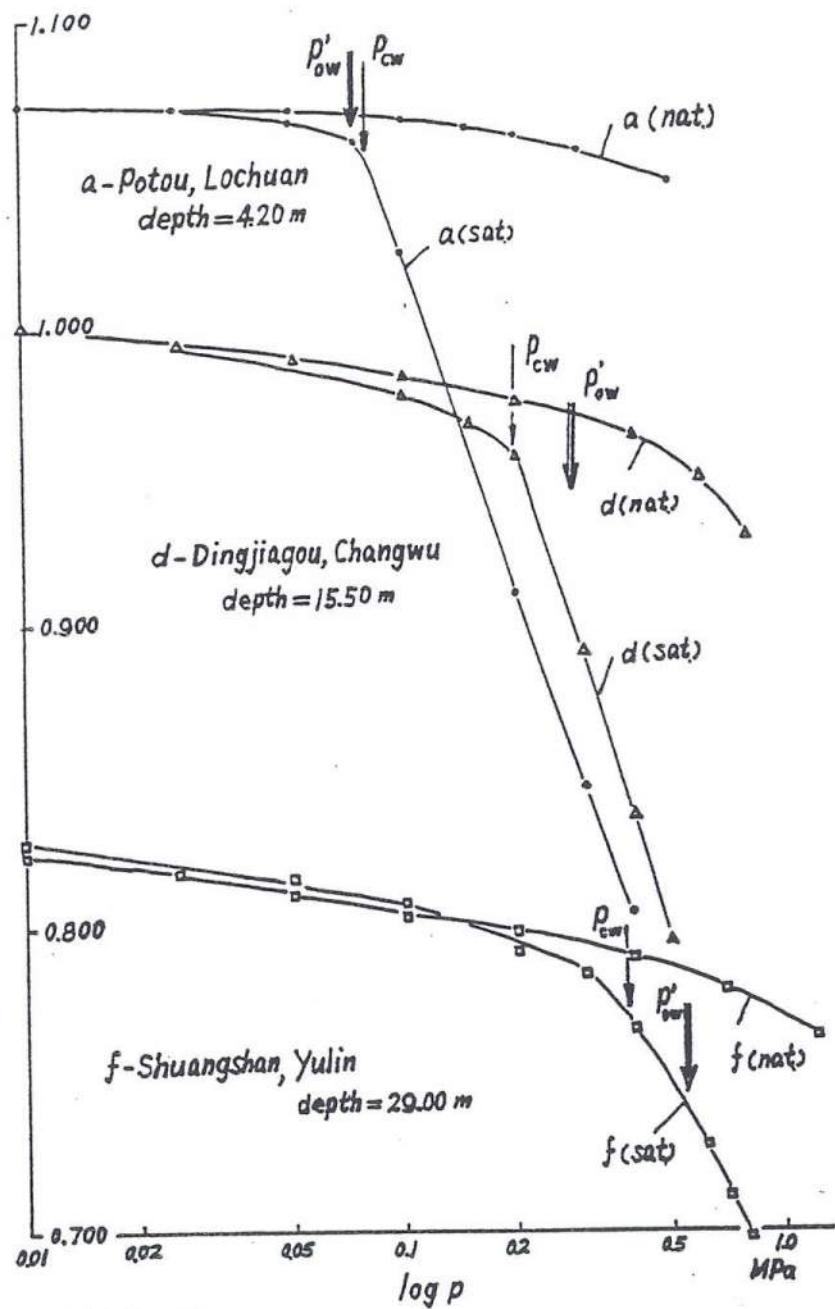
Correlation between the unconfined compressive strength q_u and the "preconsolidation pressure" in the natural state.

FROM LIN AND WANG, 1988

FIGURE 14C

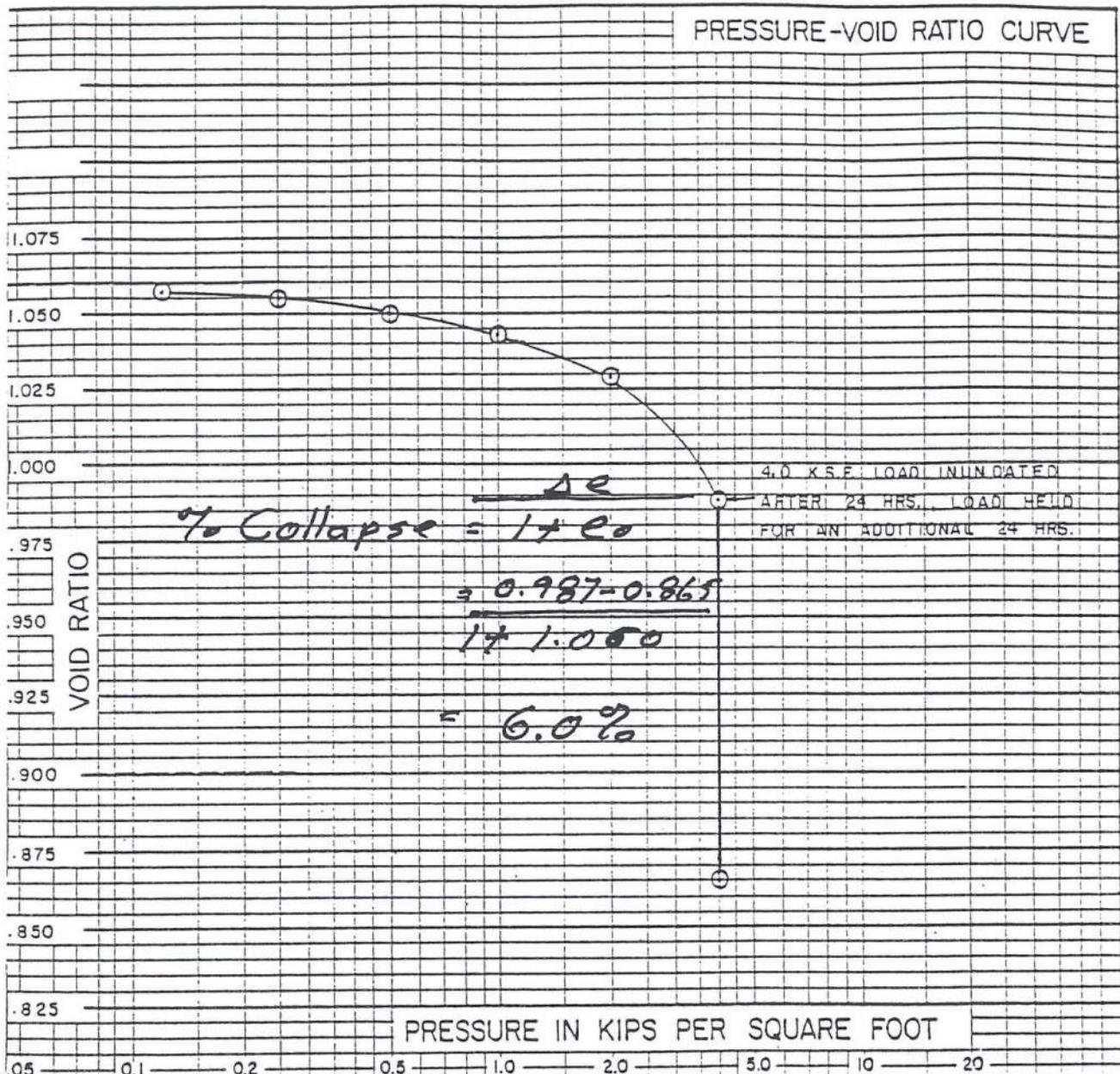


SETTLEMENT OF EMBANKMENT ON SATURATED PEORIAN LOESS
OMAHA, NEBRASKA



CONSOLIDATION OF LOESS IN NATURAL AND SATURATED STATES

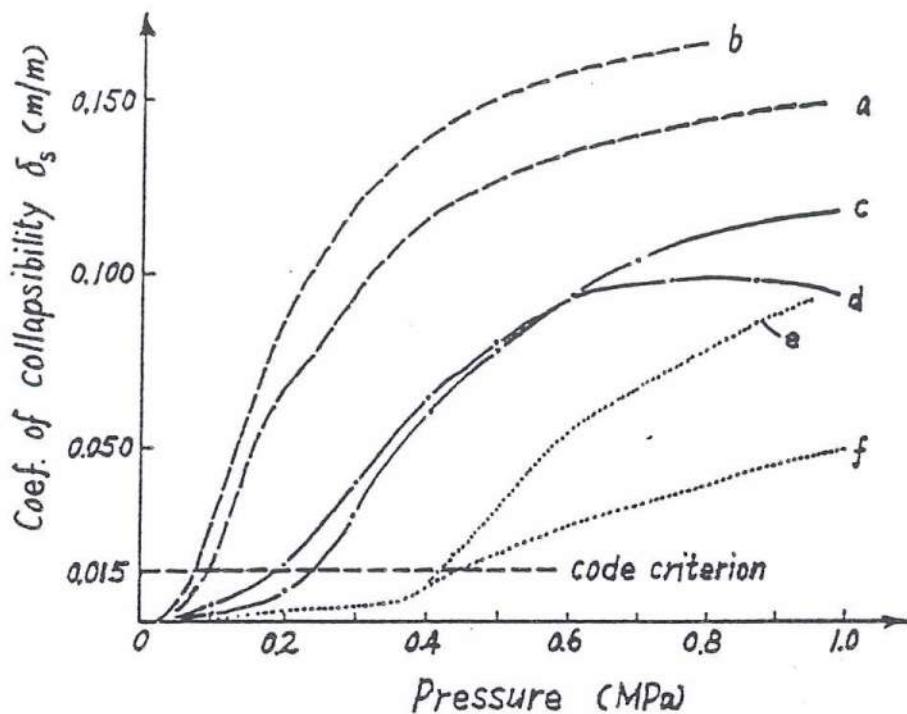
FROM LIN AND WANG, 1988



PROPERTIES OF CONSOLIDATION SPECIMEN

DIAMETER OF SPECIMEN, in.	1.930	INITIAL VOID RATIO, SHOWN THUS	1.060
INITIAL THICKNESS OF SPECIMEN, in.	1.00	FINAL VOID RATIO, SHOWN THUS	.900
INITIAL WATER CONTENT, %	17.9	PROBABLE PRECONSOLIDATION STRESS, ksf SHOWN THUS	P_c
FINAL WATER CONTENT, %	32.2	EXISTING OVERBURDEN STRESS, ksf SHOWN THUS	P_o
INITIAL DEGREE SATURATION, %	44.7	COMPRESSION INDEX, C_c	-
FINAL DEGREE SATURATION, %	94.9	REBOUND INDEX, C_r	-
INITIAL DRY DENSITY, pcf	80.3	WILLOW CREEK DAM	
UNIFIED CLASSIFICATION	CL	PIERCE, NEBRASKA	
LIQUID LIMIT, %	36	WOODWARD - CLYDE CONSULTANTS	
PLASTIC LIMIT, %	21	CONSULTING ENGINEERS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS	
PLASTICITY INDEX, %	15	CENTRAL REGION	
LIQUIDITY INDEX	-0.20	DRAWN BY: S.C.R. CHECKED BY: K.H.N.	PROJECT NO. M81-38
INDICATED SPECIFIC GRAVITY	2.65	CONSOLIDATION TEST BORING NO.: III DEPTH: 2	

FIGURE 16



LEGEND

CURVE	DEPTH, (METERS)
a	4.2
b	2.5
c	16.3
d	15.5
e	28.7
f	29.0

$$\delta_s = \frac{\text{CHANGE IN HEIGHT ON SATURATION}}{\text{ORIGINAL HEIGHT}}$$

1.0 MPa = 20.9 ksf

COLLAPSE OF LOESS FROM
VARIOUS DEPTHS IN CHINA

FROM LIN AND WANG, 1988

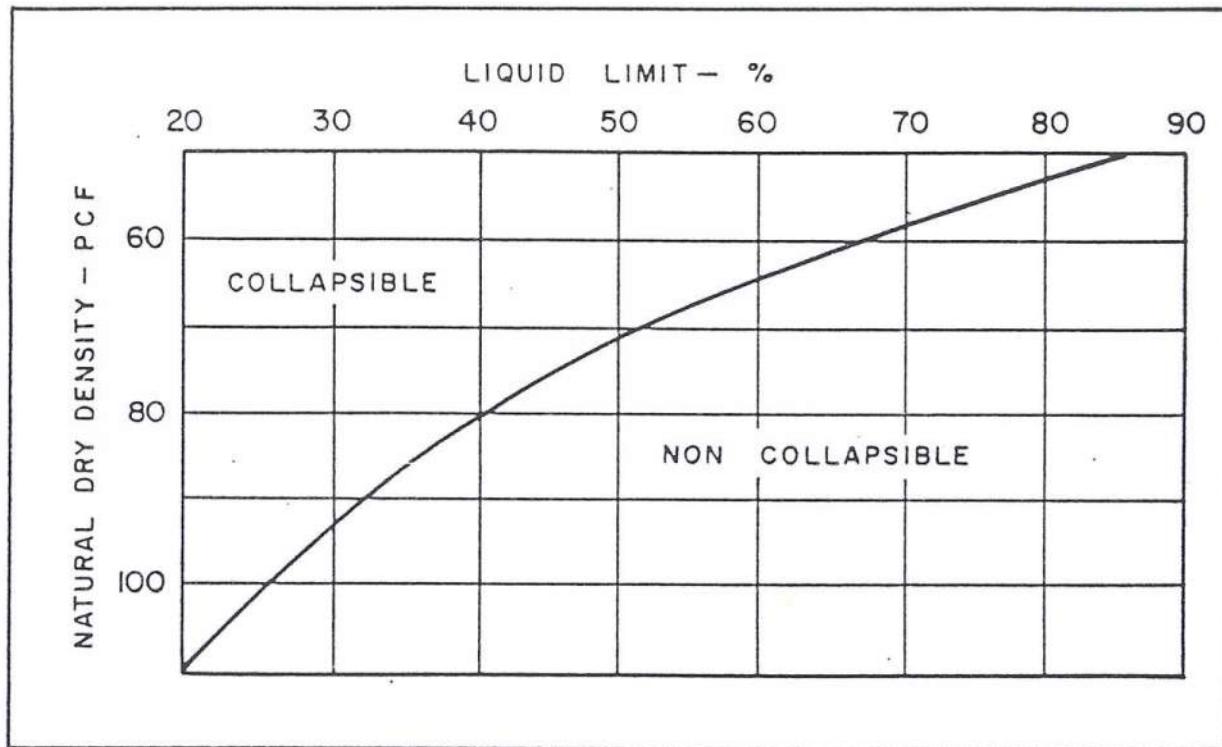
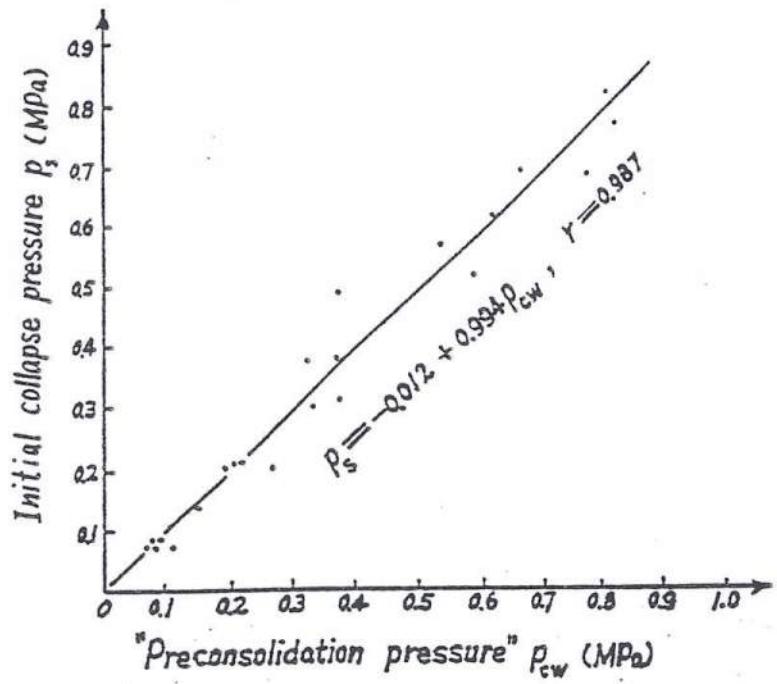
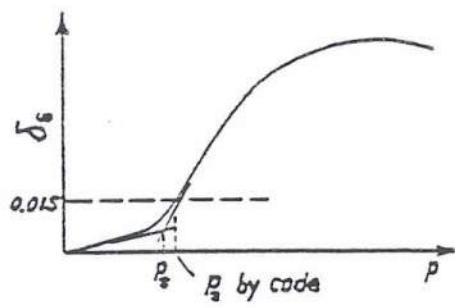


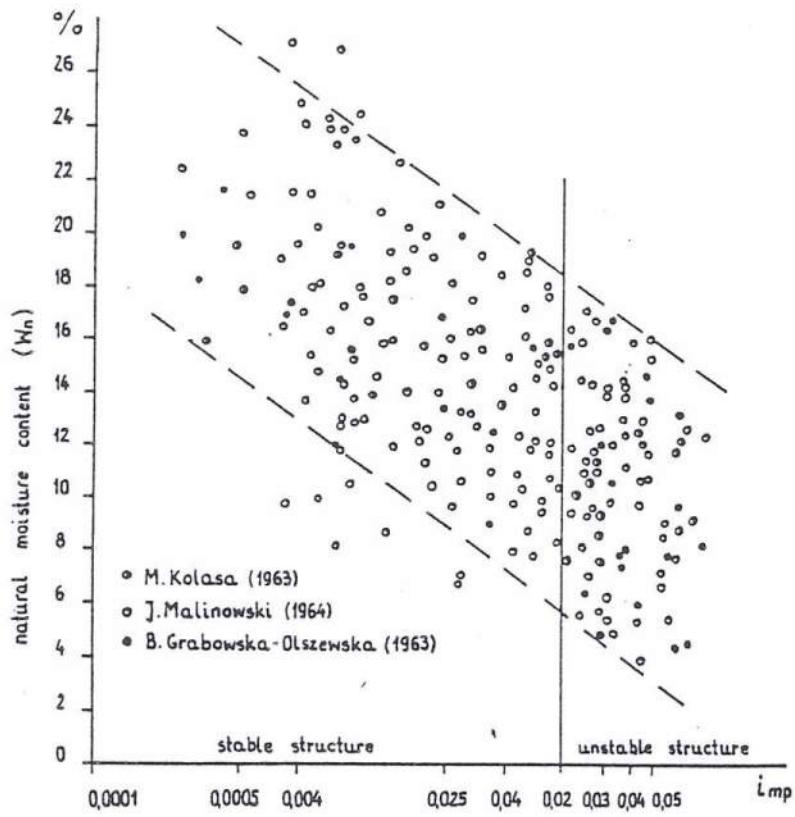
FIGURE 5
Criterion for Collapse Potential

FROM DEPARTMENT OF THE NAVY (DM7.1), 1982



Initial collapse pressure vs. "preconsolidation pressure" in saturated state.

