Prediction of Compression and Recompression Indices of Texas Overconsolidated Clays

Presented By:

Sayeed Javed, Ph.D., P.E.

Settlement Equation

$$\Delta H = \frac{C_r H}{1+e_o}\log\frac{p'_o + (p'_c - p'_o)}{p'_o} + \frac{C_c H}{1+e_o}\log\frac{p'_c + p'_f - (p'_c - p'_o)}{p'_c}$$

where

ΔH = consolidation settlement of the stratum

C_r = slope of the average rebound-recompression line

C_c = slope of the virgin compression portion of the e-log p curve

H = total thickness of the stratum

p'_o = effective overburden pressure

p'_c = preconsoldation pressure

p'_f = final pressure due to the loads in addition to the overburden pressure

e_o = original void ratio


CALIBRATION


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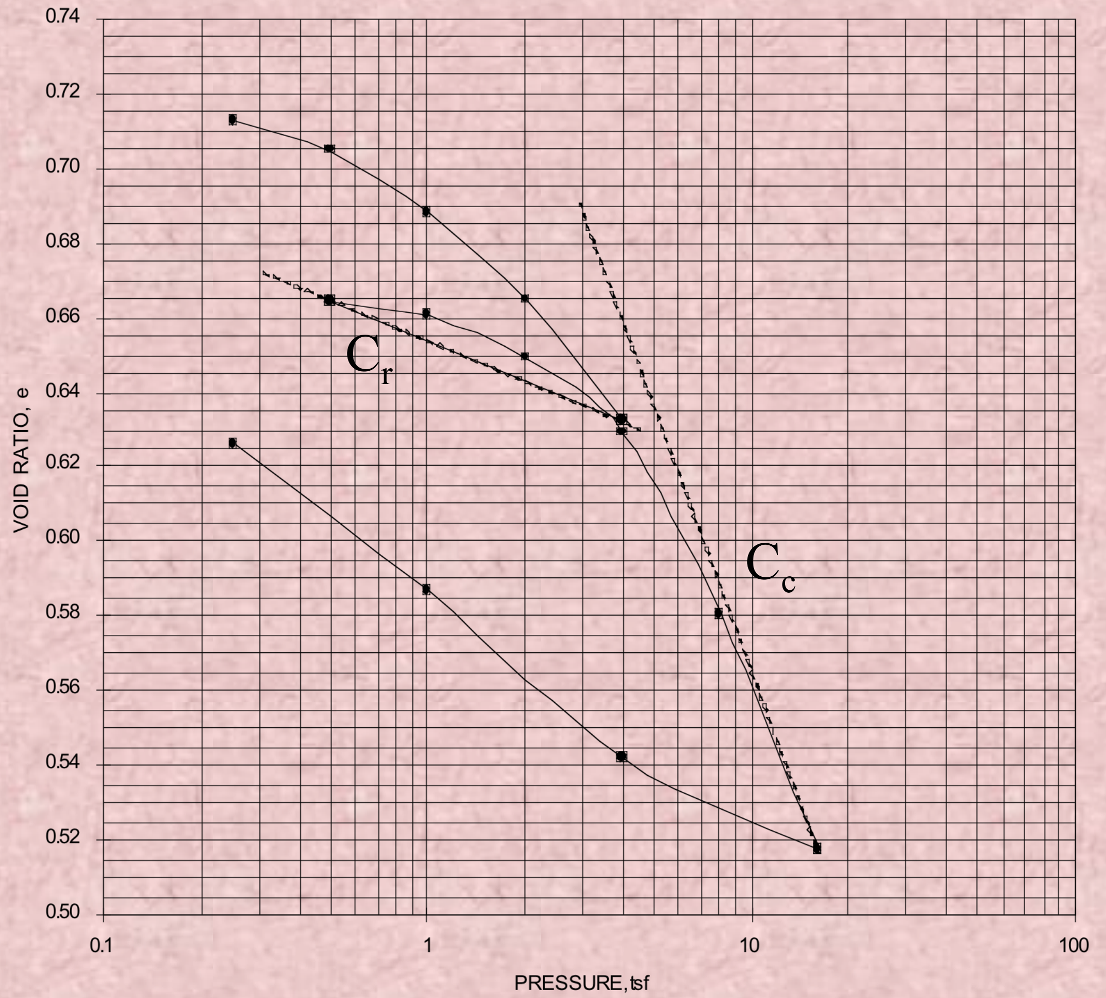
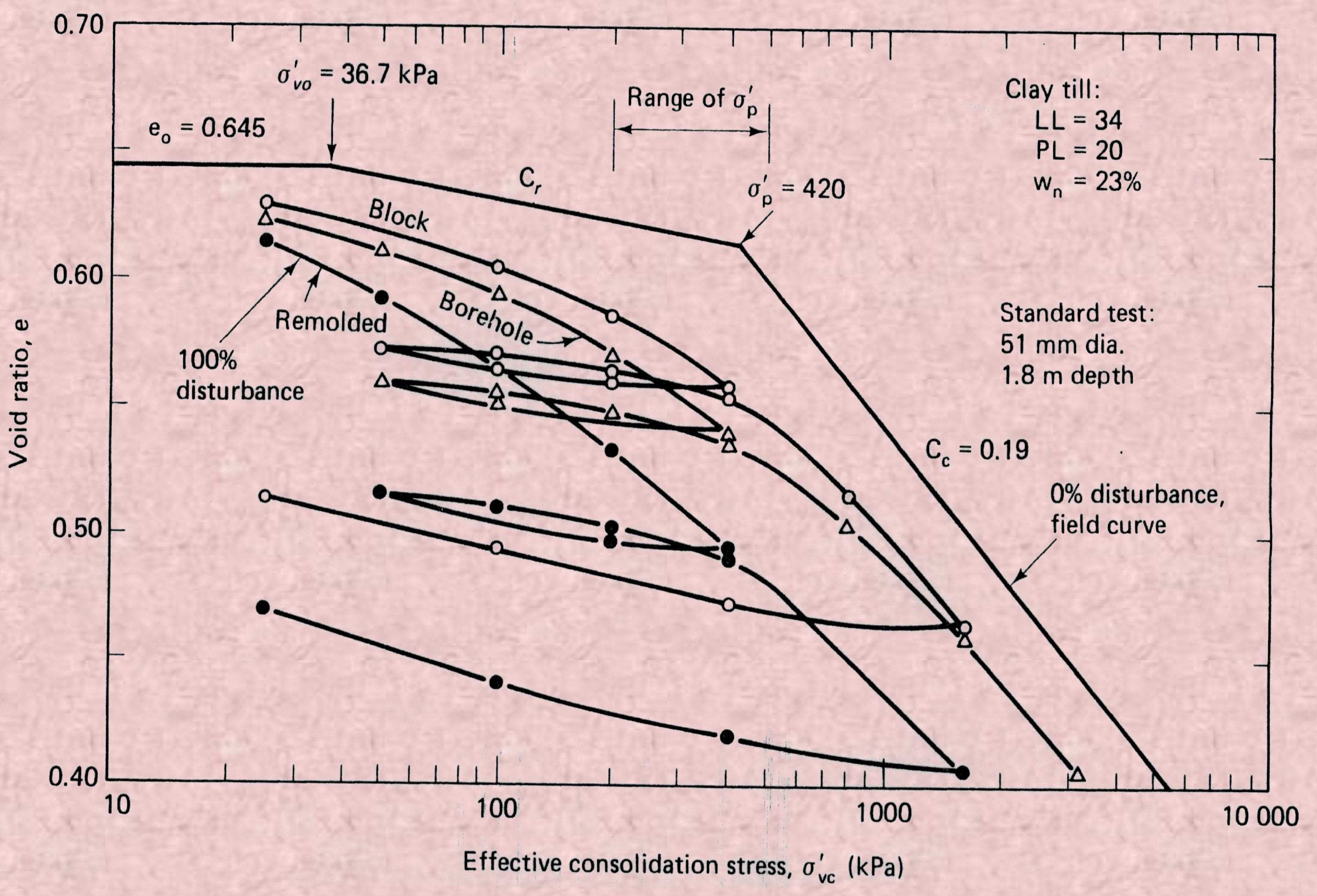
A Typical Consolidation Curve

