Bachelor Thesis

**Degree Project in
Marine Geology 15 hp**

Consolidation characteristics and permeability of Quaternary sediments from the Lomonosov Ridge, Central Arctic Ocean; A Study in consolidation behaviour of marine sediments

Niklas Wikesjö

Stockholm 2014

Department of Geological Sciences
Stockholm University
SE-106 91 Stockholm

Contents

Abstract

The LOMROGIII 2012 (LR) expedition and the Arctic Coring Expedition (ACEX) 2004 both recovered sediments from the Lomonosov Ridge (Figure 1). The consolidation and compression characteristics coupled with permeability and porosity results from ACEX were used to compare with tests on LR samples. The samples from LR were also tested as remolded to compare with undisturbed samples to investigate what the differences were. The LR results showed similar compression characteristics as ACEX, but the permeability and porosity results were showing slightly different trends. The remolded samples compared to the undisturbed samples showed a clear difference in the Compression index (Cc) where remolded samples displayed a significantly lower value. If the data can be used to model regionally is unclear and more testing is suggested.

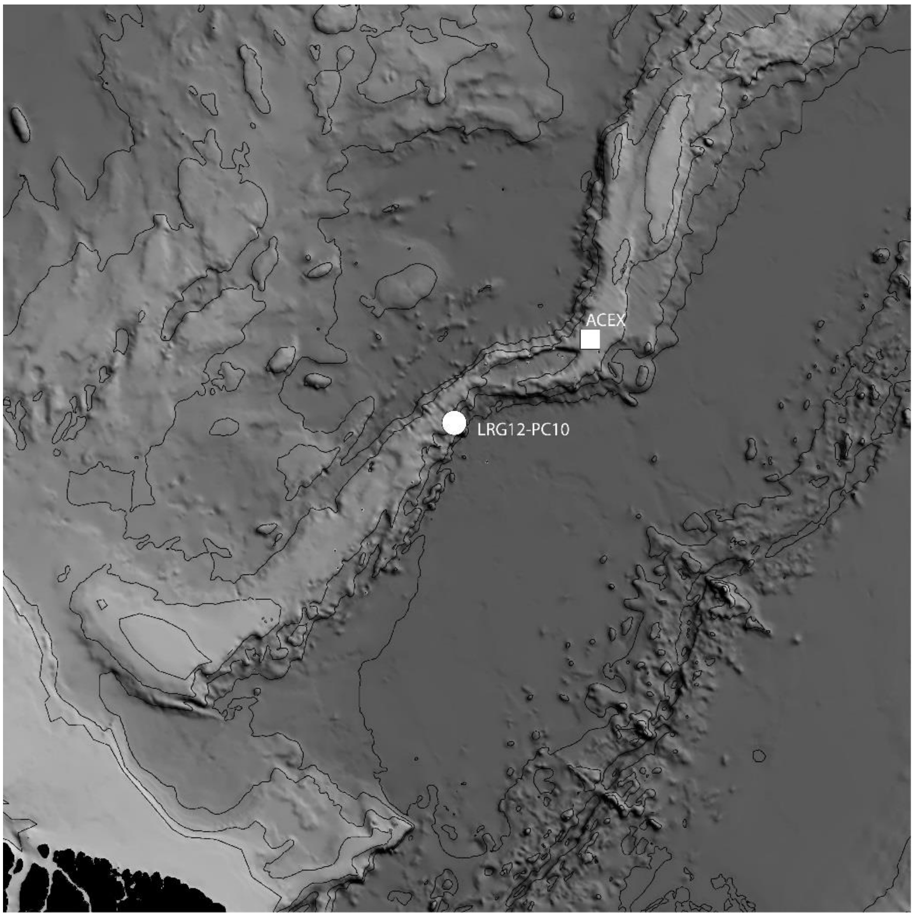


Figure 1. An overview of the two sites Lomrog12-PC10 and ACEX

Introduction

The physical properties of sediments are important for modelling many geologic processes. In particular, it is critical to define how the porosity and permeability evolve during burial. One dimensional consolidation tests provide a way to quantitatively evaluate these processes and can also be used to assess the stress, or burial history of sediments and soils (Terzaghi. 1943). Consolidation tests are commonly used in the construction field to predict the amount of settlement under a new building. Post building soil compaction is a hazard the construction companies don't take lightly as it can cause major structural damage. In this field the amount of settlement and the settlement rate are often calculated for the specific structure or foundation.