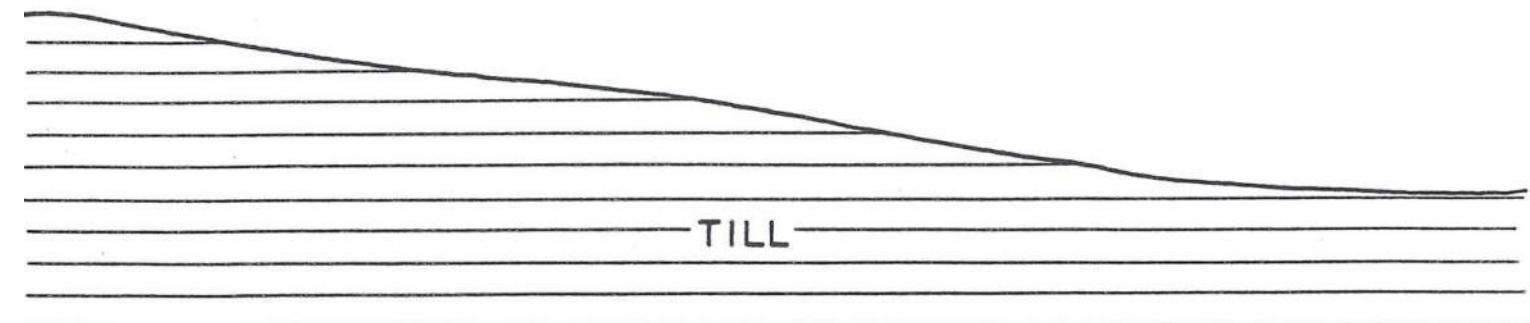
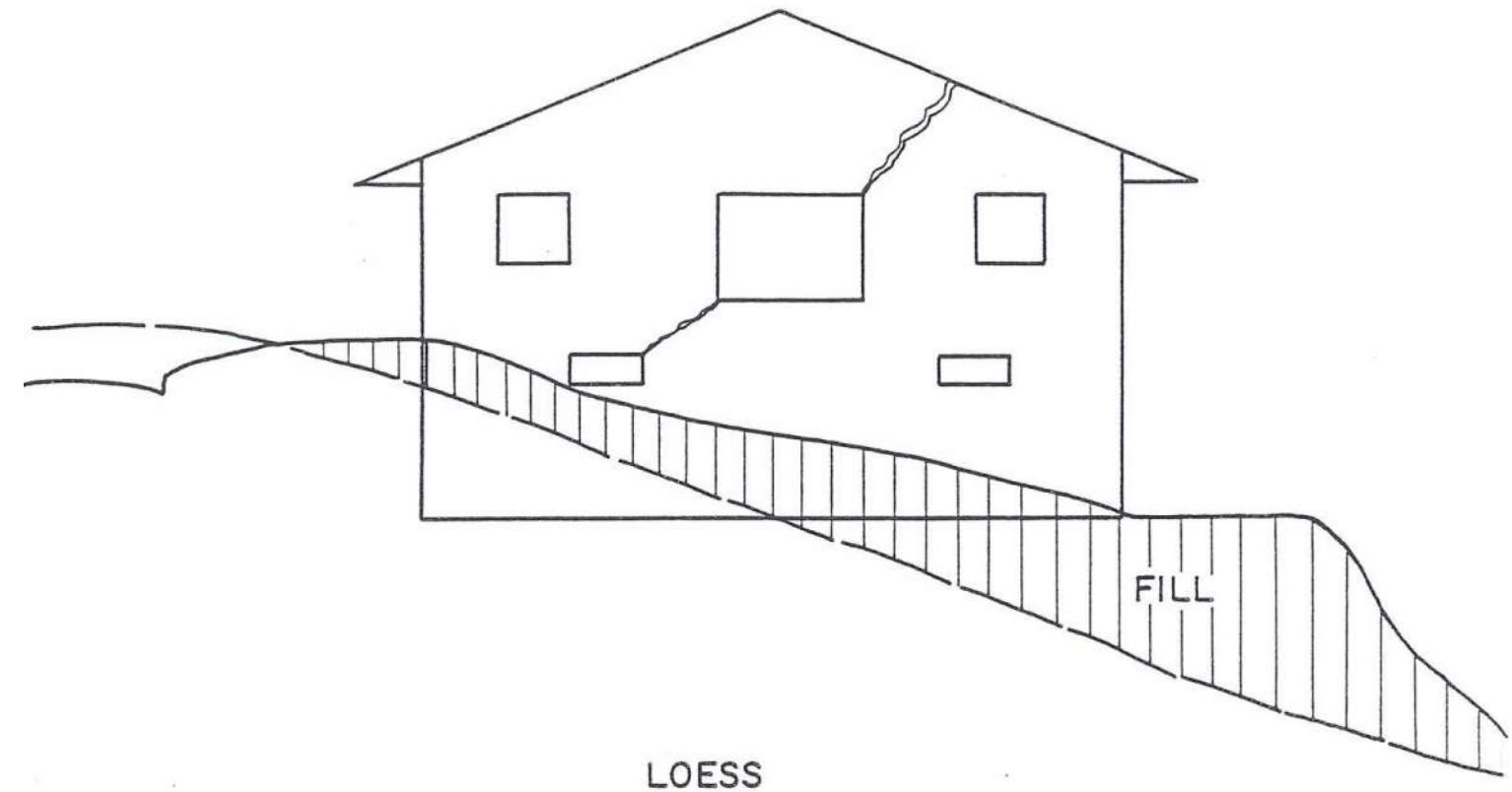
FROM LIN AND WANG, 1988



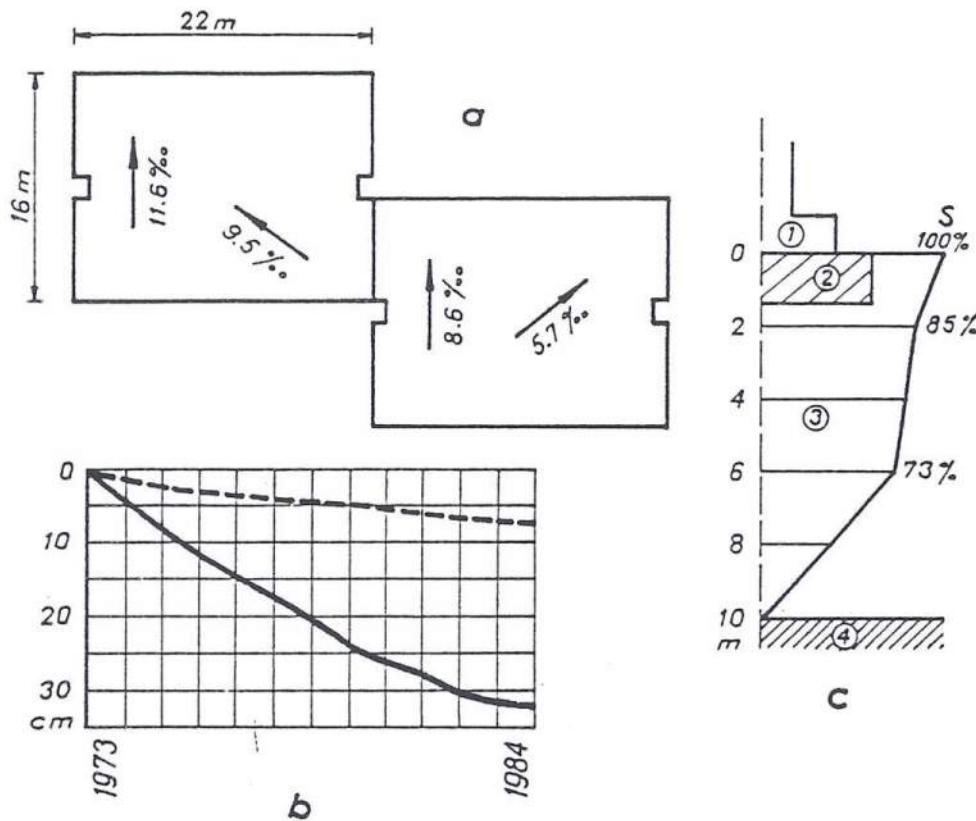
Interrelation between the collapsing coefficient (i_{mp}) of loess deposits and their natural moisture content (W_n).

$$i_{mp} = \frac{\text{CHANGE IN HEIGHT ON SATURATION}}{\text{ORIGINAL HEIGHT}}$$

FROM GRABOWSKA-OLSZEWSKA, 1988

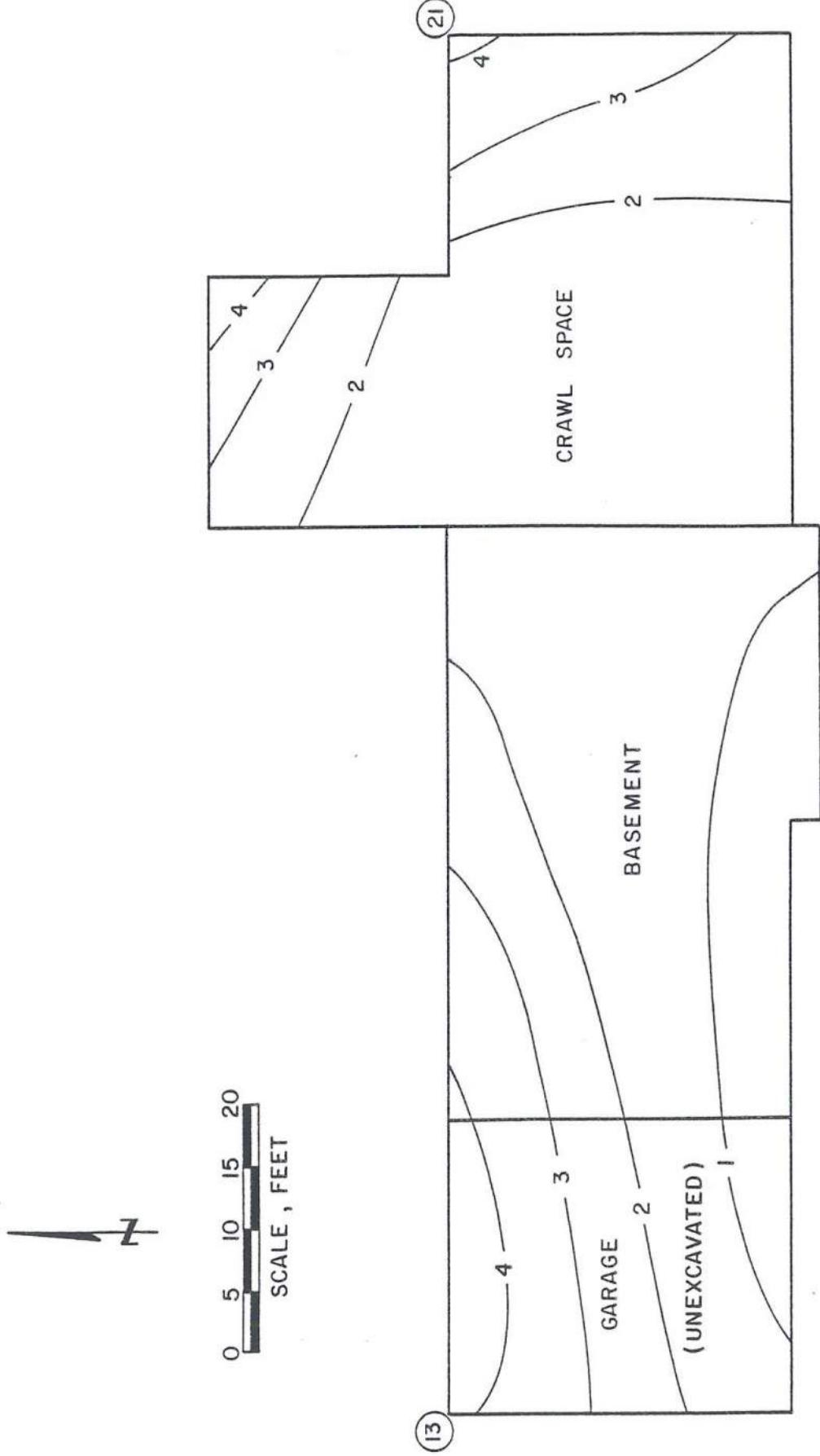


DIFFERENTIAL LOADING
CAUSED BY SIDEHILL DEVELOPMENT



An eleven story dwelling block with long-term settlements mainly due to long-term deformation of deep wetted loess strata: (a) representative tilting after 12 years of measurements; (b) maximal and minimal settlements of marks on the building; (c) percentage settlement distribution in depth, during a 34 month period (1. foundation; 2. compacted loess cushion; 3. natural loess; 4. clay).