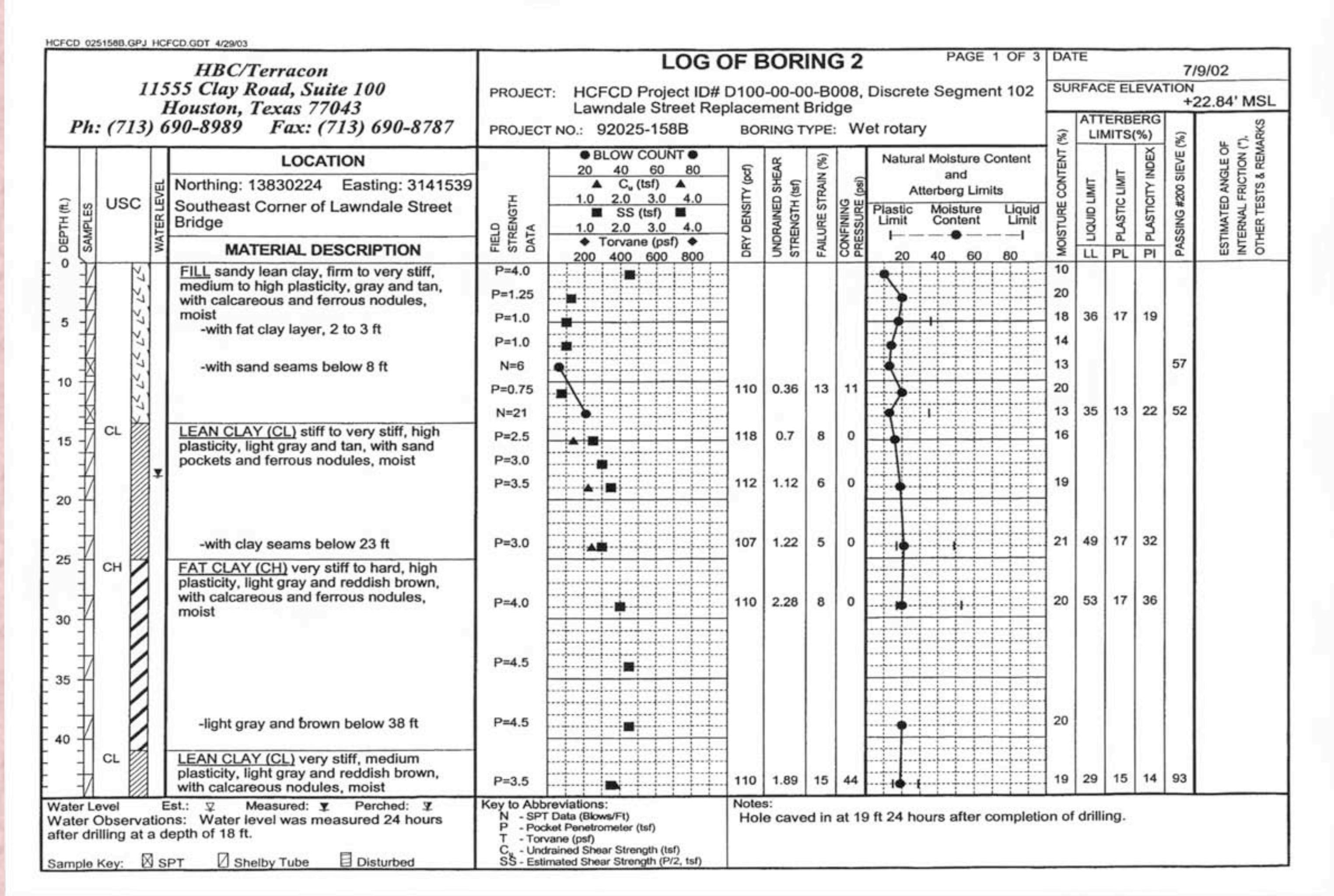



0.70
0.60
0.50
0.40
10
100
1000
10 000
Void ratio, e
Effective consolidation stress, σ'vc (kPa)
σ'vo = 36.7 kPa
eo = 0.645
Range of σ'p
σ'p = 420
Cr
Block
Borehole
Remolded
100% disturbance
Cc = 0.19
0% disturbance, field curve
Clay till:
LL = 34
PL = 20
wn = 23%
Standard test:
51 mm dia.
1.8 m depth

Budget & Time Constraints

- A typical budget of $3,000
  - – Field: $1,200
  - – Lab: $800
  - – Engineering: $1,000
- Cost of a "Consolidation Test" ranges between $250 and $300
- Consolidation test takes about a week

Subsurface Stratigraphy



HCFCD 025158B.GPJ HCFCD.GDT 4/29/03

HBC/Terracon
11555 Clay Road, Suite 100
Houston, Texas 77043
Ph: (713) 690-8989 Fax: (713) 690-8787

LOG OF BORING 2 PAGE 1 OF 3

PROJECT: HCFCD Project ID# D100-00-00-B008, Discrete Segment 102
Lawndale Street Replacement Bridge

PROJECT NO.: 92025-158B BORING TYPE: Wet rotary

DATE 7/9/02

SURFACE ELEVATION +22.84' MSL

LOCATION

Northing: 13830224 Easting: 3141539
Southeast Corner of Lawndale Street Bridge

MATERIAL DESCRIPTION

FILL sandy lean clay, firm to very stiff, medium to high plasticity, gray and tan, with calcareous and ferrous nodules, moist
-with fat clay layer, 2 to 3 ft
-with sand seams below 8 ft

CL — LEAN CLAY (CL) stiff to very stiff, high plasticity, light gray and tan, with sand pockets and ferrous nodules, moist
-with clay seams below 23 ft

CH — FAT CLAY (CH) very stiff to hard, high plasticity, light gray and reddish brown, with calcareous and ferrous nodules, moist
-light gray and brown below 38 ft

CL — LEAN CLAY (CL) very stiff, medium plasticity, light gray and reddish brown, with calcareous nodules, moist

FIELD STRENGTH DATA	DRY DENSITY (pcf)	UNDRAINED SHEAR STRENGTH (tsf)	FAILURE STRAIN (%)	CONFINING PRESSURE (psi)	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	PASSING #200 SIEVE (%)	ESTIMATED ANGLE OF INTERNAL FRICTION (°), OTHER TESTS & REMARKS
P=4.0					10					
P=1.25					20					
P=1.0					18	36	17	19		
P=1.0					14					
N=6					13				57	
P=0.75	110	0.36	13	11	20					
N=21					13	35	13	22	52	
P=2.5	118	0.7	8	0	16					
P=3.0										
P=3.5	112	1.12	6	0	19					
P=3.0	107	1.22	5	0	21	49	17	32		
P=4.0	110	2.28	8	0	20	53	17	36		
P=4.5										
P=4.5					20					
P=3.5	110	1.89	15	44	19	29	15	14	93	

Water Level Est.: ▽ Measured: ▼ Perched: ▽
Water Observations: Water level was measured 24 hours after drilling at a depth of 18 ft.

Sample Key: ☒ SPT ◿ Shelby Tube ▤ Disturbed

Key to Abbreviations:
N - SPT Data (Blows/Ft)
P - Pocket Penetrometer (tsf)
T - Torvane (psf)
C_u - Undrained Shear Strength (tsf)
SS - Estimated Shear Strength (P/2, tsf)

Notes:
Hole caved in at 19 ft 24 hours after completion of drilling.

Statistical Correlation

- Maximum use of index properties
- Lot of variables – difficulty of memorizing

  – lot of calculations
- Reduce number of variables such that they are still representative of several other index properties

Factors Influencing C_c and C_r

1. Type and Amount of Clay Minerals
   - PI

2. Physical State of Soil
   - Moisture Content
   - Density
   - Stress History
   - Presence of fissures, joints and cracks