FROM BALLY, 1988



DISTRESSED HOUSE SETTLEMENTS

FIGURE 17AA

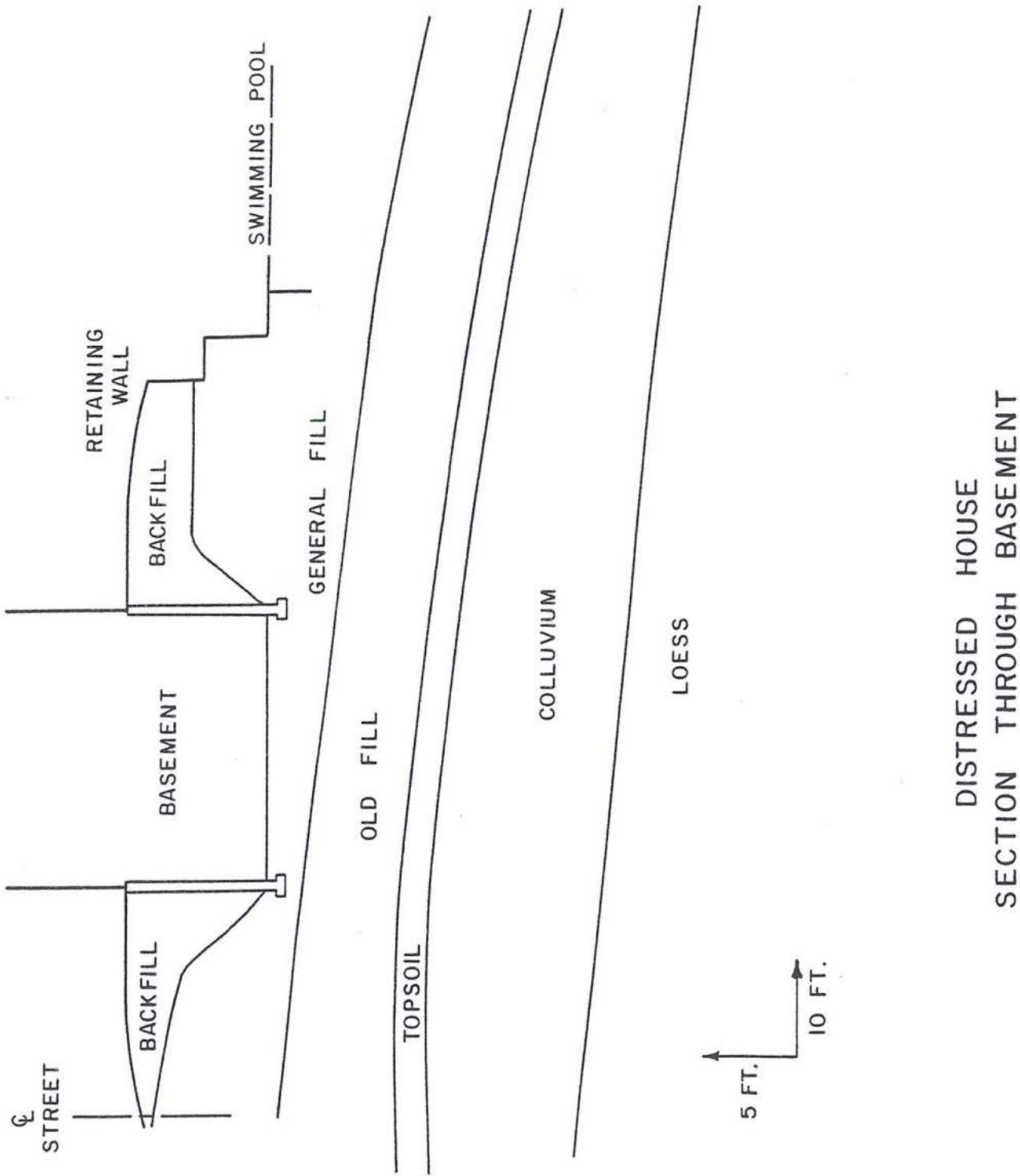


FIGURE I7AB

DISTRESSED HOUSE
LONGITUDINAL SECTION

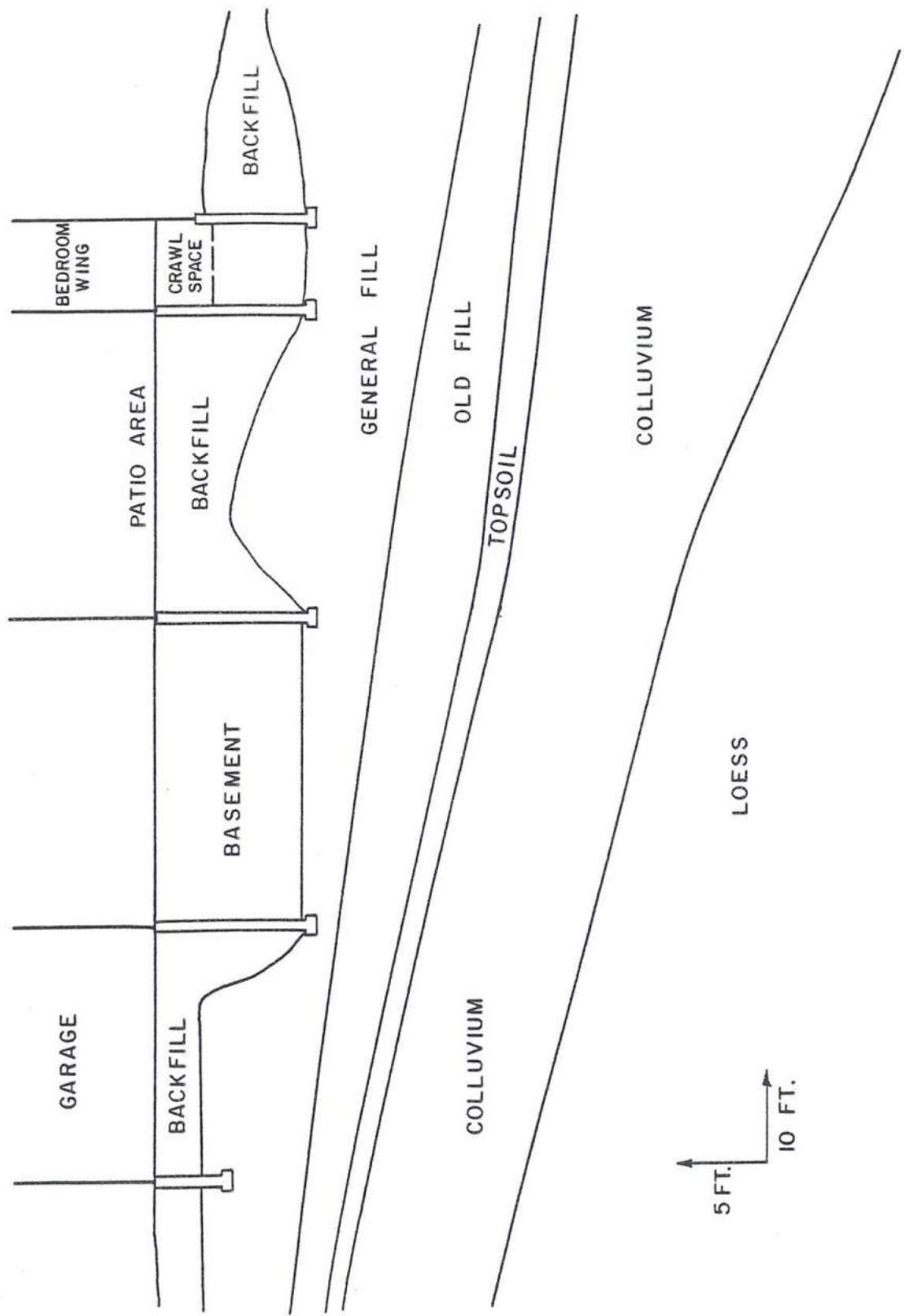
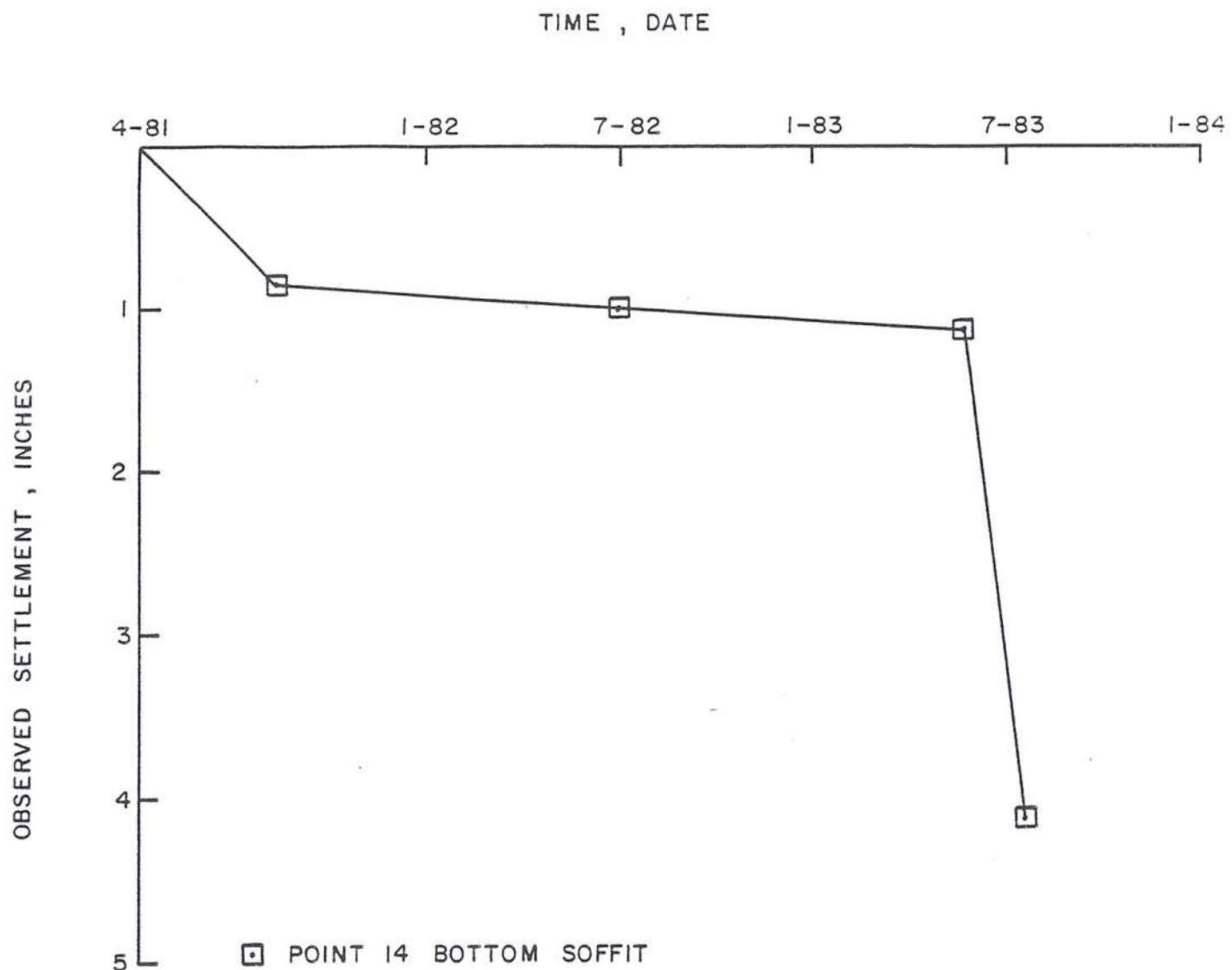
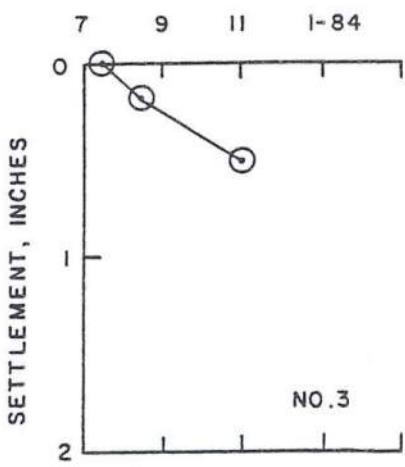
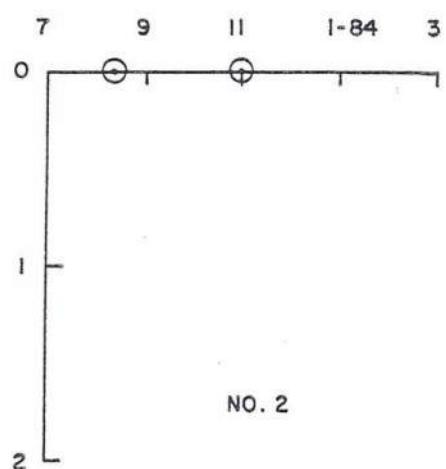
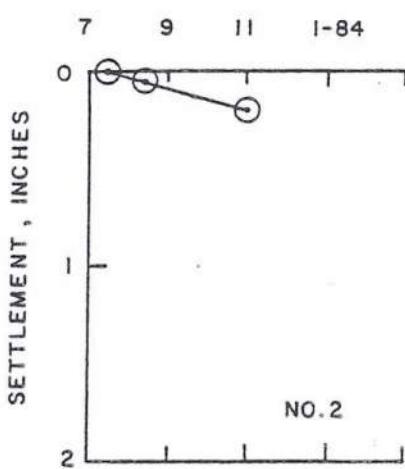
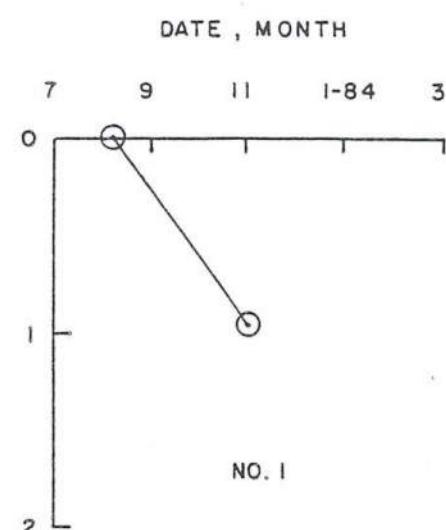
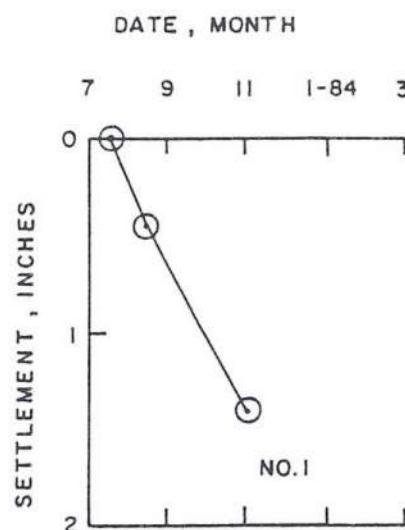


FIGURE I7AC

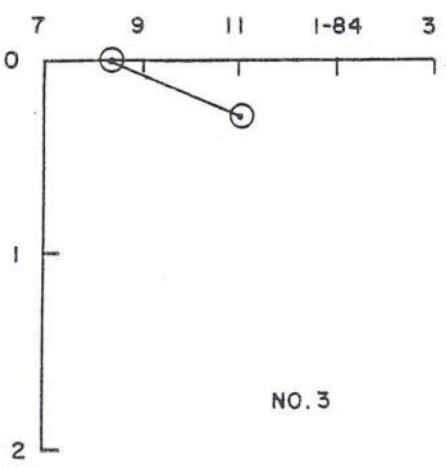


DISTRESSED HOUSE
SETTLEMENT OF POINT 21

FIGURE I7AD

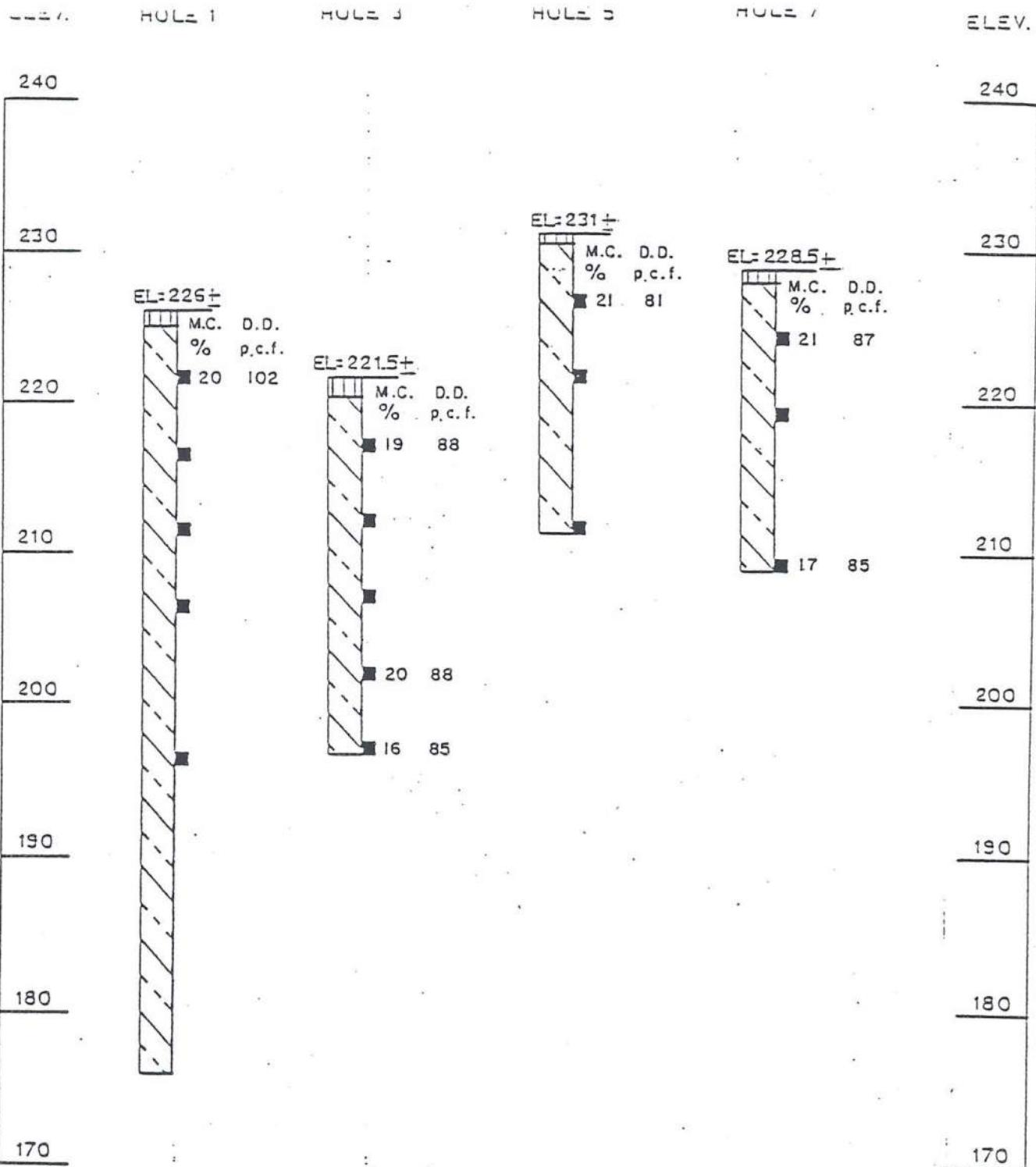


TELLTALE



DISTRESSED HOUSE
TIME - SETTLEMENT CURVES

FIGURE 17AE



Clay, silty, dark brown, organic topsoil, stiff.



Clay, silty, light brown to light gray and reddish-brown, stiff to very stiff, loess.

JULY 20

S.P. NO.