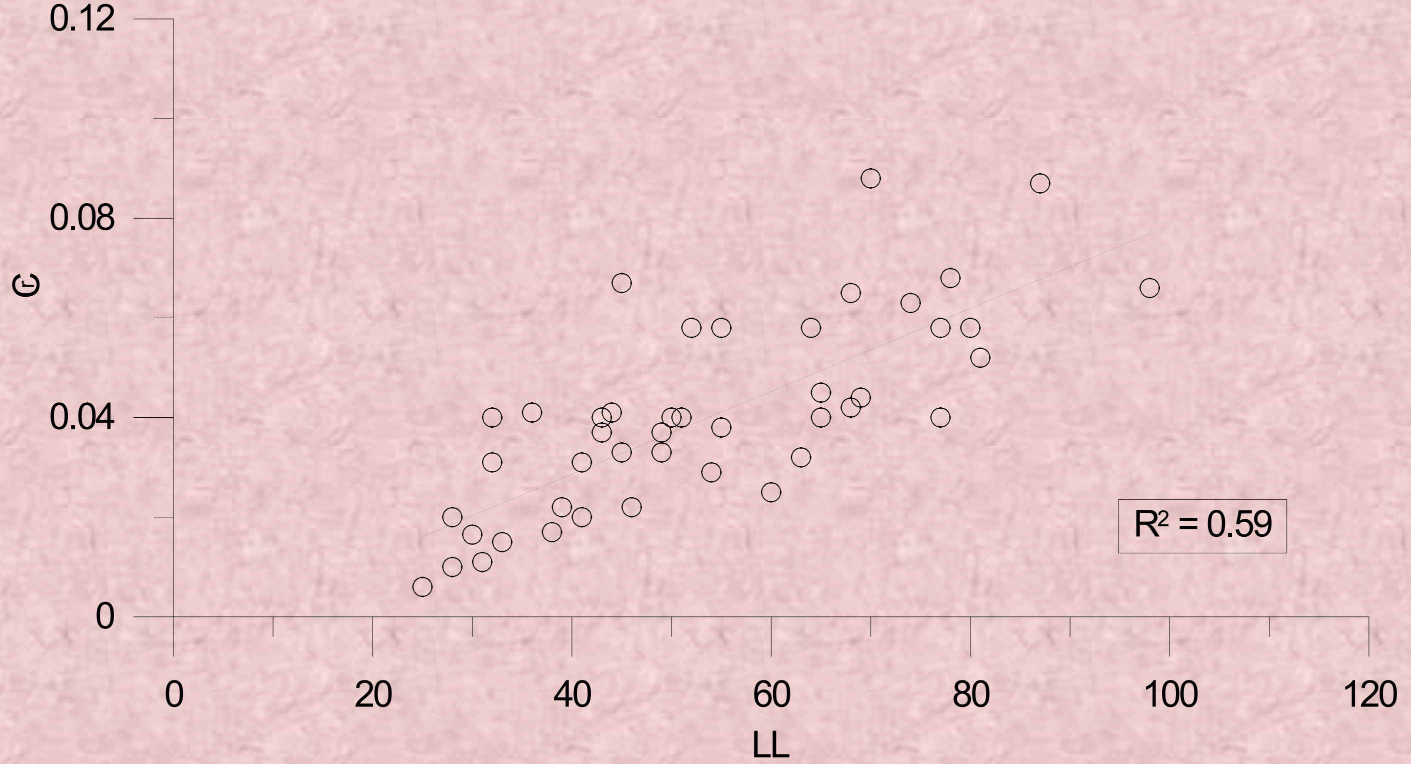


FIGURE 1. Recompression Index versus Liquid Limit

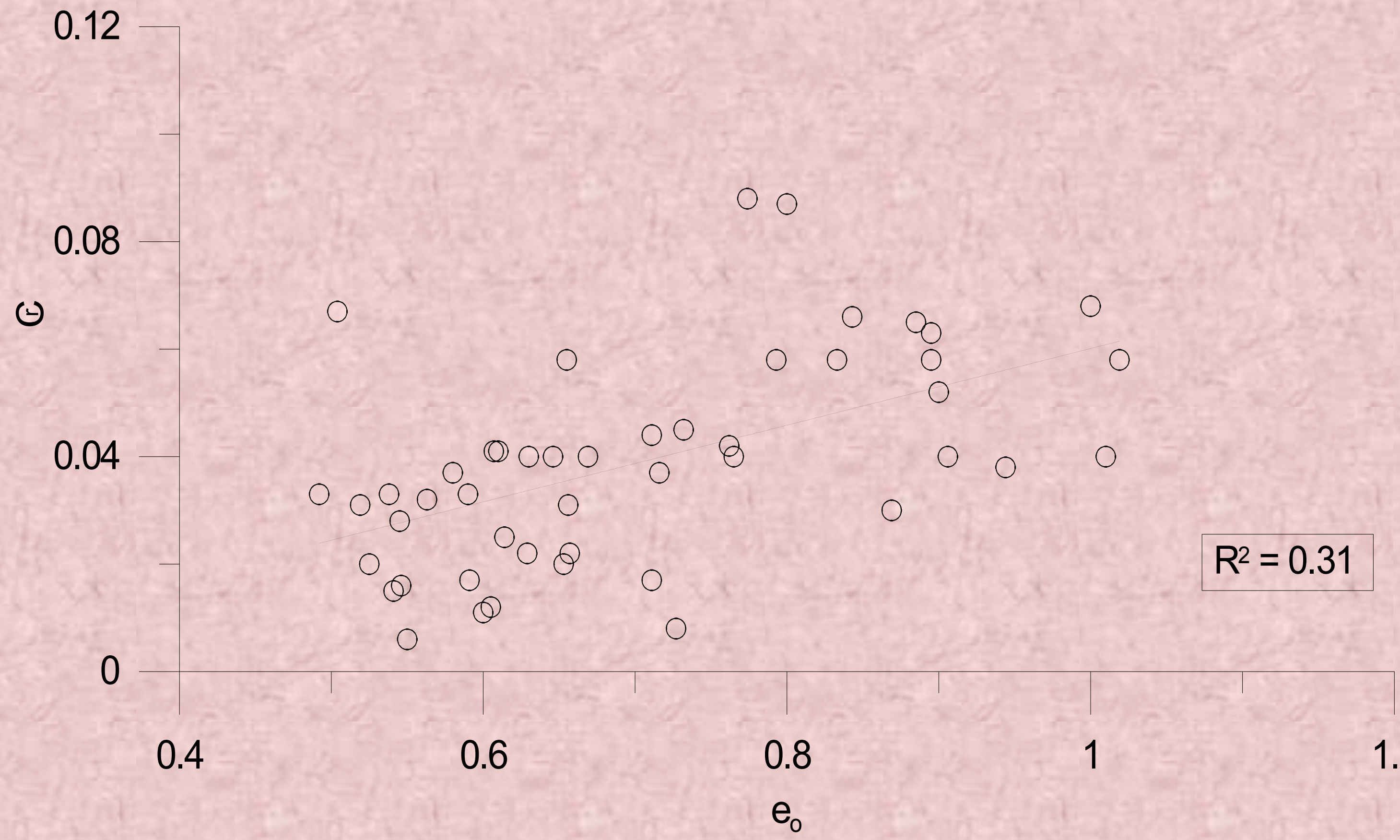


FIGURE 2. Recompression Index versus Void Ratio

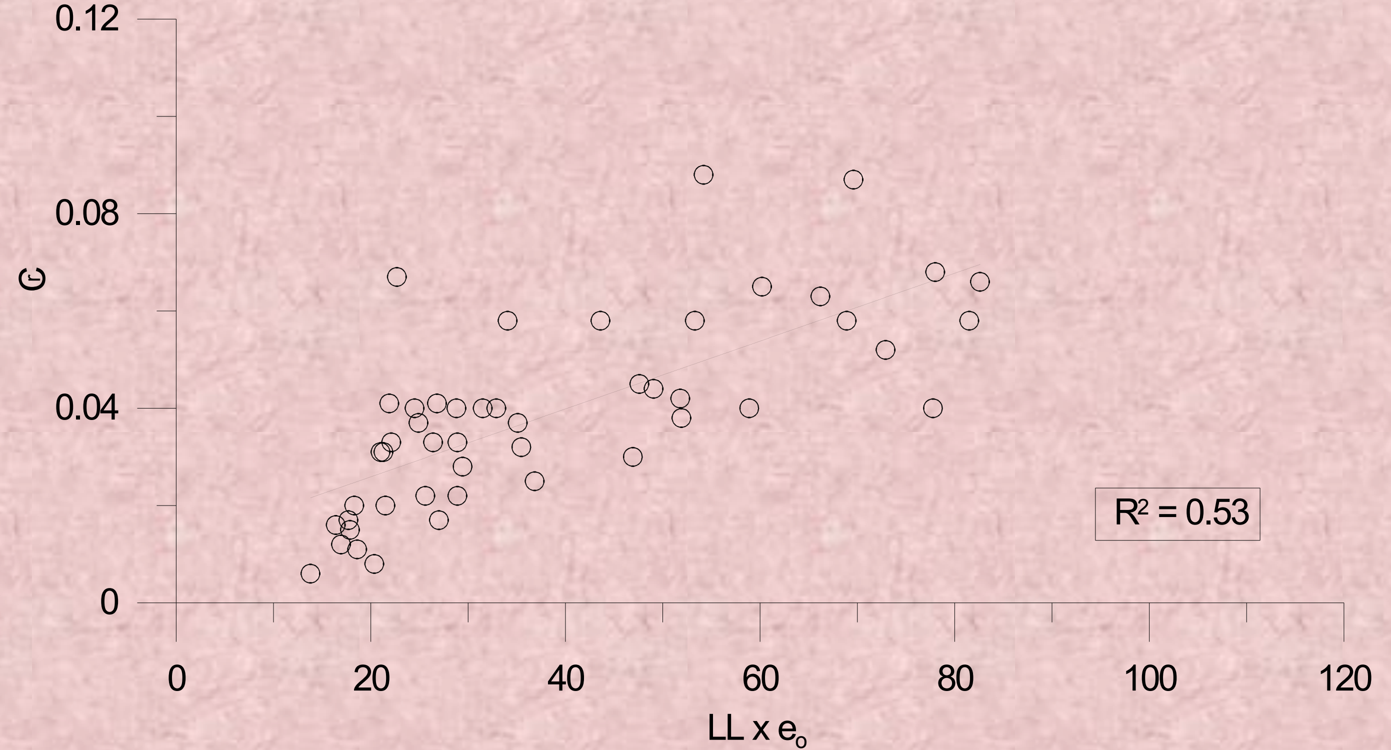


FIGURE 3. Recompression Index versus Product of Liquid Limit and Void Ratio

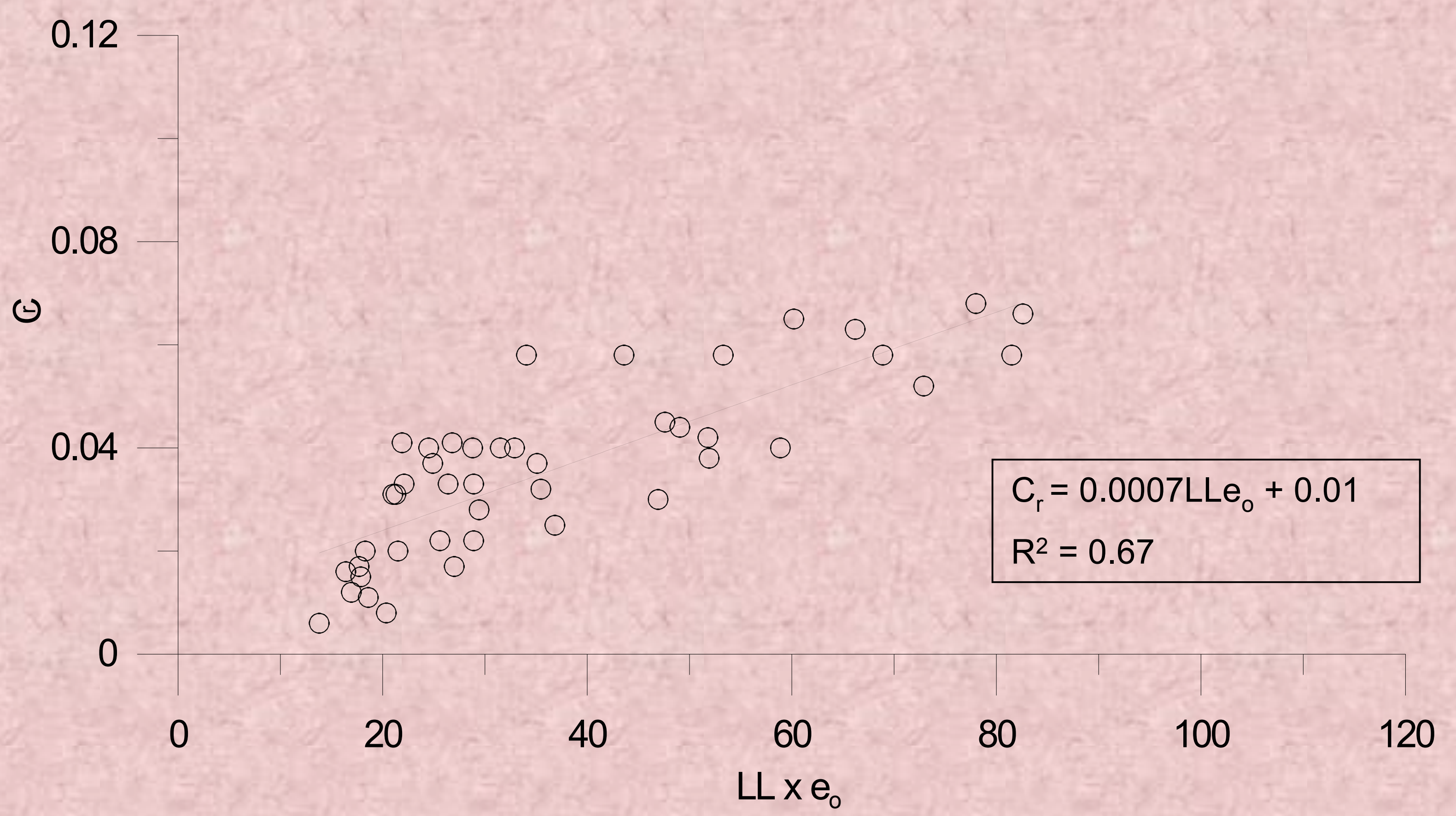


FIGURE 4. Recompression Index versus Product of LL and Void Ratio After Removing Outliers