S.P. NO. 2

S.P. NO. 3

APRIL 21

FILL HEIGHT, FEET

SETTLEMENT, INCHES

4

1000

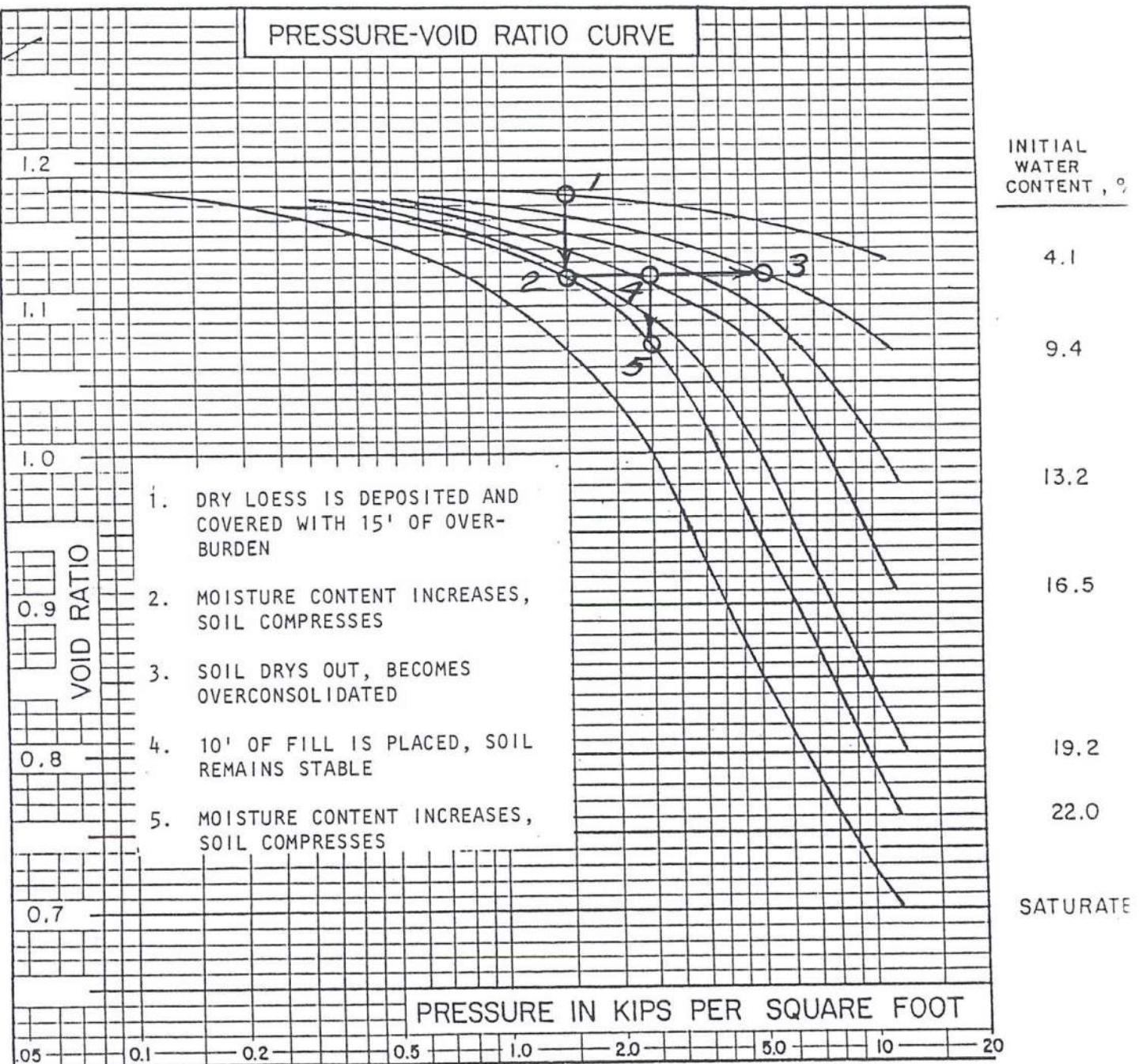
100

10

TRIADENIAN TIME HAVE

HIGH SCHOOL, PAVILLION, NEBRASKA

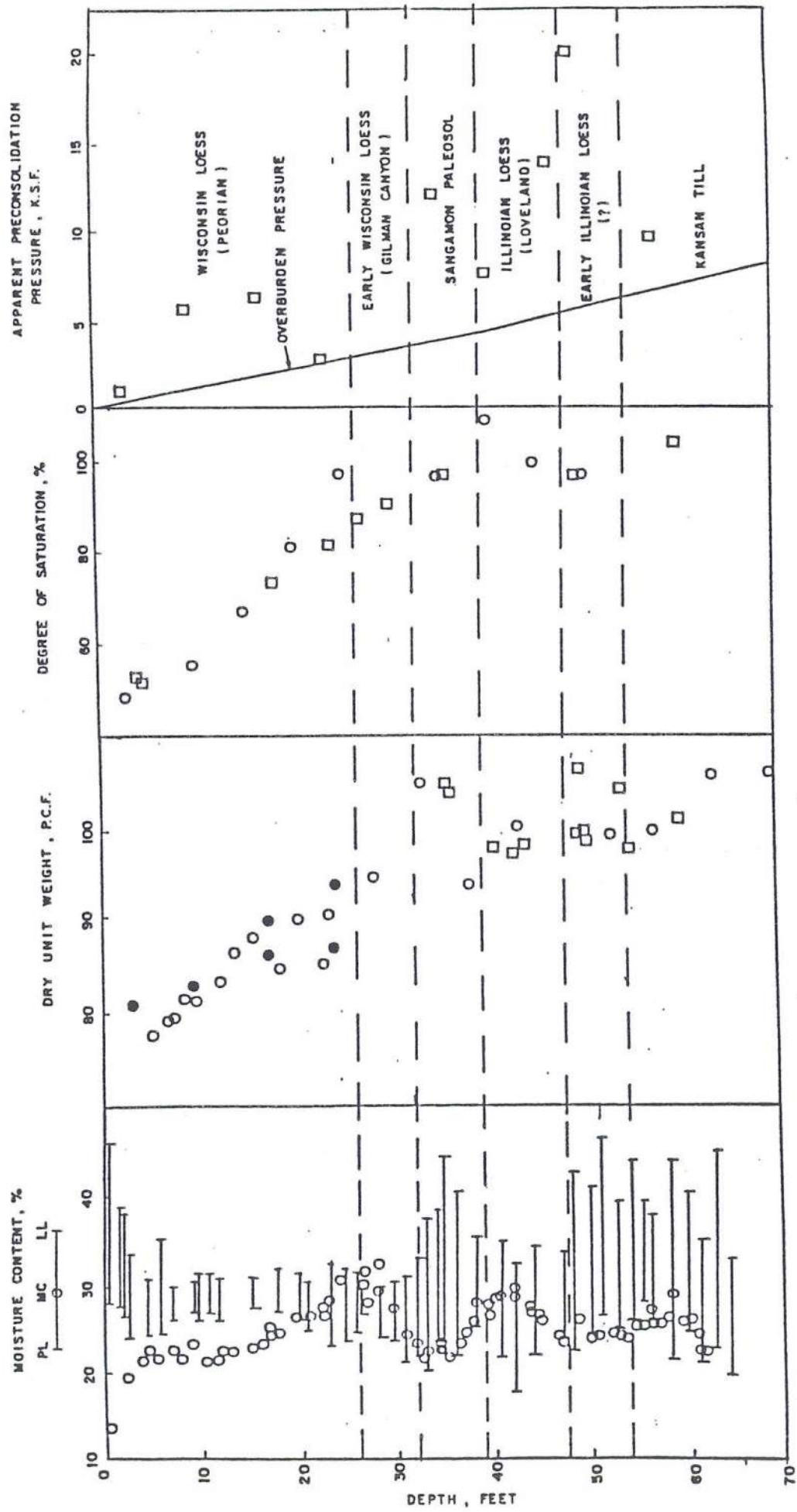
FIGURE 17C



COMPRESSION OF LOESS AT DIFFERENT WATER CONTENTS

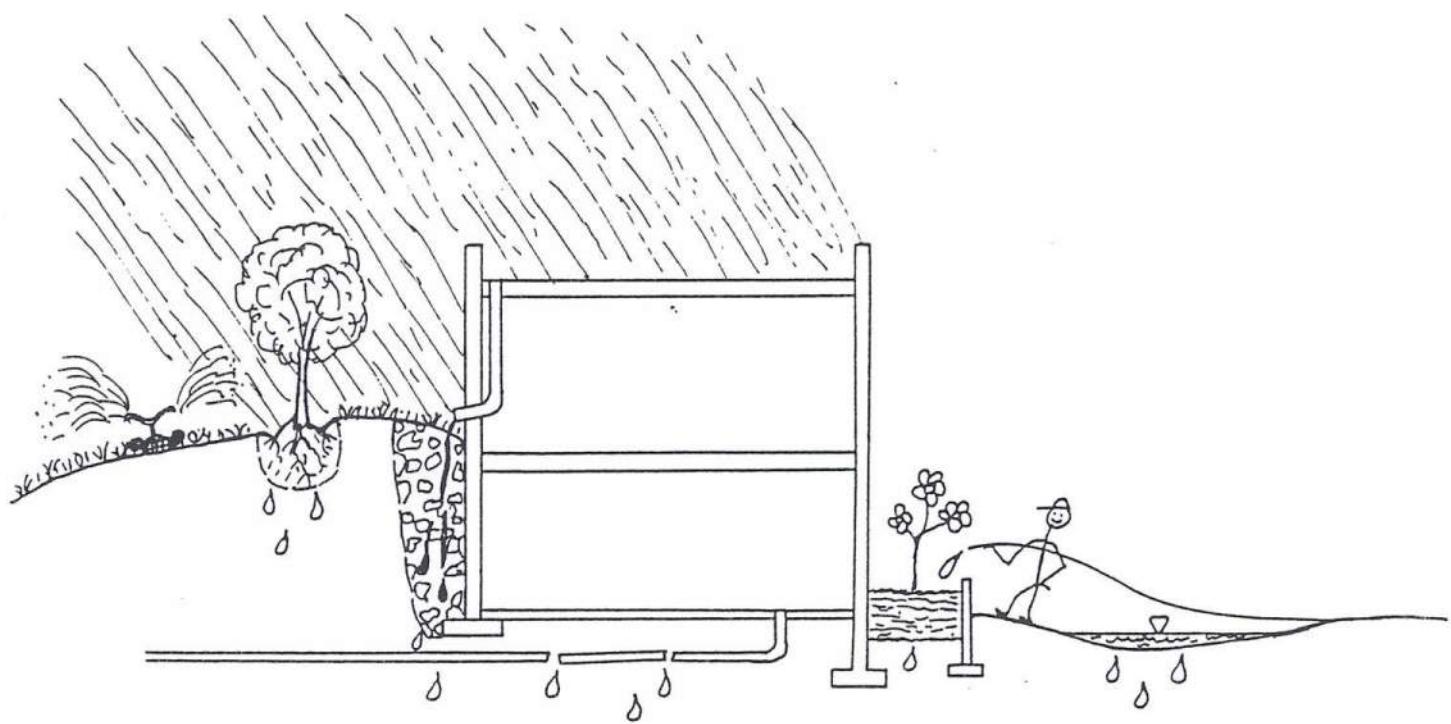
INITIAL DRY UNIT WEIGHT = 78 LB./FT.³

REPLOTTED FROM MILOVIC

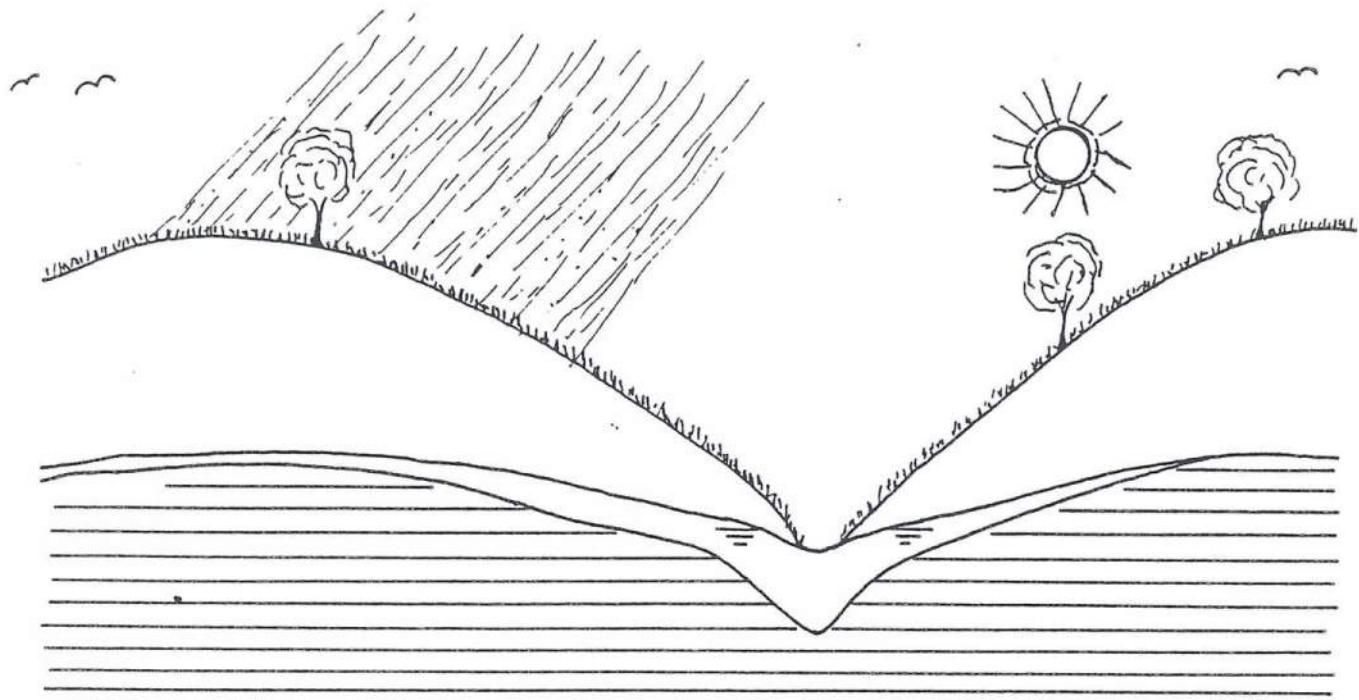


WATER TANK SITE
OMAHA, NEBRASKA

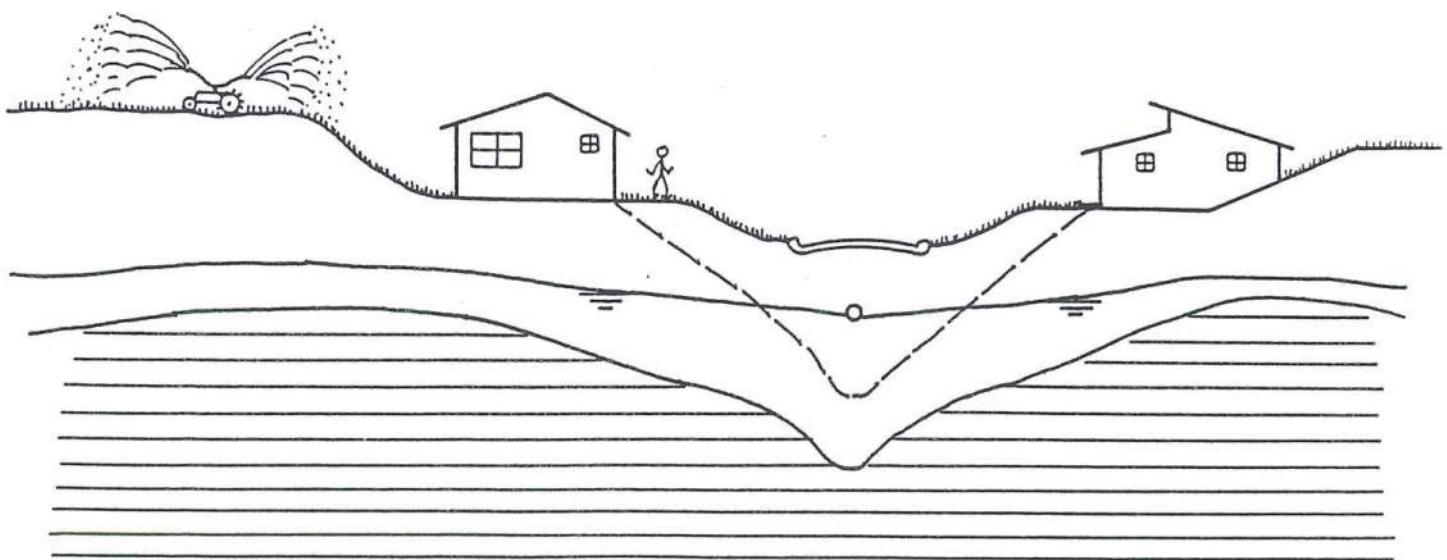
FIGURE 17E



LOCALIZED SOURCES OF INFILTRATION



UNDEVELOPED



WATER TABLE RISE CAUSED BY DEVELOPMENT

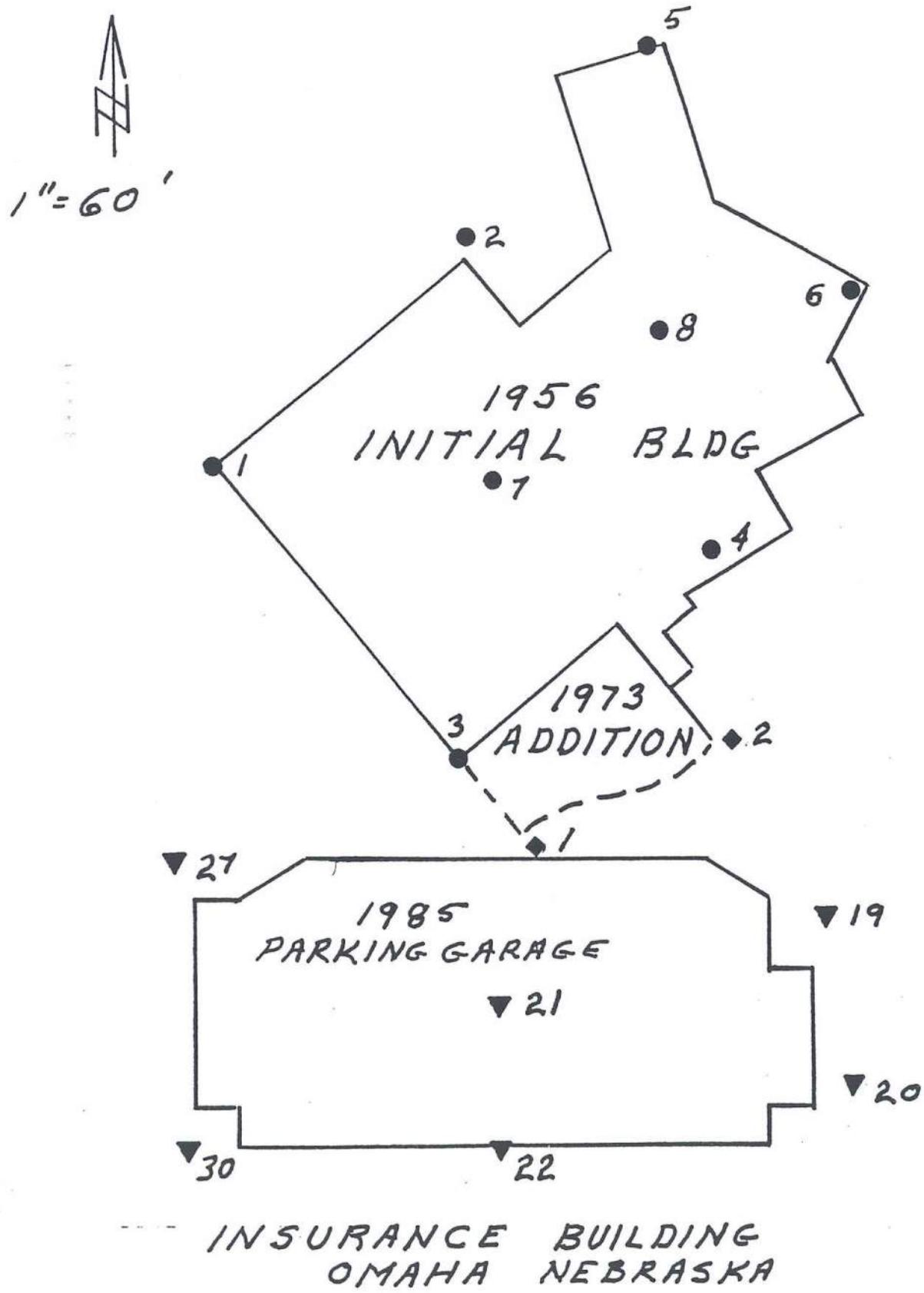
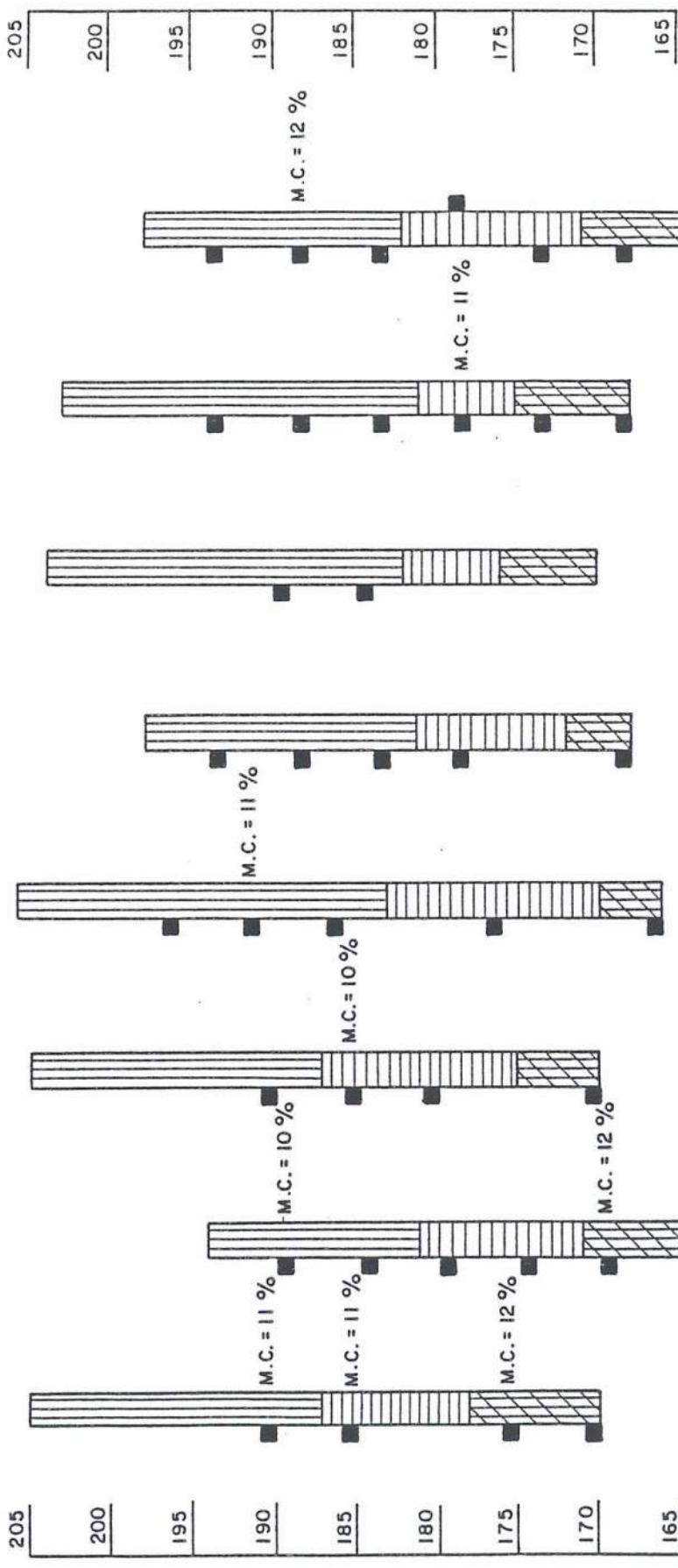


FIGURE 17H

DEPTH, FEET HOLE 1 HOLE 3 HOLE 7 HOLE 2 HOLE 4 HOLE 8 HOLE 5 HOLE 6



SILT, DRY AND FIRM, CONTAINS LARGE POCKETS OF POROUS MATERIAL THAT SOFTENS WHEN WETTED.