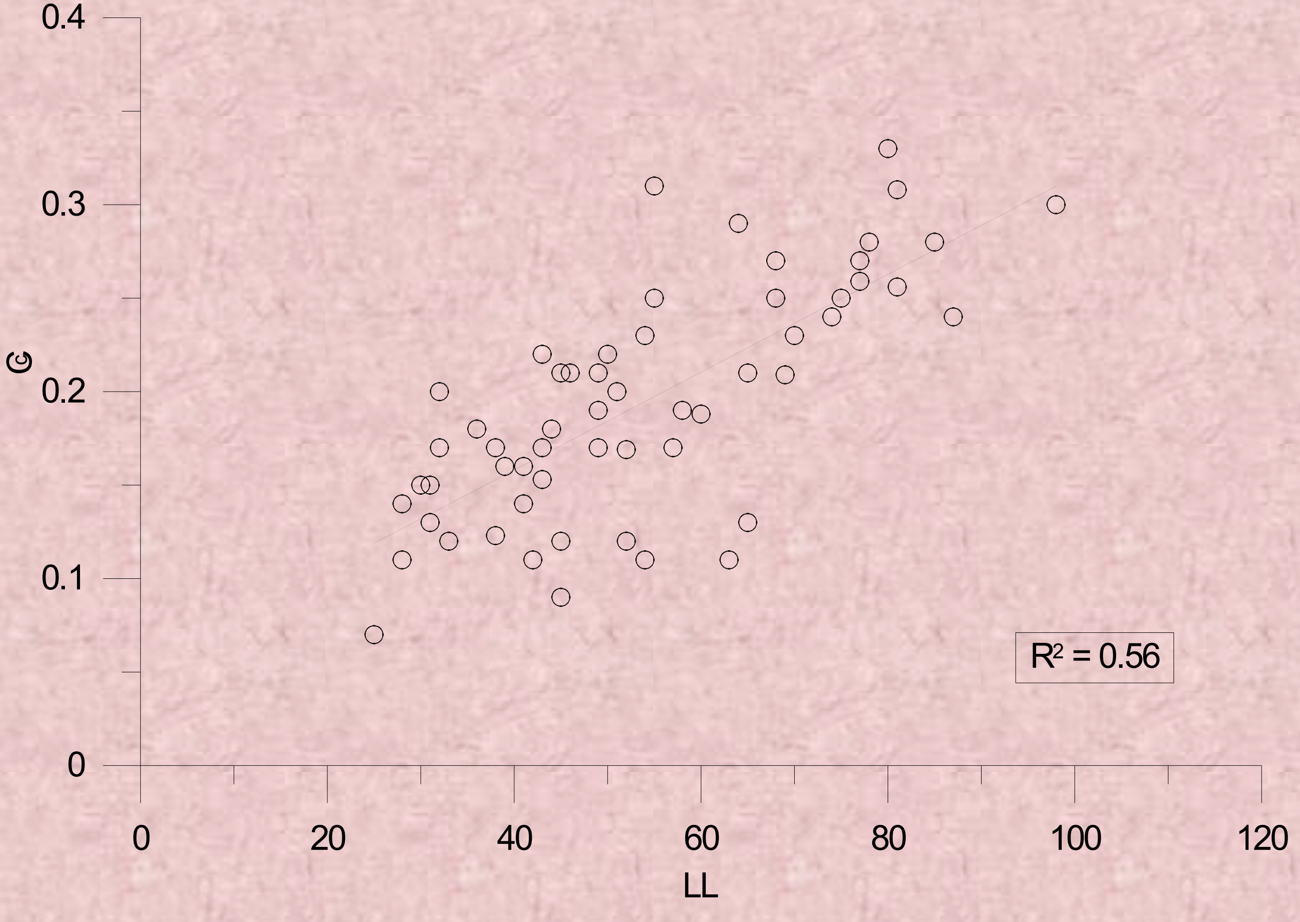


FIGURE 5. Compression Index versus Liquid Limit

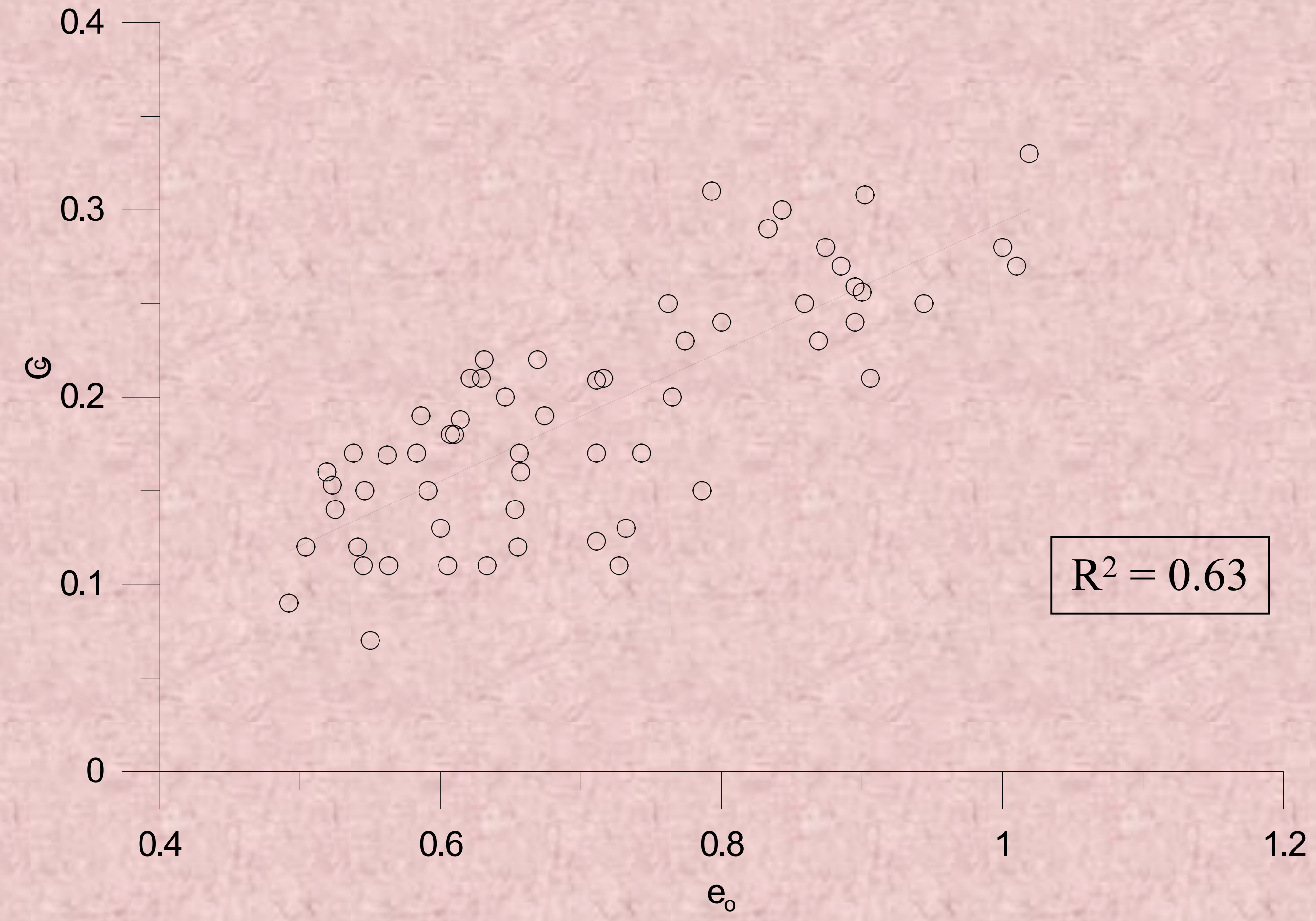


FIGURE 6. Compression Index versus Void Ratio

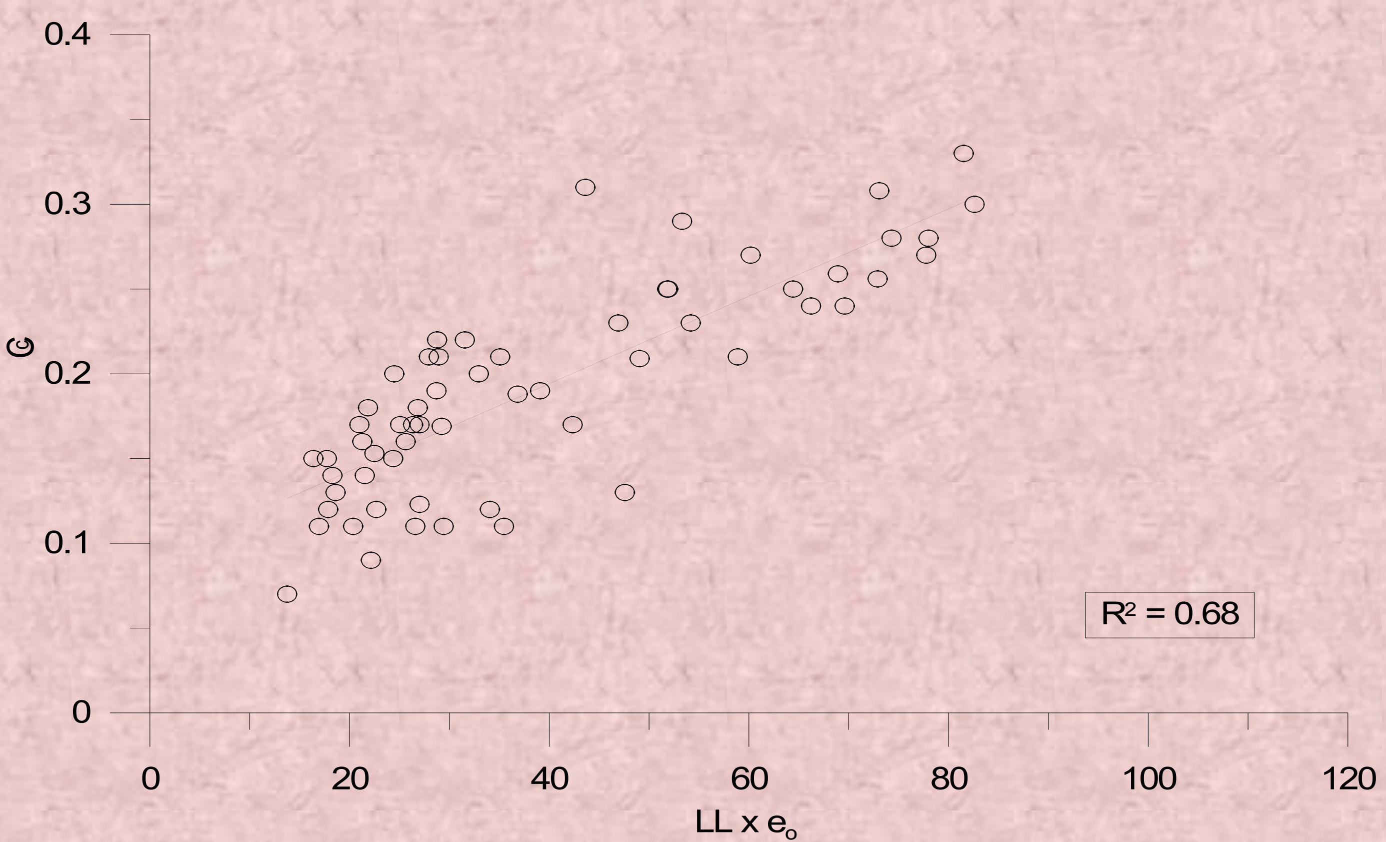


FIGURE 7. Compression Index versus Product of Liquid Limit and Void Ratio

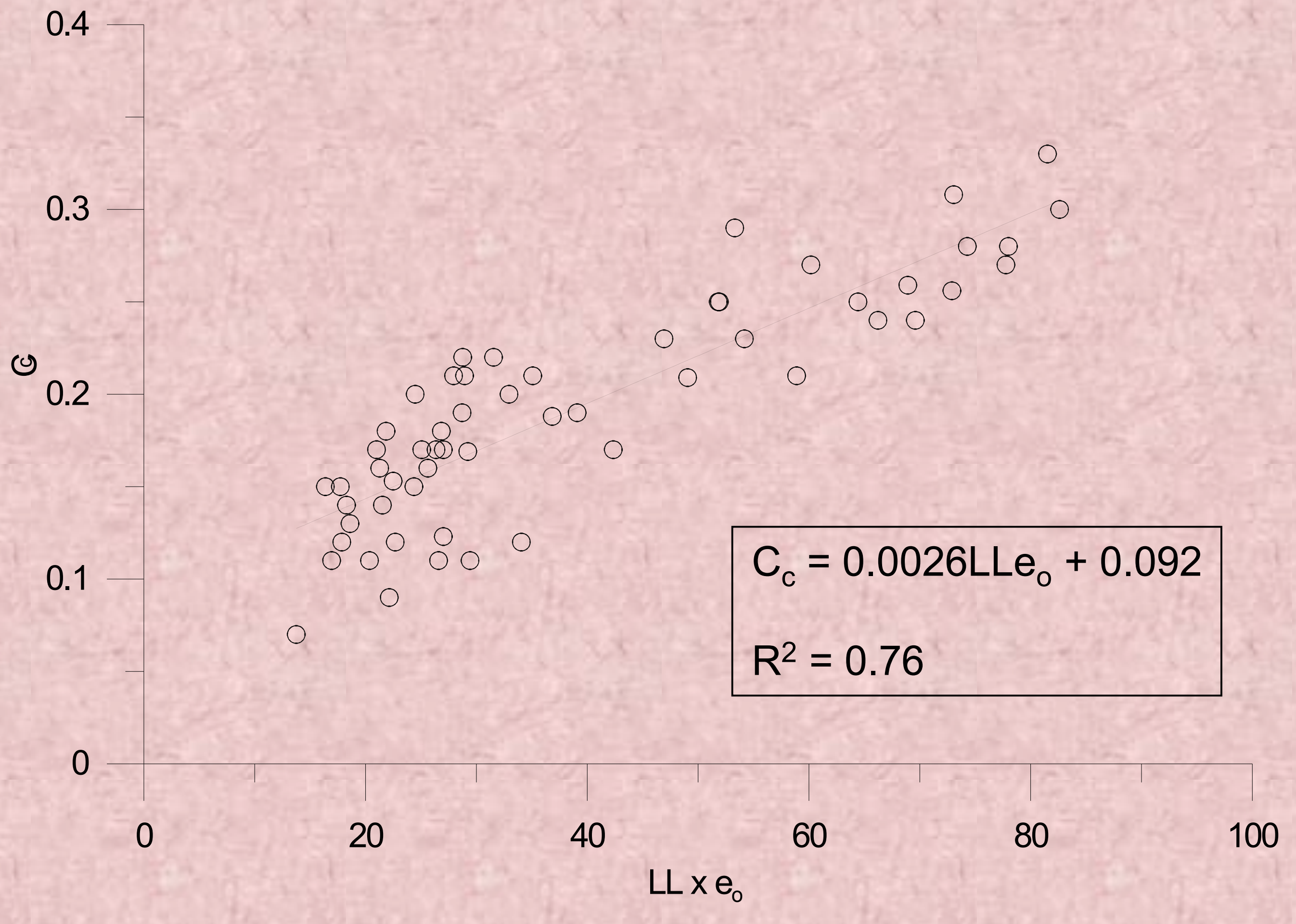
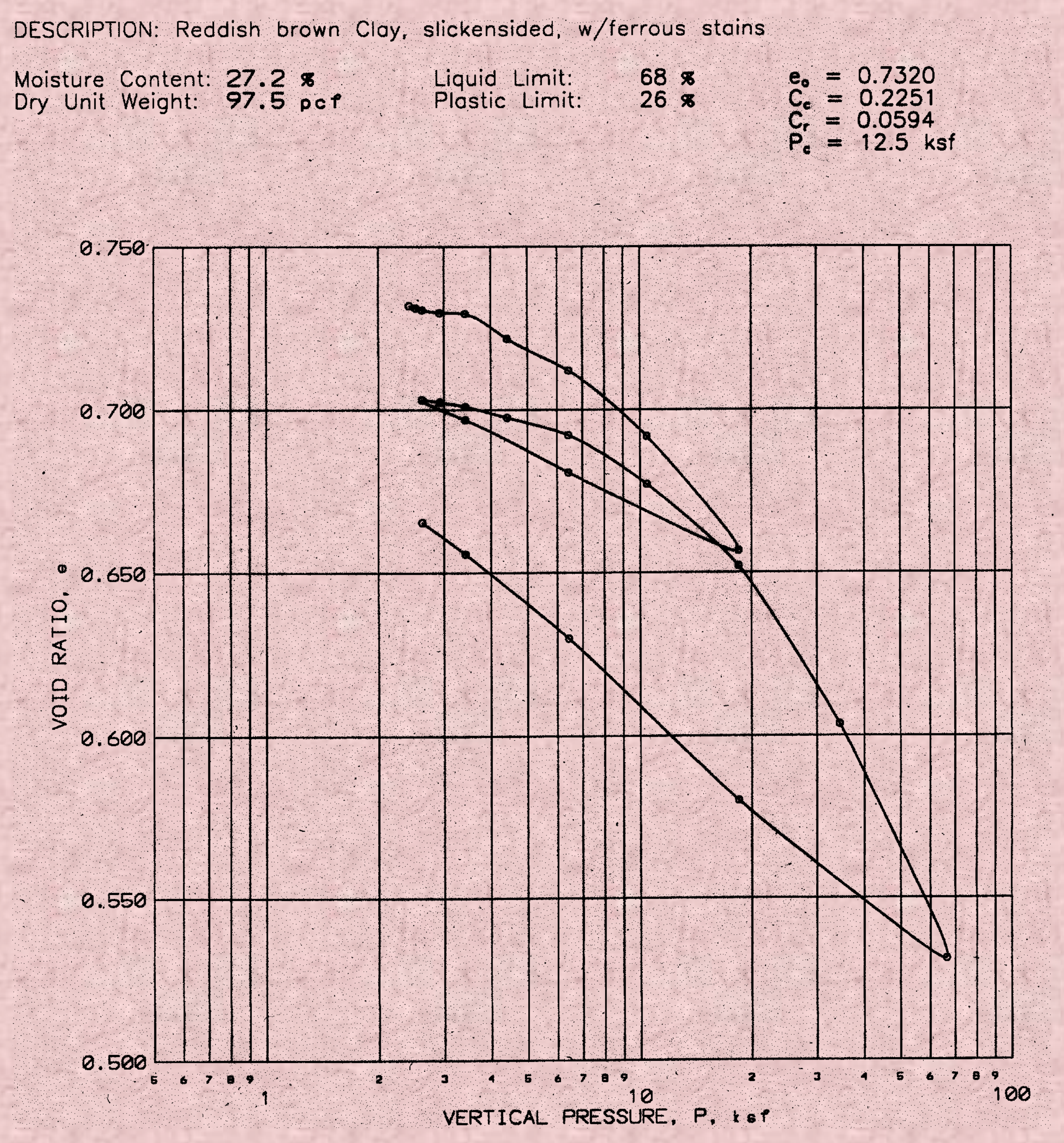