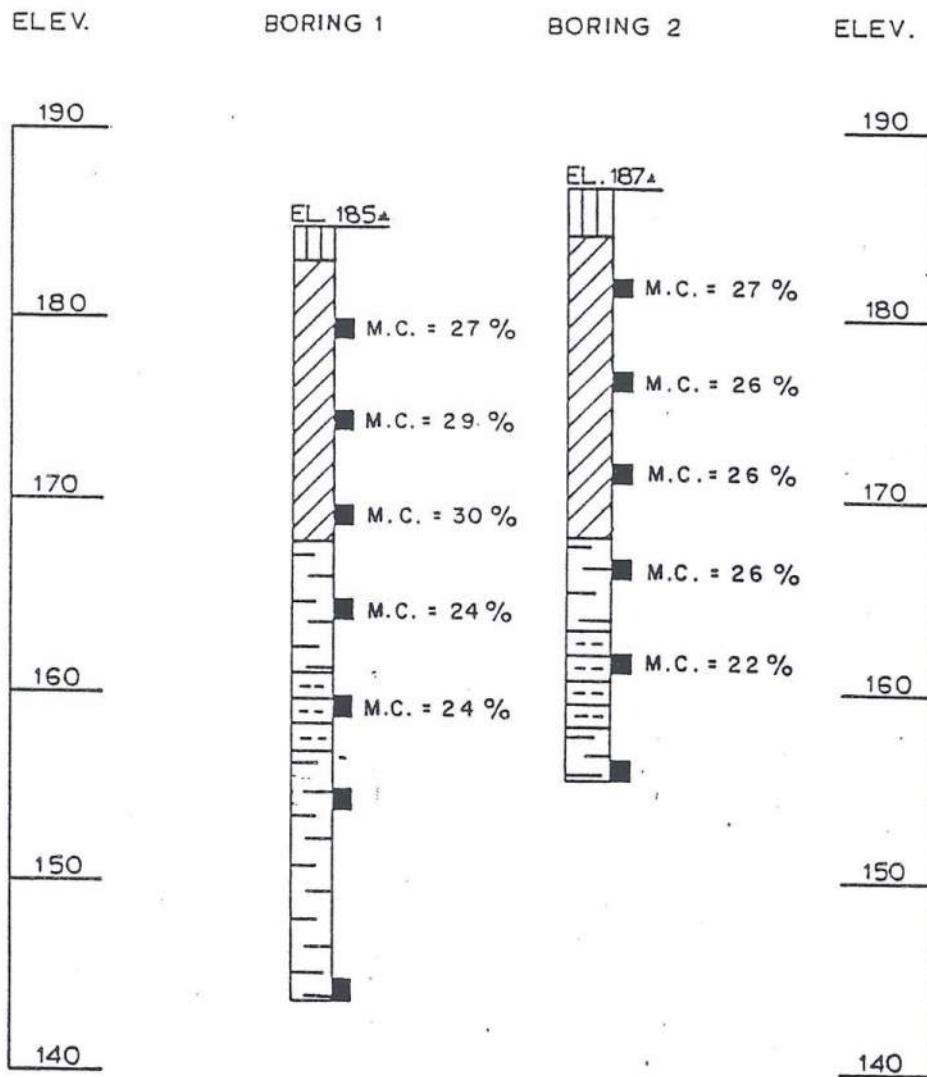


SILT, DRY AND FIRM, DOES NOT SOFTEN WHEN WETTED.



CLAY, SILTY, EXTREMELY STIFF.





CLAY, SILTY, DARK BROWN, MEDIUM PLASTIC, STIFF, WITH ORGANIC MATTER. (CL) (FILL)

CLAY, SILTY, LIGHT BROWN, LOW PLASTIC, FIRM TO STIFF. (CL) (LOESS)

CLAY, SILTY, REDDISH-BROWN, MEDIUM TO HIGHLY PLASTIC, STIFF TO VERY STIFF. (CH) (MODIFIED LOESS)

CLAY, DARK REDDISH-BROWN, HIGHLY PLASTIC, VERY STIFF TO HARD. (CH) (MODIFIED LOESS)

Note: No water entered the borings during drilling.

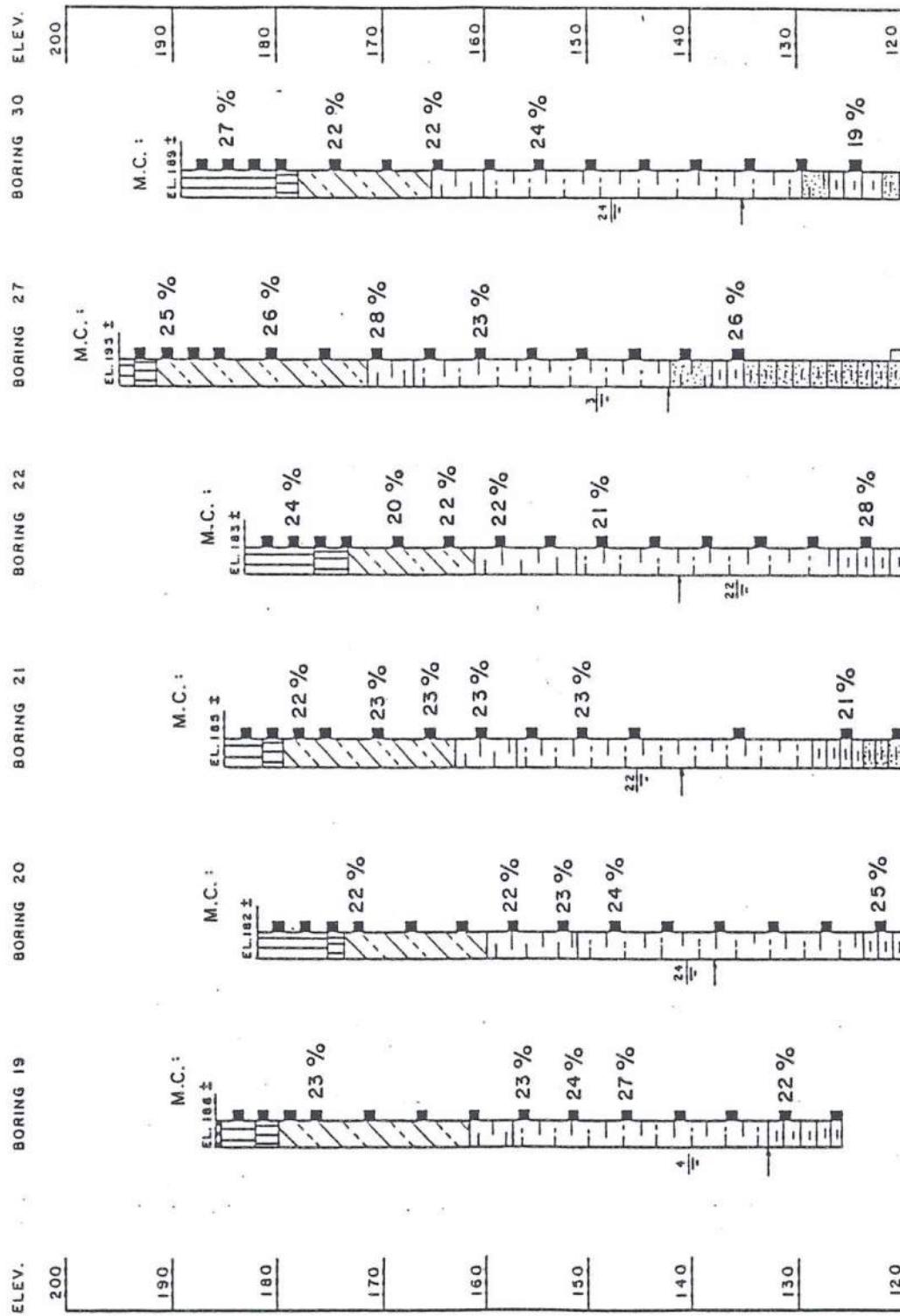
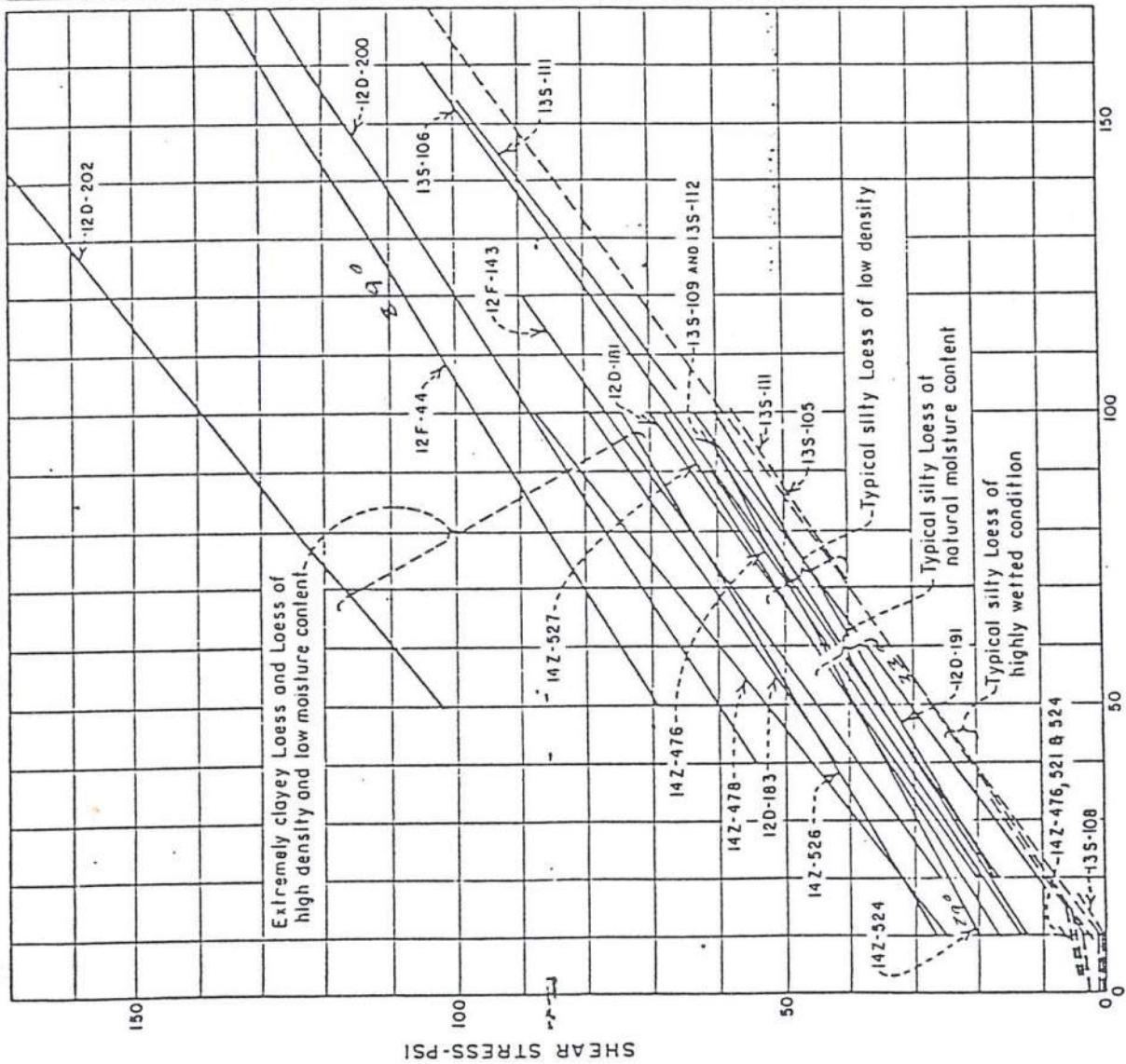


FIGURE 17K

LAB. SAMPLE NO.	TEST CONDITIONS	TYPE OF LOESS	DENSITY MOIST. AT TIME OF TEST	REMARKS
12D-202	NATURAL	CLAYEY	100.2	10.1
12F-44		SILTY	94.1	8.4
12D-200		CLAYEY	84.9	8.6
14Z-476		SILTY	90.2	7.4
12D-183		SILTY	84.2	4.5
12F-143		SILTY	103.5	18.0
14Z-526		CLAYEY	83.1	13.3
12D-161		SILTY	79.1	6.2
14Z-527		SILTY	89.5	6.9
14Z-476		SILTY	63.6	8.6
13S-106		SILTY	69.0	6.0
13S-111		SILTY	81.7	6.5
13S-109		SILTY	63.6	7.3
13S-112		SILTY	81.3	9.5
14Z-524		SILTY	82.0	10.6
12D-191		CLAYEY	76.6	20.3

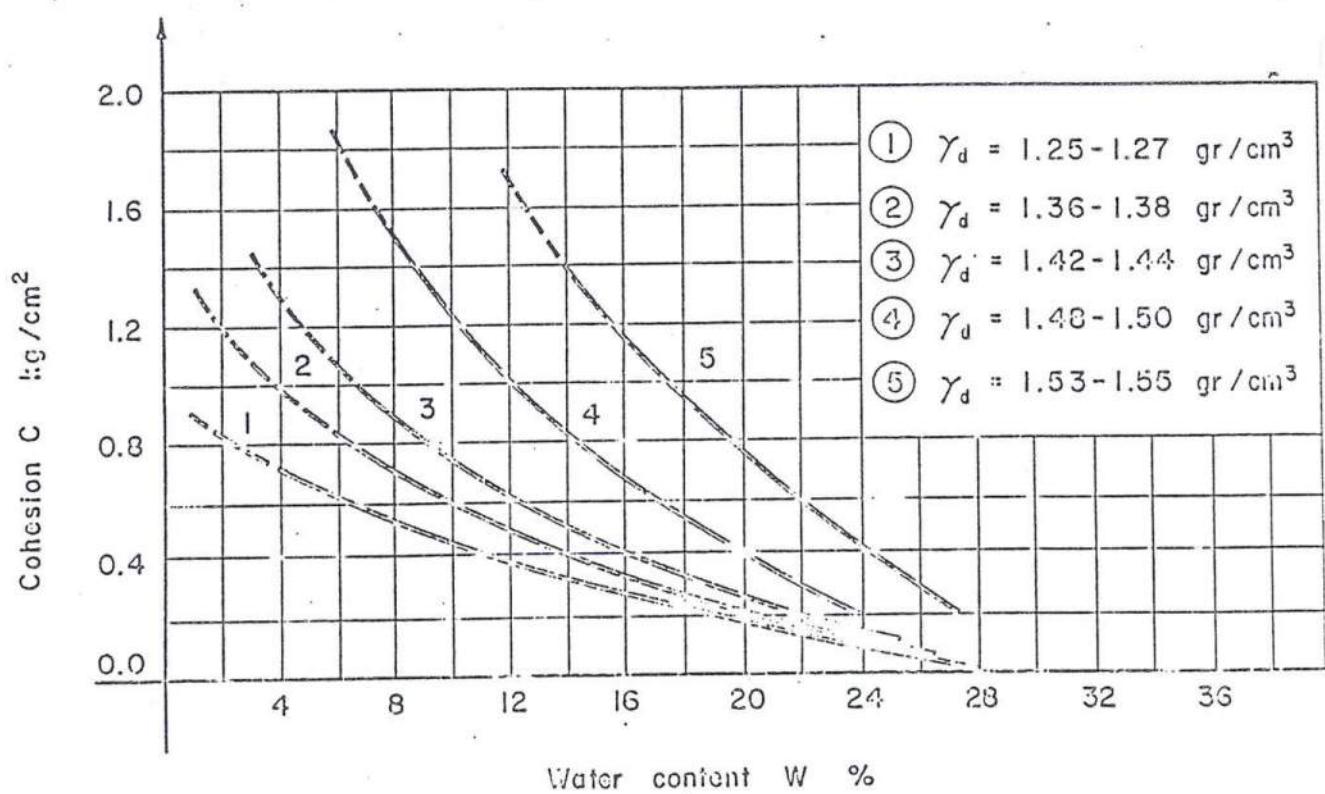
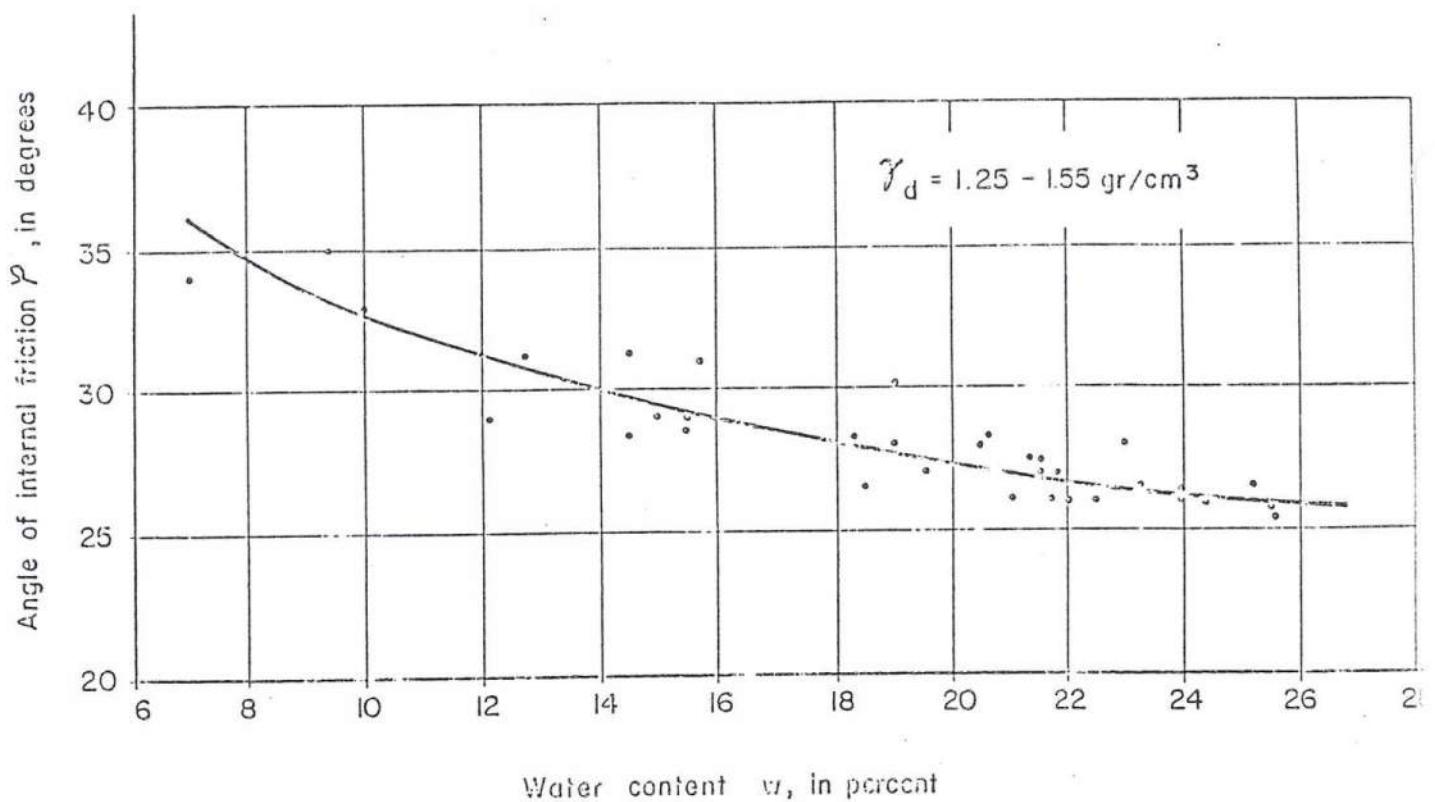


SHEAR TESTS OF REPRESENTATIVE LOESSIAL SOILS

FIGURE 10

FROM GIBBS AND HOLLAND, 1960

FIGURE 18



FROM MILOVIC.

FIGURE 18A

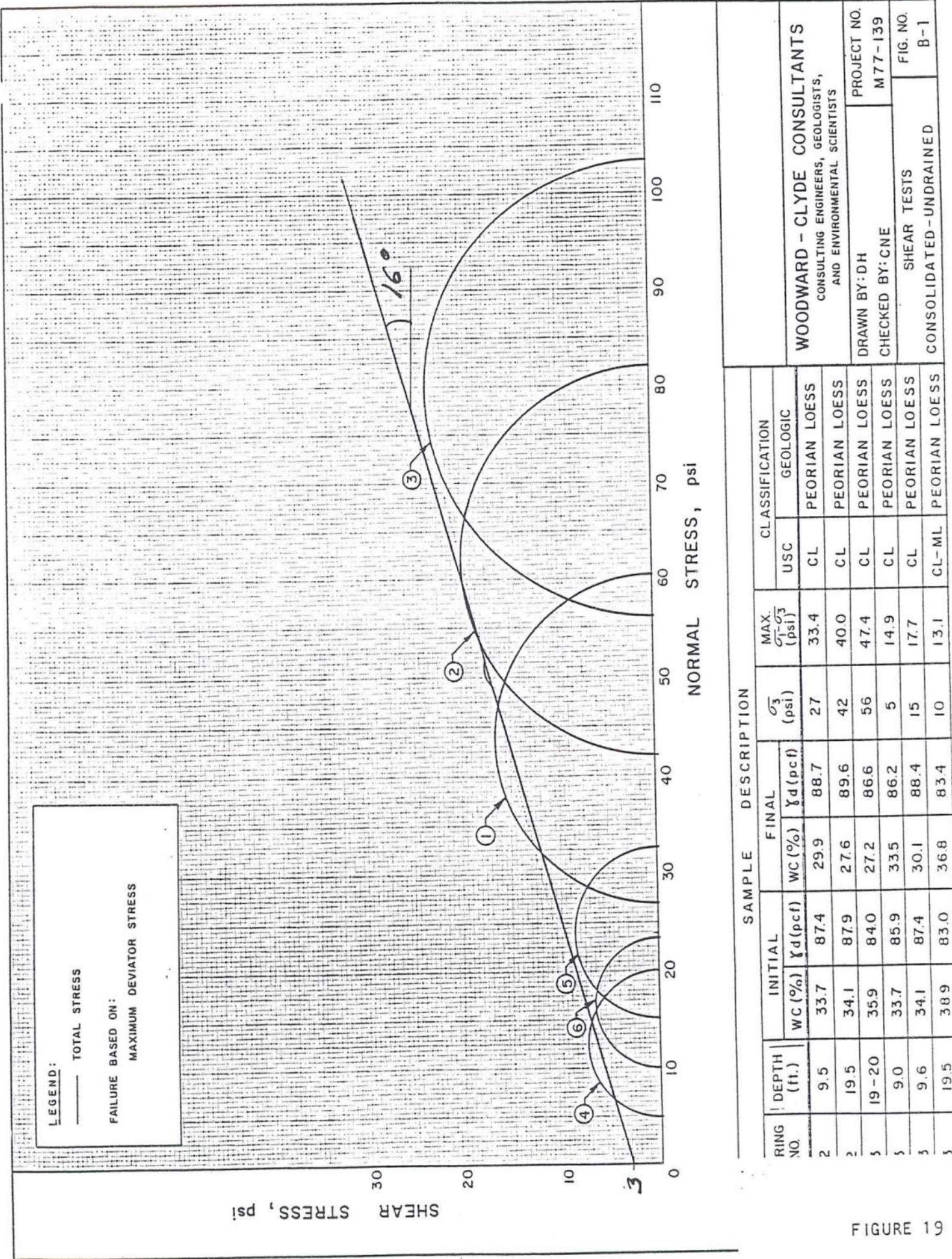
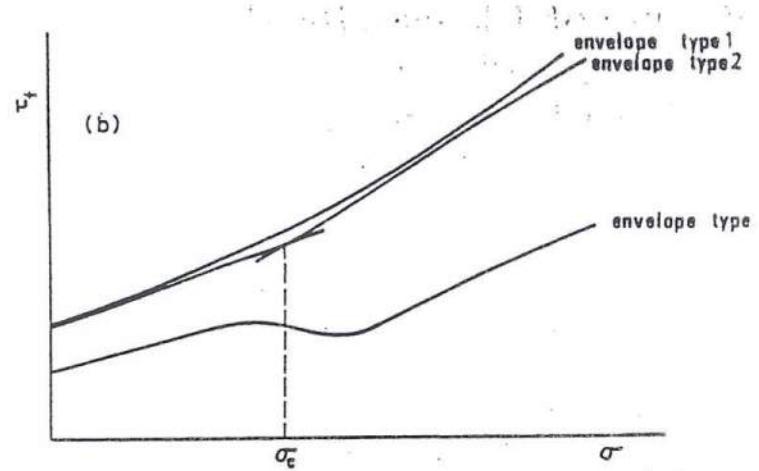
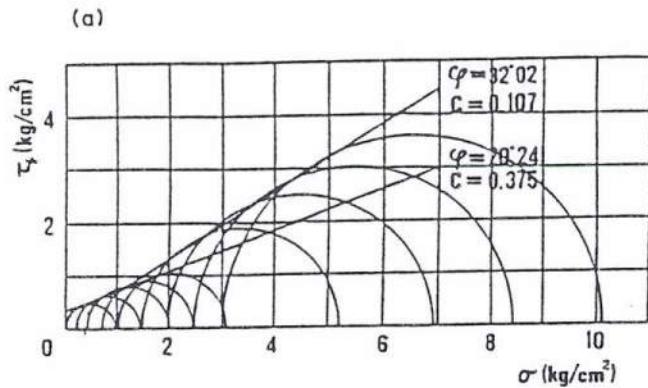
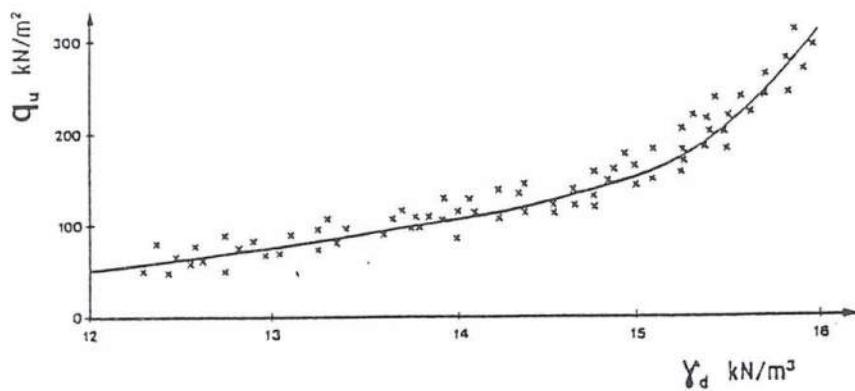


FIGURE 19

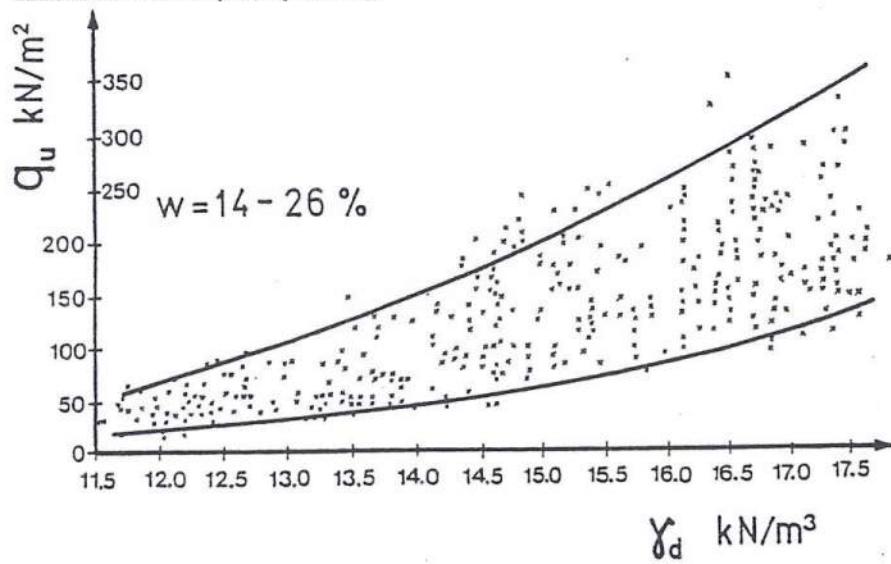


(a). Failure Mohr's circles and envelope from triaxial testing. (b). Failure envelope for loess. Envelope 3 is typical for macroporous unsaturated loess at high water contents.

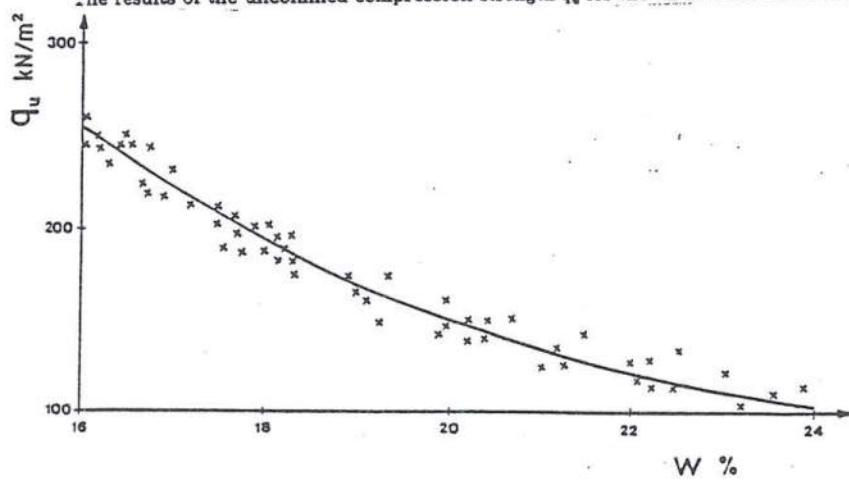
FROM TAN TJONG KIE, 1988



Relationship between the unconfined compression strength q_u and dry density γ_d for the undisturbed loess samples; $w_s = 22-24\%$.



The results of the unconfined compression strength q_u for the undisturbed loess samples.

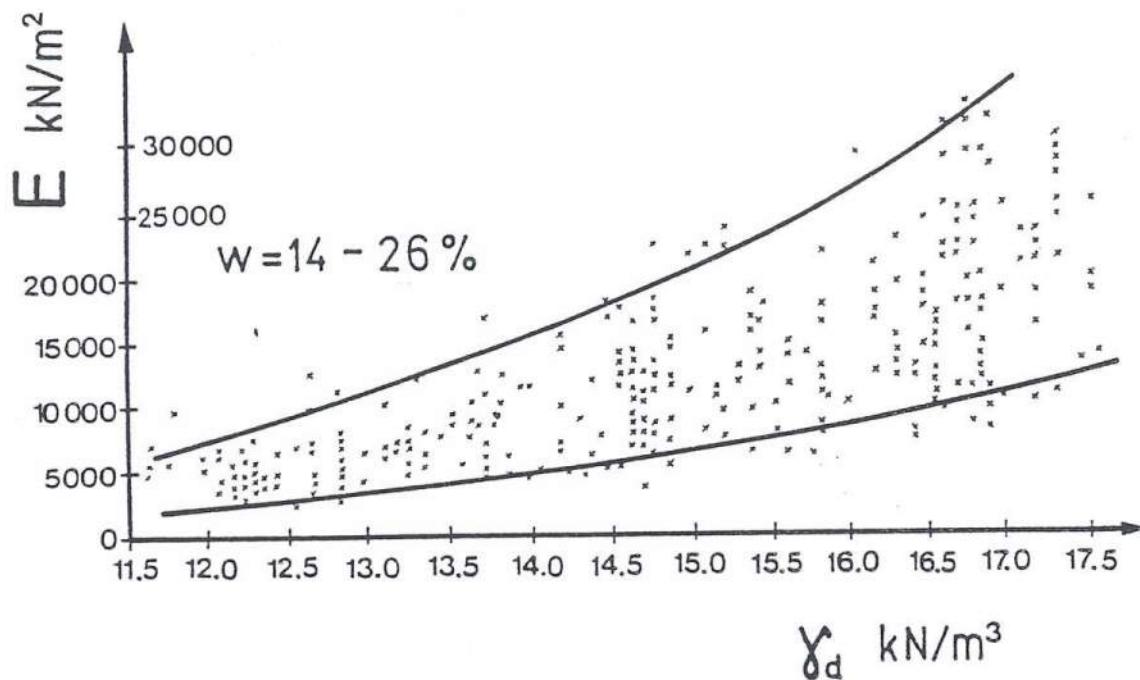


Relationship between the unconfined compression strength q_u and water content w for the undisturbed loess samples; $\gamma_d = 14.6-14.8 \text{ kN/m}^3$.

UNCONFINED COMPRESSIVE STRENGTH OF YUGOSLAV LOESS

FROM MILOVIC, 1988

FIGURE 19B



Modulus of deformation E , determined from the unconfined compression tests, for the undisturbed loess samples.

FROM MILOVIC, 1988

Table 5

Sample Size Score Sheet and Statistics

Dry Density (lb/ft ³)	Nominal I.D.	Sand Cone Method Hand Exc. Pit	Method of Obtaining Specimens					
			Trimmed 2 7/8" Tube Pushed	4 1/2" Tube Pushed	3" Tube Pushed	2 1/2" Tube Pushed	2" Tube Pushed	2 1/2" Split Spoon Driven
72.0-73.9	-	-	-	4 1/4"	2 7/8"	2 3/8"	1 7/8"	1 3/4"
74.0-75.9	2							
76.0-77.9	11		5	1				
78.0-79.9	14	5	5					
80.0-81.9	2		5					
82.0-83.9			3	3				
84.0-85.9			3	1				
86.0-87.9			1	1	1			
88.0-89.9						1	1	
90.0-91.9					1	2		
92.0-93.9					2	1	1	
94.0-95.9						1	3	2
96.0-97.9					1	2		1
98.0-99.9						1	3	1
100.0-101.9						2		2
102.0-103.9								1
104.0-105.9								1
106.0-107.9								
108.0-109.9							1	
110.0-111.9								
Mean w.c., %			26.9	22.2	24.1	23.6	23.4	24.0
STATISTICS			No obs.	29	10	9	10	8
SAMPLE			Mean	77.9	78.2	81.3	94.9	95.6
STATISTICS			Range	5.2	3.9	8.5	15.0	-
SAMPLE			Std. Dev.	1.33	1.32	2.54	5.42	10.5
STATISTICS			Coeff. Var.	1.71	1.69	3.12	6.13	4.54
SAMPLE			Std. Errr	0.25	0.42	0.60	1.81	3.42
STATISTICS			Lim. Ac.	95%	0.51	0.95	1.27	4.16
SAMPLE							3.25	2.86

*With 1% Inside clearance

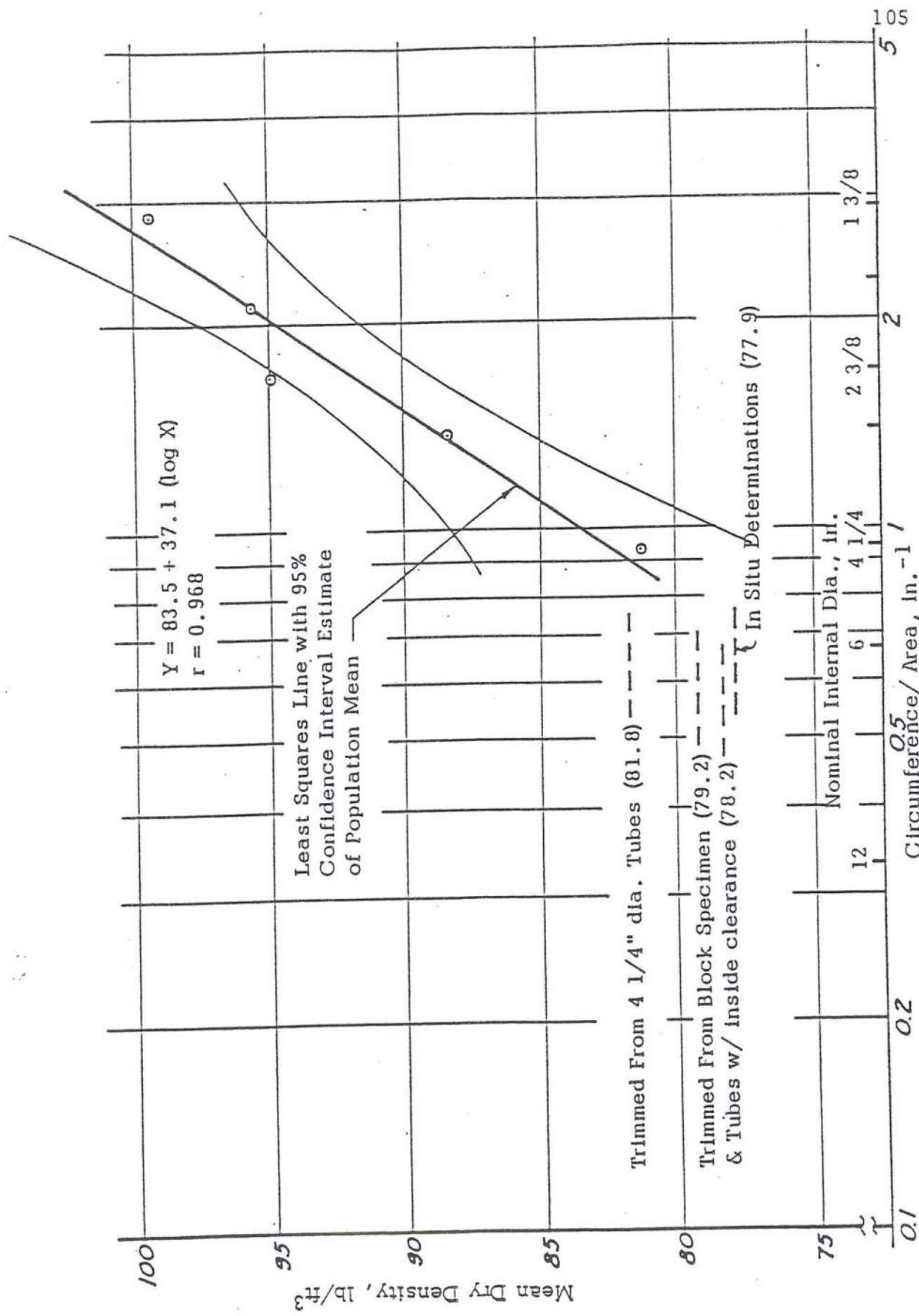
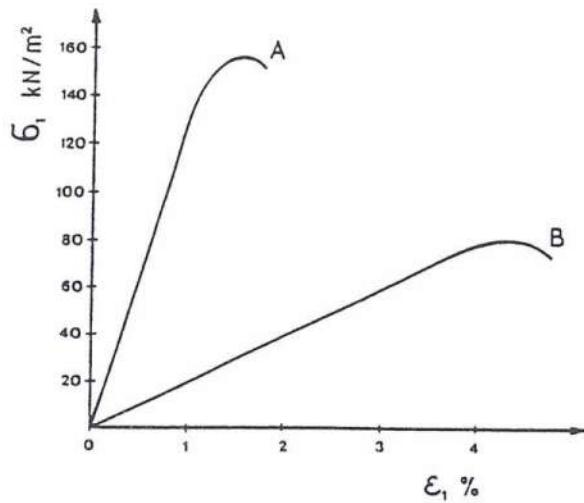
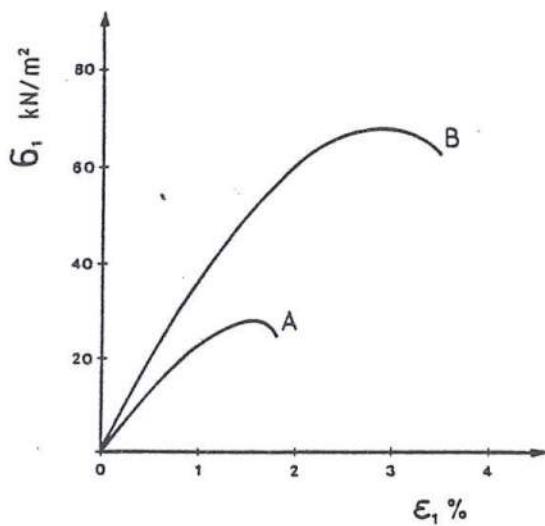