FIGURE 8. Compression Index versus Product of Liquid Limit and Void Ratio After Removing Outliers



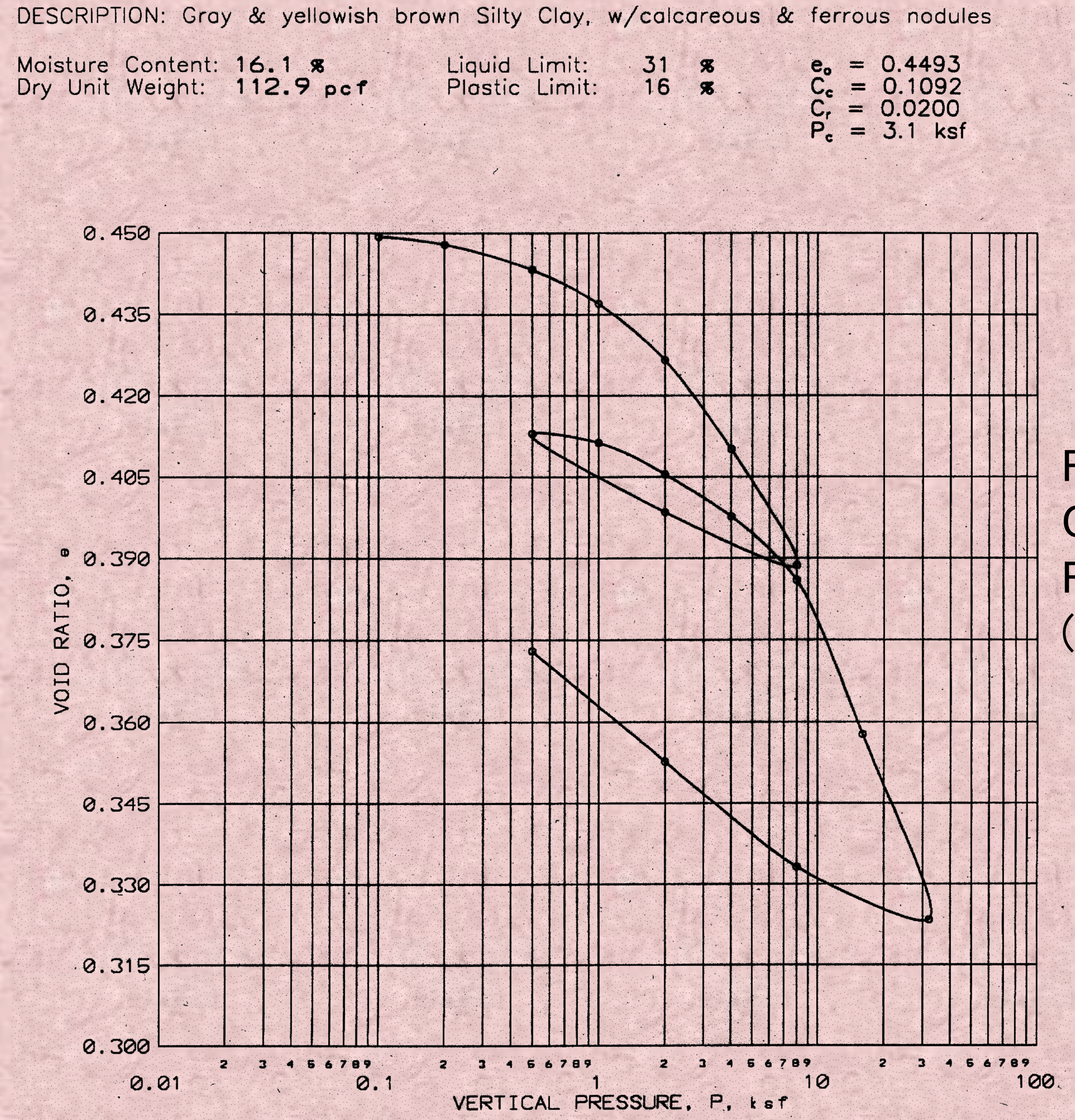
DESCRIPTION: Reddish brown Clay, slickensided, w/ferrous stains

Moisture Content: 27.2 %
Dry Unit Weight: 97.5 pcf

Liquid Limit: 68 %
Plastic Limit: 26 %

e_o = 0.7320
C_c = 0.2251
C_r = 0.0594
P_c = 12.5 ksf

FIGURE 9. Consolidation Curve for Beaumont Clay (Third Party Lab Result)



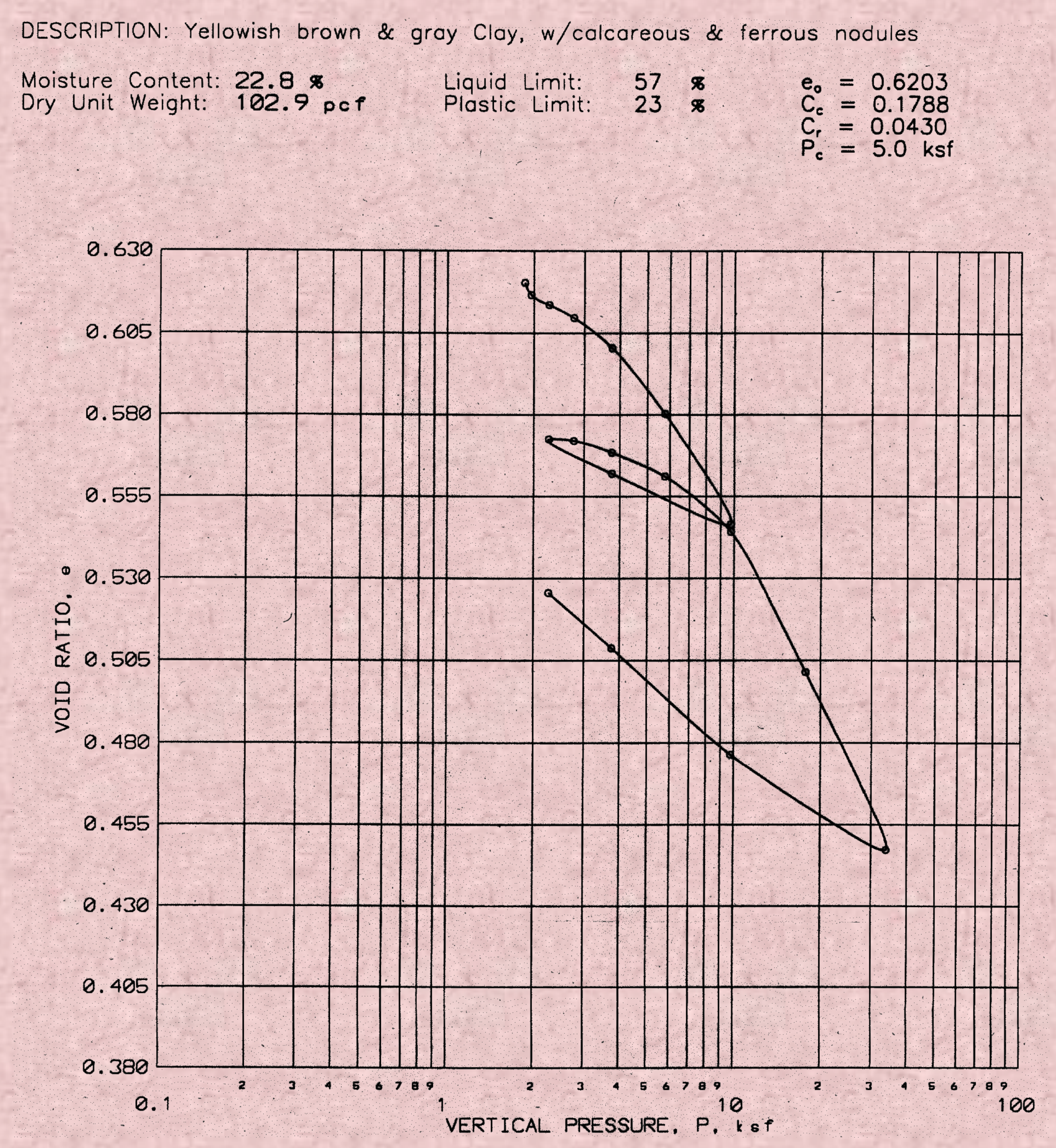
DESCRIPTION: Gray & yellowish brown Silty Clay, w/calcareous & ferrous nodules