Fig. 9 MEAN DRY DENSITY VERSUS CIRCUMFERENCE: AREA RATIO

FROM BENAK, 1967



Unconfined compression test results: (A) block samples with $\gamma_d = 17.3 \text{ kN/m}^3$, $w_o = 20.6\%$, $q_u = 160 \text{ kN/m}^2$, $E = 13300 \text{ kN/m}^2$; (B) piston samples with $\gamma_d = 16.7 \text{ kN/m}^3$, $w_o = 23.1\%$, $q_u = 86 \text{ kN/m}^2$, $E = 2300 \text{ kN/m}^2$.



Unconfined compression test results: (A) block samples with $\gamma_d = 12.9 \text{ kN/m}^3$, $w_o = 12.2\%$, $q_u = 27 \text{ kN/m}^2$, $E = 2500 \text{ kN/m}^2$; (B) piston samples with $\gamma_d = 15.1 \text{ kN/m}^3$, $w_o = 12.8\%$, $q_u = 74 \text{ kN/m}^2$, $E = 4100 \text{ kN/m}^2$.

EFFECTS OF SAMPLE DISURBANCES ON UNCONFINED COMPRESSIVE TEST RESULTS

FROM MILOVIC, 1988

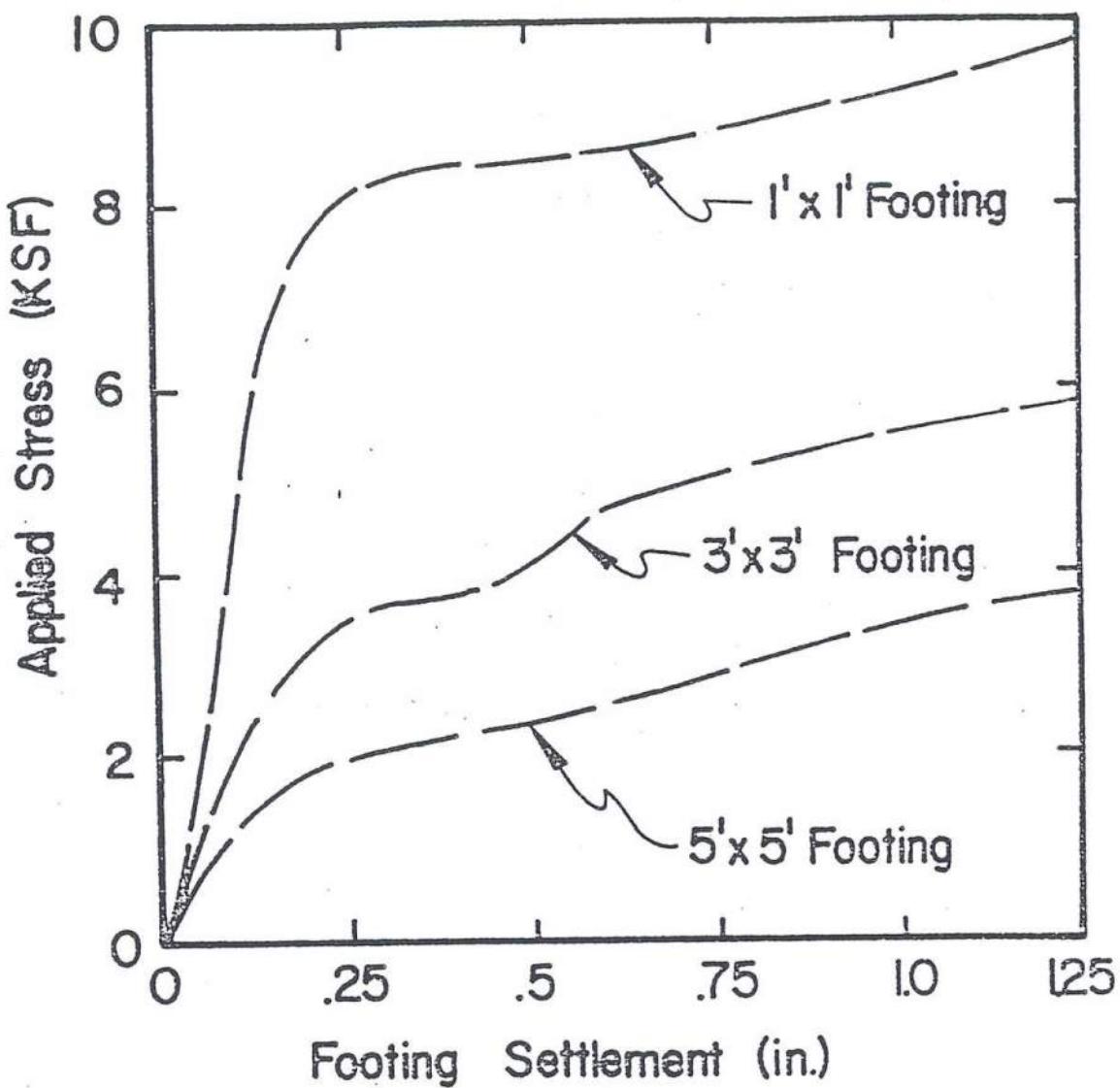


Fig. 3. Field Stress-Deformation at Ashton, Nebraska

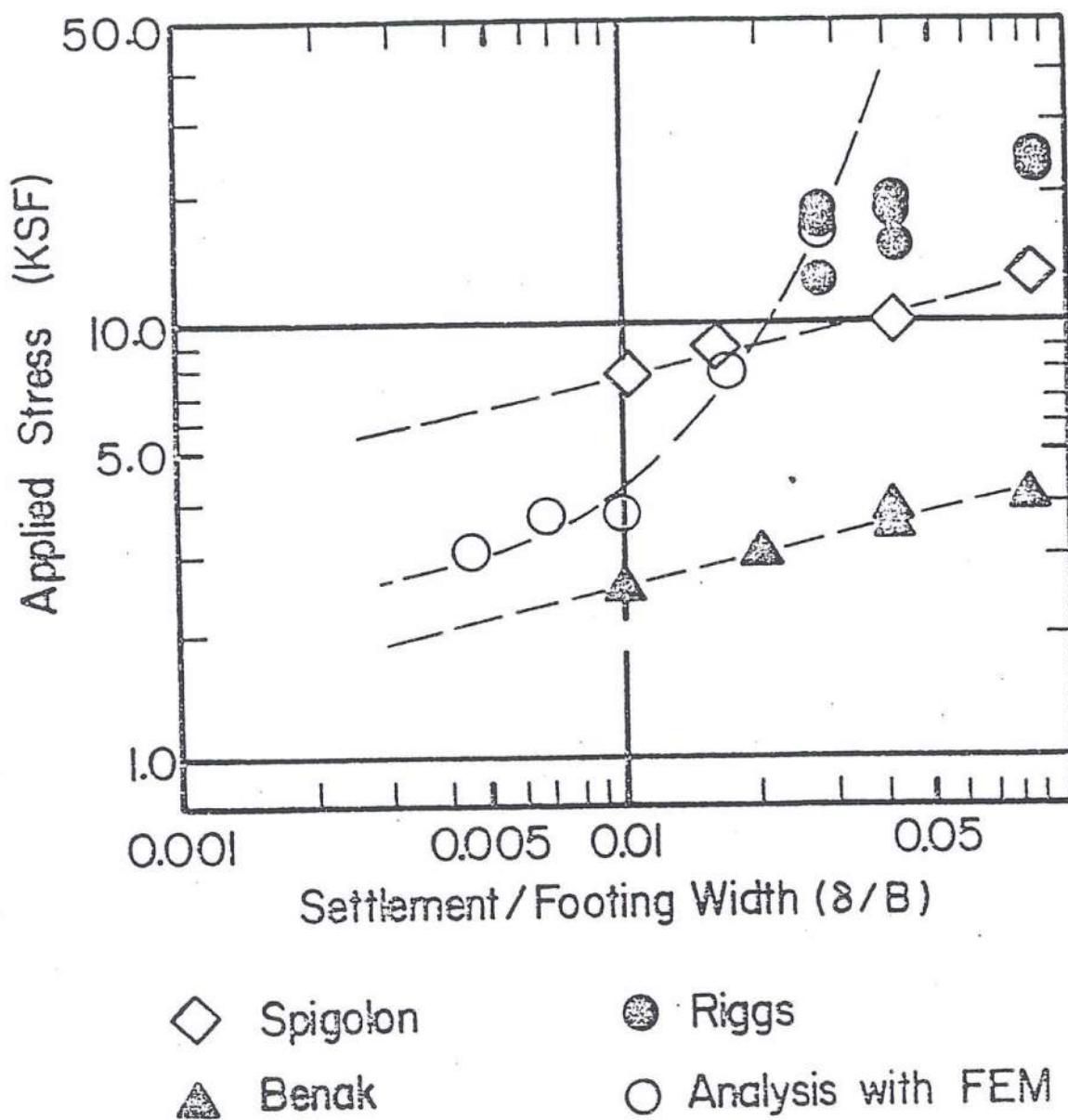


Fig. 12. Applied Stress vs. Settlement Ratio (1.0 ksf = 47.85 kN/m^2 ,
 1.0 in. = 25.4 mm)

BEARING CAPACITY EXAMPLE
CONTINUOUS FOOTING ON LOESS

ASSUME:

1. DRAINED BEHAVIOR
2. $\phi = 30^\circ$
3. $\gamma_r = 100 \text{ psf}$
4. C VARIES WITH WATER CONTENT

ANALYSIS

FOR COMPRESSIBLE LOESS USE TERZAGHI BEARING CAPACITY FACTORS FOR "LOCAL SHEAR", SIMILAR TO USING ϕ' & C' , WHERE
 $\tan \phi' = \frac{2}{3} \times \tan \phi$
 $C' = \frac{2}{3} \times C$

THEN FROM DM 7.2:

$$\begin{aligned} N_{\gamma} &= 5 \\ N_c &= 12 \\ N_q &= 8 \end{aligned}$$

USING F.S. = 3 :

$$q_{all} = q_{ult}/3 = \frac{1}{3} \left[\frac{2}{3} C N_c + \frac{1}{2} \gamma B N_\gamma + \gamma D N_q \right]$$

FOR 16" WIDE FOOTING 3'-0" DEEP:

$$q_{all} = 2.67 C + 910$$

SOIL CONDITION	ASSUMED C PSF	q_{all} PSF
Loose, Silty & SATURATED	0	900
WET & FIRM	200	1400
MOIST & STIFF	400	2000
DRY & VERY STIFF	800	3000

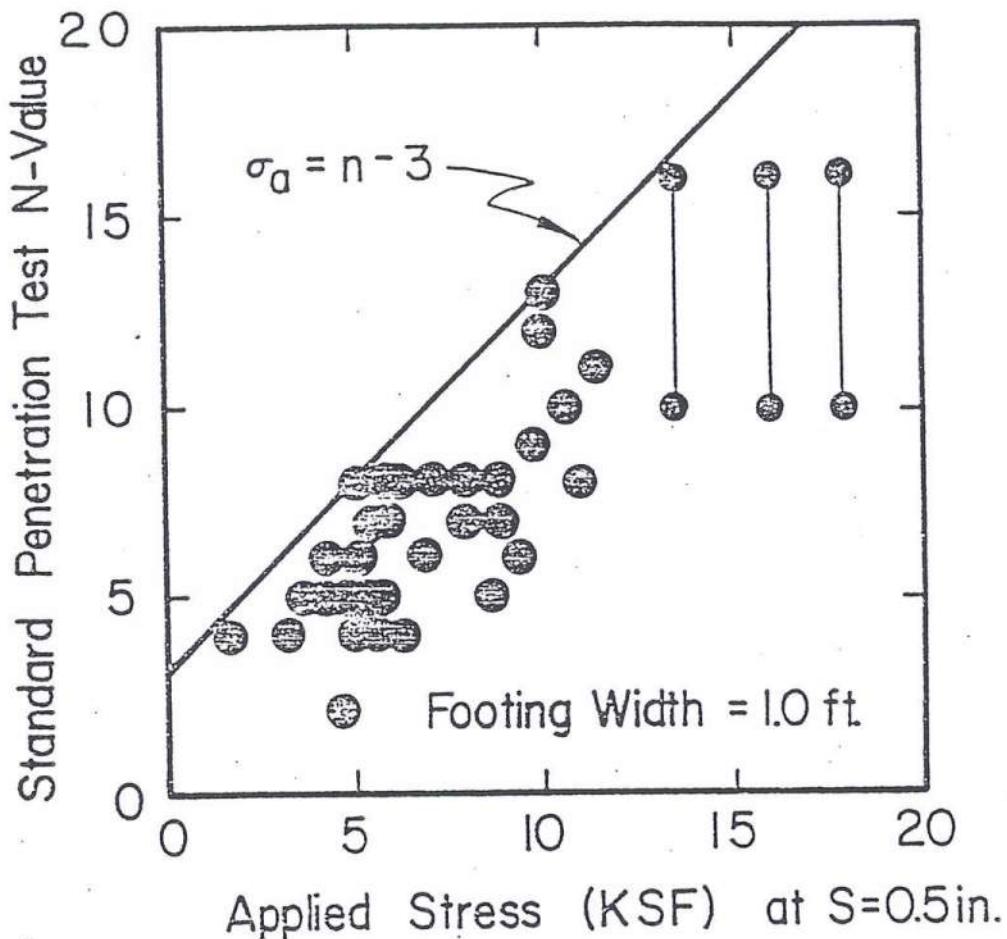


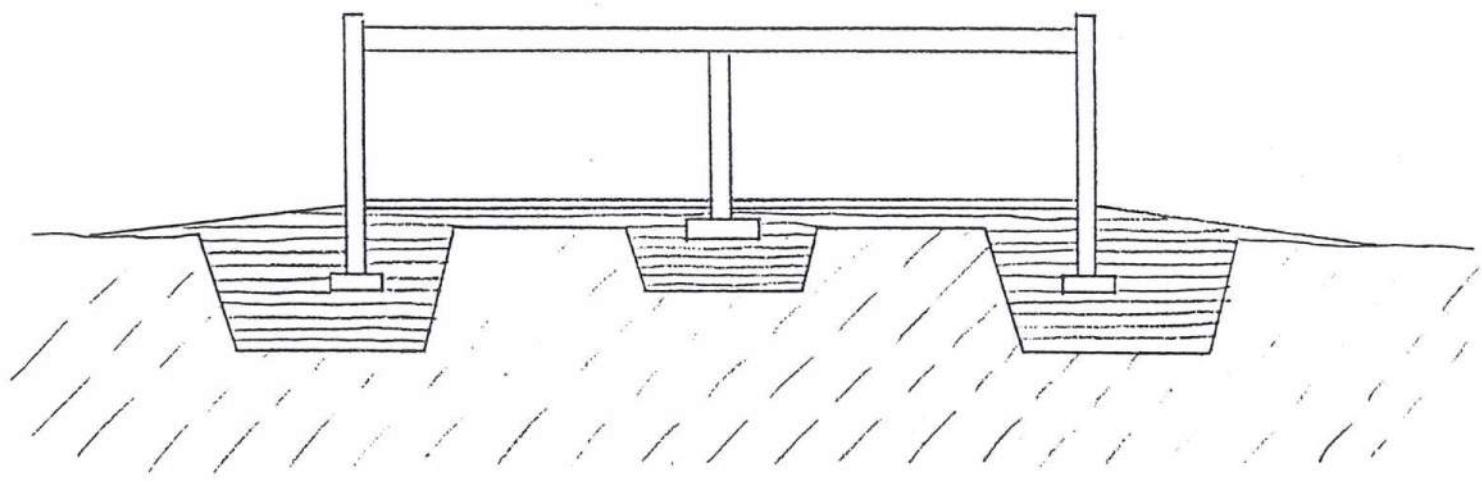
Fig. 14.

N-Values vs. Applied Stress at 0.5 in. of Settlement
 $(1.0 \text{ ksf} = 47.85 \text{ kN/m}^2, 1.0 \text{ in.} = 25.4 \text{ mm})$

TABLE 4
Guide for Consistency of Fine-Grained Soils

SPT Penetration (blows/foot)	Estimated Consistency	Estimated Range of Unconfined Compressive Strength tons/sq. ft.
<2	Very soft (extruded between fingers when squeezed)	<0.25
2 - 4	Soft (molded by light finger pressure)	0.25 - 0.50
4 - 8	Medium (molded by strong finger pressure)	0.50 - 1.00
8 - 15	Stiff (readily indented by thumb but penetrated with great effort)	1.00 - 2.00
15 - 30	Very stiff (readily indented by thumbnail)	2.00 - 4.00
>30	Hard (indented with difficulty by thumbnail)	>4.00

FROM DEPARTMENT OF THE NAVY (DM7.2), 1982



USE OF A STRUCTURAL FILL MAT
TO DISTRIBUTE FOUNDATION LOADS
AND REDUCE INFILTRATION

FIGURE 27

No.	Methods	Type of loess base	Kind of construction	Degree of elaboration
1.	<i>Compaction by:</i>			
1.1.	Rollers, light tampers, vibration plates	all types	all kinds	high, instructions
1.2.	Heavy tampers	I ^a	civil, water irrigation	high, instructions
1.3.	Short pyramidal piles	I ^a	civil	high, instructions
1.4.	Ribbed foundations	I ^a	civil	medium, publications
1.5.	Soil piles	I ^b and II ^a	civil	high, instructions
1.6.	Gas explosions	I ^b and II ^a	civil, water irrigation	medium, publications
1.7.	Compaction injections	I ^b and II ^a	civil	experimentation
1.8.	Injection of clay suspension	I ^b and II ^a	civil	good, publications
1.9.	Moistening	II ^a and II ^b	water irrigation, civil	high, instructions
1.10.	Moistening and deep vibration	I ^b and II ^a	civil	good, publications
1.11.	Moistening and surface explosions	I ^b and II ^a	civil, water irrigation	high, publications
1.12.	Moistening and deep explosions	I ^b , II ^a and II ^b	civil, water irrigation	high, instructions
1.13.	Injection of vapour	II ^a	civil	experimentation
1.14.	Water stream	II ^a and II ^b	civil	experimentation
2.	<i>Improvement of the granulometric composition</i>	all types	road, water irrigation	good, literature
3.	<i>Stabilization</i>			
3.1.	<i>Surface stabilization by:</i>			
3.1.1.	Cement, lime and waste materials	all types	road, water irrigation	high, instructions
3.1.2.	Bitumen and bituminous emulsions	all types	road, water irrigation	good, literature
3.1.3.	Macromolecular compounds	all types	road, water irrigation	medium, literature
3.1.4.	Salts, acids and alkali	all types	road, water irrigation	experimentation
3.2.	<i>Stabilization in depth by:</i>			
3.2.1.	Injection of silicate grouts; Electro- and gas silicatization	I ^b and II ^a	civil	high, regulations
3.2.2.	Injection of gases	I ^b and II ^a	civil	medium, literature
3.2.3.	Injection of cement, lime and other grouts	I ^b and II ^a	civil	medium, literature
3.2.4.	Injection of large molecular compounds	I ^b and II ^a	civil	experimentation
3.2.5.	Mechanical mixing with Portland cement and lime	I ^b and II ^a	civil	good, literature
3.2.6.	Mixing with cement by jet-grouting	I ^b , II ^a and II ^b	civil	good, literature
3.2.7.	Burning of liquid and gas fuels	I ^b and II ^a	civil	high, regulations
4.	<i>Replacement by:</i>			
4.1.	Soil cushion	I ^a	civil and water irrigation	good, instructions
4.2.	Sand cushion	I ^a	civil	good, literature
4.3.	Soil-cement cushion	I ^a and I ^b	civil	high, instructions
4.4.	Cement-bentonite grout introduced by jet-grouting	I ^b and II ^a	civil	good, literature
5.	<i>Reinforcement</i>	all types	civil and road	good, literature
6.	<i>Geomembranes</i>	all types	water irrigation and civil	good, literature
7.	<i>Desiccation by:</i>			
7.1.	Surface draining	all types	civil	high, regulations
7.2.	Drainage boreholes and wellpoints	all types	civil	high, instructions
7.3.	Horizontal boreholes	all types	civil	good, literature
7.4.	Electro-osmosis	all types	road and civil	good, literature
7.5.	Hygroscopic substances	all types	civil	medium, literature
8.	Correction, terracing, grassing and afforestation of slopes	all types	all kinds	high, literature

Classification of loess improvement methods

FROM EVSTATIEV, 1988

APPENDIX A

Bibliographic Review of Geotechnical Investigations of
Loess in North America

By
Alan J. Lutenegger

Loess Letter Supplement No. 7

Published by Department of Earth Sciences

University of Waterloo
Waterloo, Ontario, Canada

February, 1985

Bibliographic Review of Geotechnical Investigations of
Loess in North America

i) Settlement Observations

In 1979, a first edition of this bibliography was prepared for the North American Committee Report to the INQUA Subcommission on Loess. This effort consisted of references. Subsequently it was published, in slightly modified form, as an Open File Report by the Iowa Geological Survey. Since this initial effort, the senior author of that report has had opportunity to carefully review the literature in more detail and hence this second edition bibliography is being presented as part of the Report of the North American Working Group on Geotechnical Properties of Loess.

In keeping with the form of the first edition, this second edition is divided into two main topics: (I) Geotechnical Characterization of Loess, and (II) Geotechnical Performance of Loess. Where a reference contains abundant material on both main topics, an asterisk precedes the listing. Indexed subject matter following individual reference listings is organized according to the following letter code:

- a) Composition - chemical, mineralogical, textual
- b) Moisture & Density Measurements - *in situ*, remolded, including proctor
- c) Consistency - Atterberg Limits
- d) Shear Strength - field, laboratory, *in situ*, remolded
- e) Compressibility - consolidation, collapse
- f) Permeability & Infiltration - field, laboratory
- g) Stabilization - chemical, mechanical
- h) Slope Stability & Erosion

i) Field Testing - pile load test, plate load test

j) In addition to indexing of each reference by main topic and subject matter, an additional index on geographic areas occurs at the end of the bibliography. References have been arranged according to geographic location of subject matter by State within the United States and Canada. Where a reference describes loess materials from more than one state, some cross indexing occurs. Any references which have been inadvertently left out should be brought to my attention:

A.J. Lutenegger
Clarkson University
Potsdam, NY 13676

April, 1984

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SHALLOW FOUNDATIONS ON LOESS

WCC OMAHA PRACTICE

BACKGROUND

Loess in eastern Nebraska and western Iowa includes the Peorian Loess of Wisconsin age and the underlying Loveland Loess of Illinoian age. The maximum thickness of each formation is generally about 50 feet, although much greater thicknesses are found in the bluffs adjacent to the Missouri River Valley. Thickness varies widely with such factors as distance from the source, slope and erosion, and either formation may be absent. Kansan Till most commonly underlies the loess, and its lower permeability often results in a water table perched in the loess above the till. This saturated zone may be absent beneath the hilltops and thickens towards the valleys. In some places the loess is underlain by granular outwash or sedimentary bedrocks. Certain Wisconsin-age terraces along the Missouri River have only Peorian Loess underlain by fine and coarse grained alluvium.

Most of the Peorian and Loveland Loess classifies as CL, but extensive deposits of ML occur close to the source; for example, in Council Bluffs. At greater distance from the sources the loess is more clayey and may classify as CH. The modern A horizon is usually less than 1 foot thick. The B horizon is commonly about 2 feet thick and may classify as CL or CH. The Sangamon Paleosol at the surface of the Loveland Loess can be a very stiff, highly plastic clay as much as 5 or 6 feet thick, but it may be thinner, less pronounced or absent. Several modified zones may be found within the Loveland Formation.

The writer has practiced geotechnical engineering in Omaha since 1970 and has adopted many of the practices of Howard McMaster, who founded the local practice of Woodward-Clyde Consultants in 1956, and of Kenneth Nass, who has directed the Omaha operation since 1964. The traditions and guidelines of this practice are based largely on experience.

Departures from the general guidelines described below can be made based on more extensive laboratory testing, analyses, and field observations where the scope of the project and the potential savings justify the expenditures.

PRINCIPLES

Formulation of design recommendations for site development and building foundations on loess are based largely on the generalizations and assumptions summarized below:

1. Unsaturated Peorian Loess is assumed to be collapse-susceptible until demonstrated otherwise, using the relationship between density and liquid limit, consolidation tests with water added at some selected pressure, or densities generally above 90 pounds per cubic foot.
2. Unsaturated loess is easily compressed during sampling, so considerable care is necessary in selecting samples for density testing. If the samples from a building site show a wide variation in density, the low densities usually control the recommendations. If the low densities are confined to a fairly shallow layer, this layer can be replaced with structural fill, or footings can be lowered to bear below it.
3. Saturated Peorian Loess is presumed to be normally consolidated until demonstrated otherwise by consolidation testing or field measurements of embankment settlements. Although deposits of overconsolidated saturated Peorian Loess are fairly common, their occurrence cannot yet be predicted using geology. Dry loess deposits (water contents less than about 15 percent) with low densities are considered particularly susceptible to collapse.

4. Man's activities such as forest removal, cultivation, grading, building construction, installation of plumbing, and irrigation, generally lead to increases in infiltration. This can raise the water content of the loess and possibly result in settlement. Loosely placed backfill, poorly defined surface drainage, and poor maintenance of roof drains are common sources of concentrated infiltration near foundations.
5. Loading the loess with earth fills more than about 3 or 4 feet thick can be expected to result in settlement sooner or later. If the water content of the loess is above the plastic limit, settlements may begin immediately, but can continue for some time due to secondary consolidation or a similar phenomenon. Preloading the site with a temporary surcharge of additional fill can greatly reduce future settlement. If the loess is dry, it will not compress immediately under the new fill loads, but it may begin to compress at some future time due to a rise in the water table or to a general increase in water content that may result from cutting off the surface evaporation. Preloading is not effective in preventing this future settlement.
6. The Loveland Loess is generally not collapse susceptible, exhibiting dry unit weights of 90 pounds per cubic foot or higher. The Loveland Loess is generally moderately overconsolidated, even where saturated. Where the loess thickness is great and the loads to be applied are large, the overconsolidation ratio of Loveland Loess should be investigated by testing.
7. Any of the non-organic loess can be used to construct a stable structural fill by compaction at water contents generally within about 4 percent below to 3 percent above optimum per ASTM D698 (standard Proctor). Specified minimum relative compaction is usually 95% for routine structural fill, 98% where the construction is more critical or a very stiff subgrade is desired, and occasionally 100% where heavy footing loads will be supported. The workable moisture range for compaction is narrower for ML loess, and fills constructed with CH loess may be expansive.

Compacted loess has a much lower permeability than natural loess and can be used to construct a protective barrier to reduce the risk of moisture increases.

PROCEDURES

Investigations of loess sites for support of 1- to 3- story buildings usually proceed more or less as follows:

1. Information is obtained regarding planned grading, basements, and expected foundation loads.
2. Borings are located at least at the 4 corners of the building and at intermediate locations for larger buildings. If substantial fills are planned, one or more borings are extended through all loess and compressible alluvium to relatively incompressible soils. If expected foundations loads exceed about 200 kips, exploration will be continued to Loveland Loess or underlying stronger soils under the assumption that shallow footings may not be feasible.
3. Borings are drilled using continuous flight augers. Samples are obtained at 2-1/2 to 5 foot intervals using a California Sampler (2-inch ID solid barrel sampler with thin brass liners). If consolidation testing is planned or if many of the samples are compressed during sampling, 3-inch thin-walled tube samples will be taken at selected depths. In special cases, 4-1/4 inch thin-walled tubes will be used with special sampling techniques, or test pits may be excavated and block samples cut by hand. First groundwater entry is noted in each boring, and delayed water levels are obtained 24 hours after drilling.

4. The engineer examines the recovered samples with particular attention to consistency and sample quality. Samples that appear to have been compressed can be tested for water content and Atterberg limits, but should not be evaluated for strength, compressibility or density. Such samples are often hard to extrude from the tubes, exhibit a subtle "shaley" structure, and may not have visible root holes. Testing usually consists of density, water content, and possibly penetrometer strength at a number of depths in each boring; Atterberg limits on a few selected samples; and possibly unconfined compression on carefully selected samples. Unconfirmed tests may underestimate strength because samples are brittle and may fail at low strains.
5. If the building area is to receive more than about 3 to 4 feet of net new fill and water contents are above the plastic limit, a temporary surcharge is often recommended. Various methods may be used to design the surcharge, but usually the weight of the surcharge is equal at least to 50% of the permanent fill weight plus 150% of the expected building weight. Settlements are monitored, and surcharge is left in place until settlement is essentially complete, which is usually accomplished within 60 days. If the water contents are below the plastic limit, the grading design should be changed to eliminate thick fills in the building area, or the building should be supported on a deep foundation.
6. If proposed fills are thin, foundation loads are less than about 150 kips, densities generally exceed 80 pounds per cubic foot and water contents are between 15 and 25%, the building may be supported on the loess using spread footings. After existing fills and top soils are removed, the site is levelled using structural fill. Footings can then be placed on both loess and fill; design criteria are based on the loess. Bearing pressures are based largely on consistency and range from about 1500 pounds per square foot for firm loess to 3,500 pounds per square foot for very stiff, medium dense loess. Higher loads and higher bearing pressures can be supported on dense loess if justified by testing and analyses. The loess is considered frost-

susceptible, and exterior footings are placed at the depths required by local codes for frost protection.

7. If the loess has lower densities or water contents than listed above, or if the facility is considered particularly critical, the loess may be overexcavated and replaced with structural fill to depths of 2 to 4 feet below the footings. Areas between footings may be overexcavated only 1 to 2 feet, although contractors often choose to excavate the entire building area rather than dig trenches along the foundation lines. Structural fill is extended 3 to 5 feet beyond the outside edges of the foundation.
8. For somewhat higher foundation loads, or where the loess is moist and appears compressible, a combination of structural fill and surcharge may be used to provide footing support. The intent of the design is to preconsolidate compressible soils under pressures at least as high as would be expected beneath the footing using 2-layer stress distribution theory.
9. Multi-story structures, heavy storage structures, water reservoirs, and other unusual facilities require special testing, analysis and design, or deep foundations.

In Situ Testing in Loess

The use of in situ testing to evaluate the engineering properties of soil in place is increasing at a rapid pace around the world. Some test methods such as the standard penetration test have a long history in North America; other test methods such as the Marchetti Dilatometer have seen limited applications in North America.

Application of in situ testing techniques to evaluate sites underlain by loess has several advantages including: 1) the ability to efficiently obtain relatively large amounts of data, 2) rapid determination of geotechnical properties, and 3) reduction of uncertainties associated with sampling disturbance.

Representative test data for mechanical cone penetrometer, dilatometer and standard penetration tests are compared to laboratory preconsolidation stress measurements in Figure 1. The in situ test data clearly identifies relatively strong and weak zones in the loess that probably developed from the effects of desication and weathering during deposition. In the Omaha, Nebraska area the cone penetrometer is commonly used to identify the profile of strength variations with depth and to guide the locations for special sampling and laboratory testing.

In most instances, the in situ test methods do not directly measure geotechnical properties, but rely on empirical correlations. The engineering literature contains a large number of reports on in situ test methods that can be used to evaluate the geotechnical properties of soils. A limited reference listing is attached. Unfortunately, the applicability of most in situ test methods for loess has not been documented, and site specific validation of the empirical correlations must be made.

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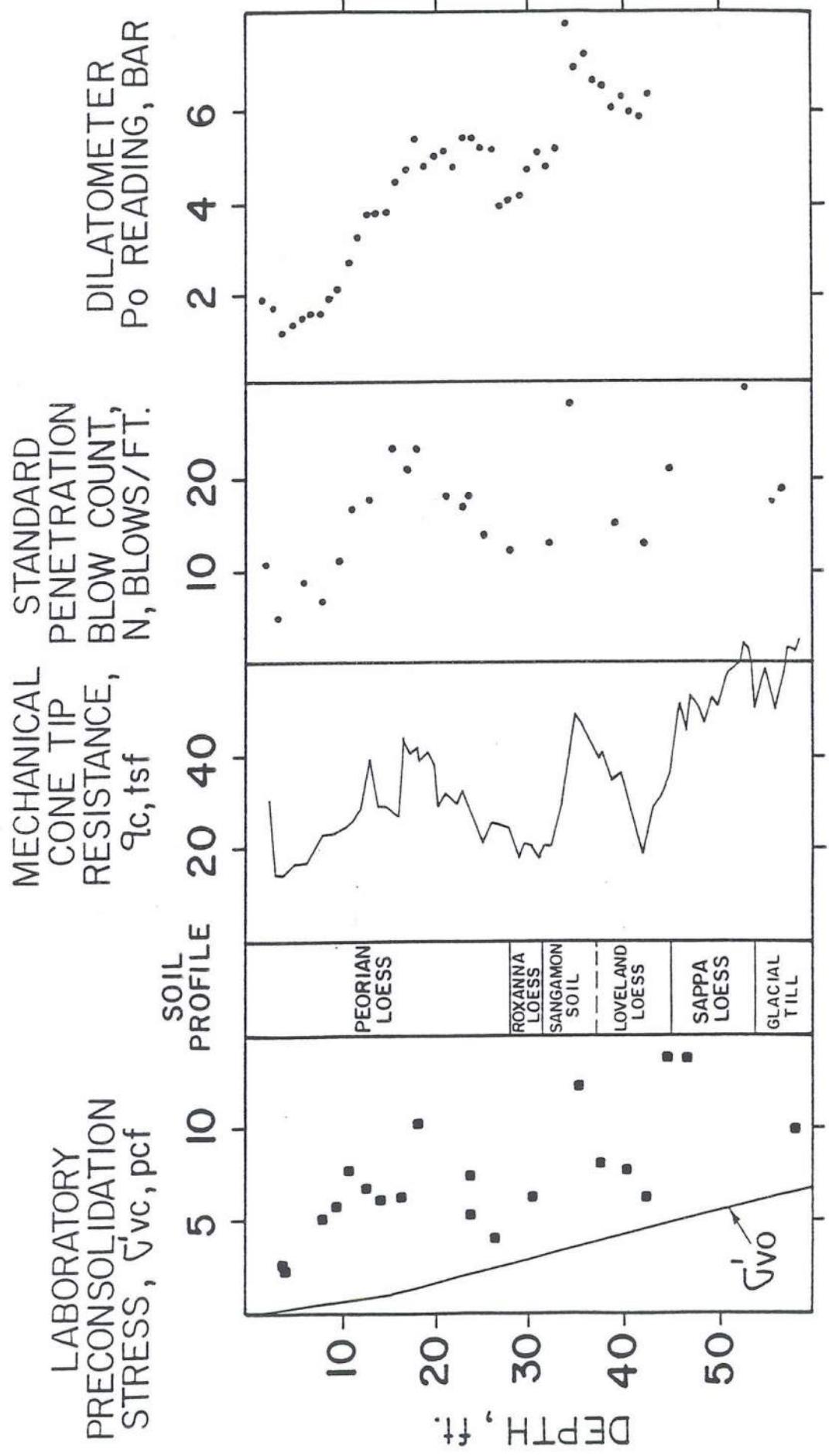


FIGURE 1 LABORATORY AND IN SITU TEST DATA
WESTSIDE RESERVOIR SITE, OMAHA, NEBRASKA