Moisture Content: 16.1 %
Dry Unit Weight: 112.9 pcf

Liquid Limit: 31 %
Plastic Limit: 16 %

e_o = 0.4493
C_c = 0.1092
C_r = 0.0200
P_c = 3.1 ksf

FIGURE 10.
Consolidation Curve
For Beaumont Clay
(Third Party Lab Result)

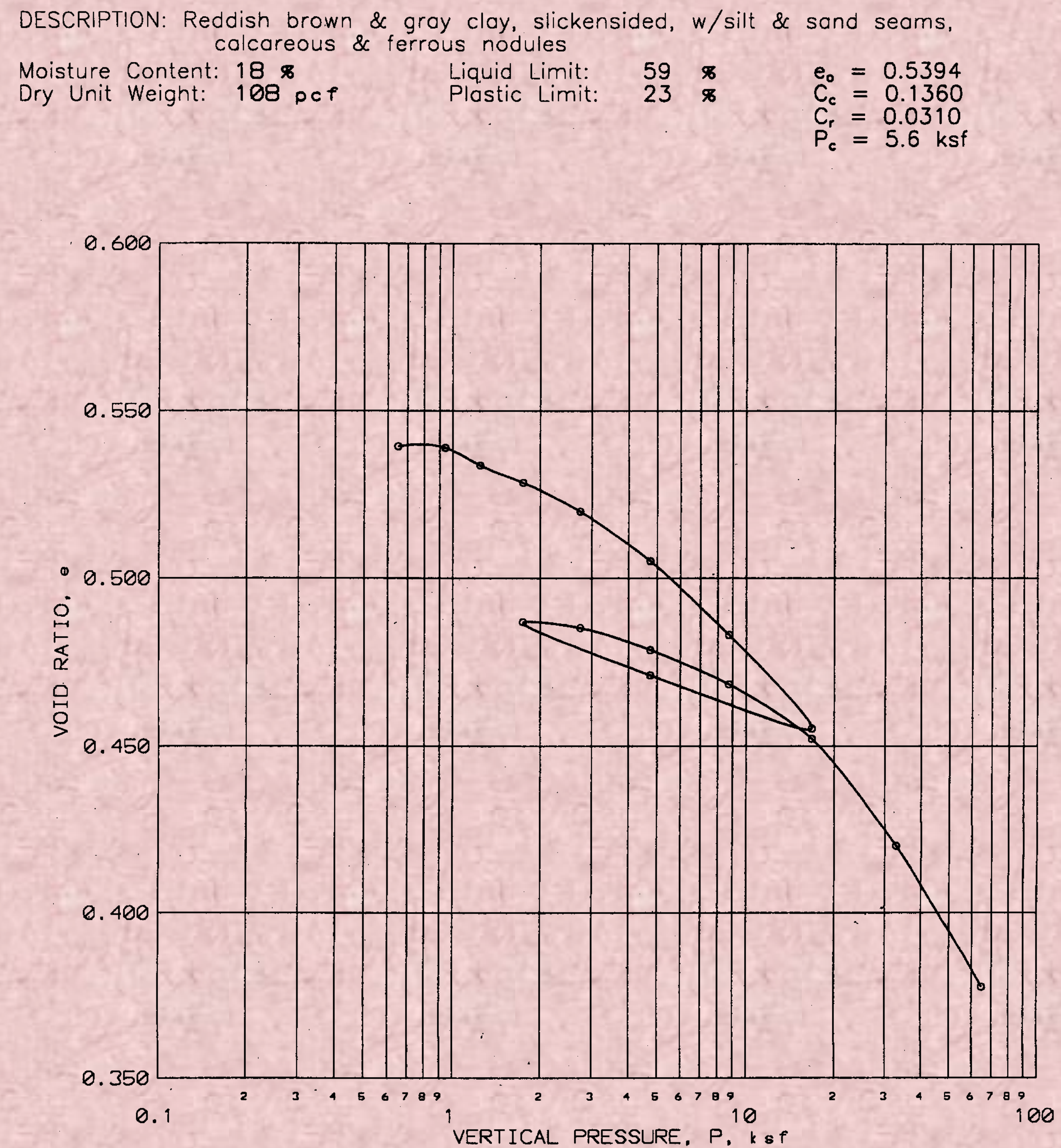

DESCRIPTION: Yellowish brown & gray Clay, w/calcareous & ferrous nodules

Moisture Content: 22.8 %
Dry Unit Weight: 102.9 pcf

Liquid Limit: 57 %
Plastic Limit: 23 %

e_o = 0.6203
C_c = 0.1788
C_r = 0.0430
P_c = 5.0 ksf

FIGURE 11. Consolidation Curve for Beaumont Clay (Third Party Lab Result)



DESCRIPTION: Reddish brown & gray clay, slickensided, w/silt & sand seams, calcareous & ferrous nodules

Moisture Content: 18 %
Dry Unit Weight: 108 pcf
Liquid Limit: 59 %
Plastic Limit: 23 %
e_o = 0.5394
C_c = 0.1360
C_r = 0.0310
P_c = 5.6 ksf

FIGURE 12.
Consolidation Curve for Beaumont Clay (Third Party Lab Result)

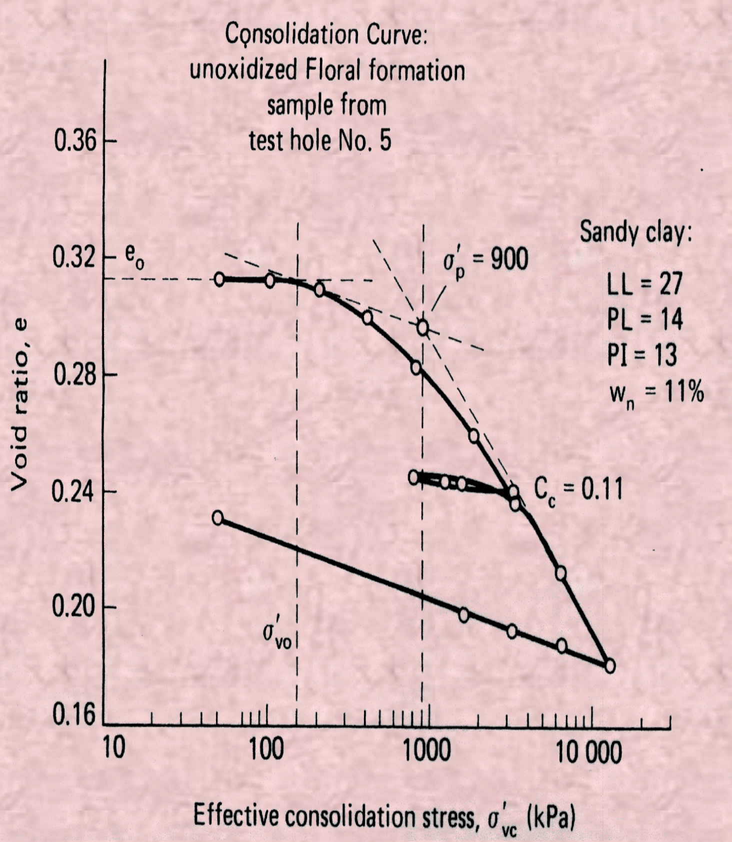


FIGURE 13

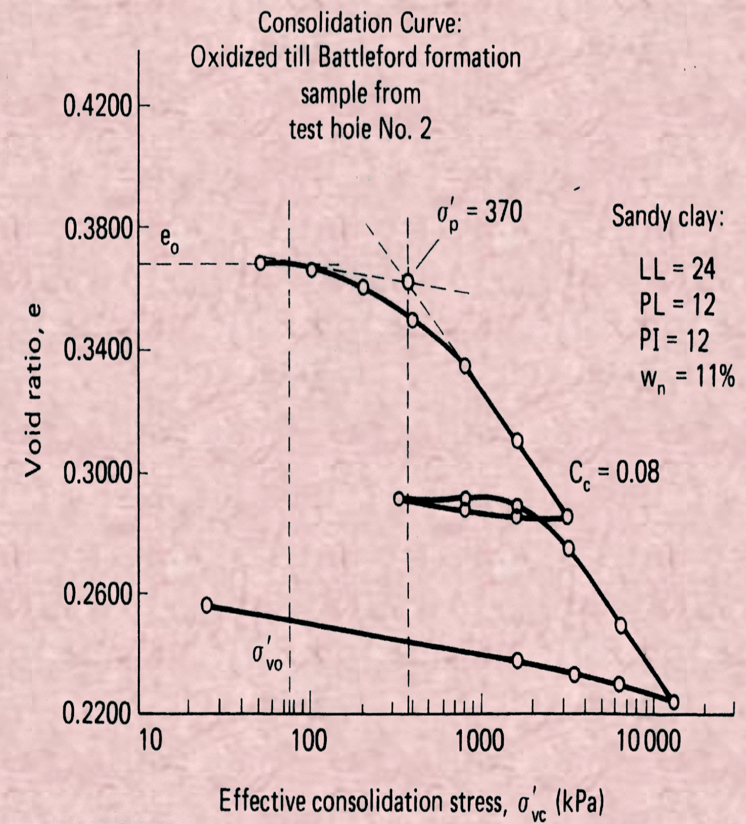


FIGURE 14

Consolidation Curves for Overconsolidated Clay Tills
（After MacDonald and Sauer, 1970）

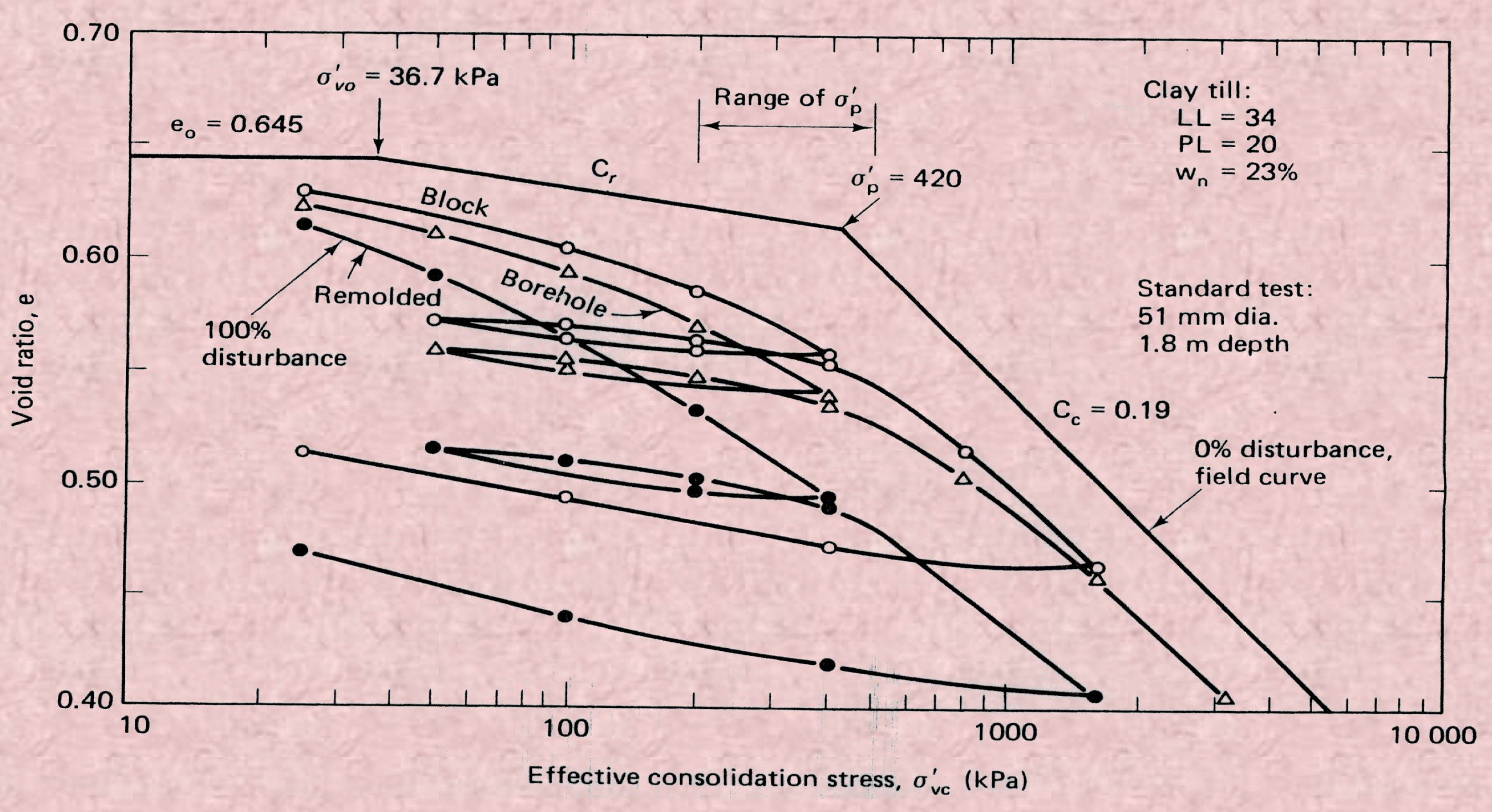


FIGURE 15. Consolidation Curve for Overconsolidated Clay Tills (After Soderman and Kim, 1970)

Equation No. 1 $C_r = 0.0007LLe_o + 0.01$

TABLE 2 Previous Published Equations for Recompression Index

Equation No.	**Recompression Index**	**Source**
3	$C_r = 0.126\ (e_o + 0.003LL - 0.06)$	Azzouz, Krizek & Corotis (1976)
4	$C_r = 0.142\ (e_o - 0.0009\ w_n$[1]$+ 0.006)$	Azzouz, Krizek & Corotis (1976)
5	$C_r = 0.003w_n + 0.0006LL + 0.004$	Azzouz, Krizek & Corotis (1976)
6	$C_r = 0.135(e_o + 0.01LL - 0.002w_n - 0.06)$	Azzouz, Krizek & Corotis (1976)
7	$C_r = 0.000463LLGs$[2]	Nagaraj and Murthy (1985)

[1] w_n denotes natural moisture content [2] Gs denotes specific gravity of solids

TABLE 3 Comparison Between Computed and Actual C_r Values

Equation No.	**Computed C_r**						
	Figure 9	**Figure 10**	**Figure 11**	**Figure 12**	**Figure 13**	**Figure 14**	**Figure 15**
1	0.045	0.020	0.035	0.032	0.016	0.016	0.025
3	0.110	0.061	0.092	0.083	0.042	0.048	0.087
4	0.101	0.063	0.086	0.075	0.044	0.052	0.089
5	0.126	0.071	0.107	0.093	0.053	0.051	0.093
6	0.175	0.090	0.145	0.139	0.068	0.071	0.119
7	0.085	0.039	0.071	0.074	0.034	0.030	0.043
Actual C_r	*0.059*	*0.020*	*0.043*	*0.031*	*0.014*	*0.010*	*0.028*

Summary of Comparison for C_r

- Azzouz et al equations overestimate by 2 to 4.5 times
- Nagaraj and Muthy's equations overestimate C_r values 1.5 to 3 times

Equation No. 2 $C_c = 0.0026LLe_o + 0.092$

TABLE 4 Previous Published Equations for Compression Index

Equation No.	**Compression Index**	**Source**
6	$C_c = 0.37(e_o+0.003LL-0.34)$	Azzouz, Krizek & Corotis (1976)
7	$C_c = 0.40(e_o+0.001w_n-0.25)$	Azzouz, Krizek & Corotis (1976)
8	$C_c = 0.009w_n+0.002LL-0.1$	Azzouz, Krizek & Corotis (1976)
9	$C_c = 0.37(e_o+0.003LL+0.0004w_n-0.34)$	Azzouz, Krizek & Corotis (1976)
10	$C_c = 0.5((1 + e_o)/Gs)^{2.4}$	Rendon-Herrero (1980)
11	$C_c = 0.009w_n-+ 0.005 LL$	Koppula (1981)
12	$C_c = 0.002343 LL Gs$	Nagaraj and Murthy (1985)

TABLE 5 Comparison Between Computed and Actual C_c Values

Equation No.	**Computed C_c**						
	Figure 9	**Figure 10**	**Figure 11**	**Figure 12**	**Figure 13**	**Figure 14**	**Figure 15**
2	0.221	0.128	0.184	0.175	0.11	0.11	0.15
6	0.221	0.075	0.167	0.139	0.02	0.04	0.15
7	0.204	0.086	0.157	0.123	0.03	0.05	0.17
8	0.281	0.107	0.219	0.180	0.05	0.05	0.18
9	0.225	0.077	0.170	0.142	0.02	0.04	0.15
10	0.172	0.112	0.147	0.130	0.09	0.10	0.15
11	0.585	0.300	0.490	0.457	0.23	0.22	0.38
12	0.430	0.196	0.361	0.373	0.17	0.15	0.21
Actual C_c	*0.225*	*0.109*	*0.179*	*0.136*	*0.11*	*0.08*	*0.19*

Summary of Comparison for C_c

- Azzouz et al equations 6 and 9 work well for higher LL but underestimate at lower LL
- Rendon-Herrero's equation 10 generally underestimates, although close to the actual values
- Kopulla's equation 11 and Nagaraj and Muthy's equation 12 significantly overestimate C_c values

Conclusions

- Significant overestimation was observed for C_r values using the previous relationships
- For C_c, the difference using the author’s equation and some previous correlations (Azzouz et al and Rendon-Herrero) was not significant. However, the author’s equation appear to be in better agreement with the observed values

QUESTIONS ???