Sediments consolidate under increasing levels of effective stress. Effective stress is equivalent to the buoyant weight of the overlying sediment column.

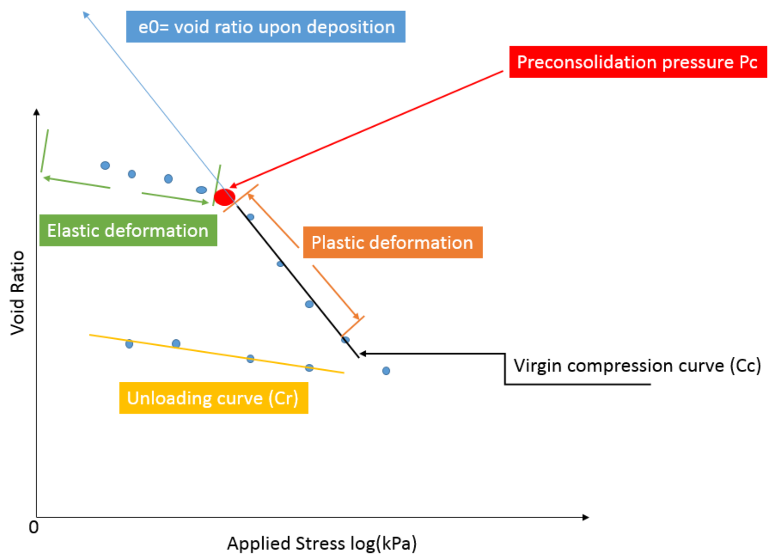


Figure 2. A theoretical example of a consolidation curve. Preconsolidation pressure is showed as a red dot. The black line is representing the Virgin compression curve. The Recompression index is indicated with a yellow line. The void ratio upon deposition is displayed as the blue line intercepting the y axis at 1kPa.

Consolidation occurs through a time dependant process, when the applied load is gradually transferred from the pore water as it dissipates, to the sediment structure. The total amount of settlement under any applied load depends on the compaction characteristics of the sediments, while the rate is a function of permeability. One dimensional consolidation tests allow us to recreate the stress history. The sediment structure remembers the greatest overburden stress it has experienced, this is because the sedimentary matrix is elastic until the point of maximum overburden pressure is passed where the deformation will become plastic (Figure 2). Primary consolidation is defined as when all the excess pore pressure has dissipated.

Through consolidation testing five key parameters can be defined as the loads is applied past the point of elastic deformation.

Preconsolidation pressure (Pc) also known as the maximum past pressure a sediment has been subjected to (Figure 2).

Compression index (Cc) describes the change in void ratio as a function of applied stress. This defines the sediments compressibility as the slope of the line on the virgin compression curve (Figure 2). The Cc from Holtz and Kovacs, (1981).

Recompression index (Cr) is graphically determined as the curve during the unloading sequence. The recompression index is given by the slope of the unloading curve (Figure 2).

Void ratio upon deposition (e_0) is a ratio of void volume over the volume of solids. The void ratio is closely linked to porosity (Figure 2).

Permeability (K_i) is a fundamental property of the sediment matrix. The rate of fluid flow through sediment is a function of both permeability and the physical properties of the fluid. The hydraulic conductivity (*k*) is the rate of fluid flow also known as Darcy's coefficient of permeability. It is derived during consolidation tests from time deformation data during each loading step using Terzaghi´s (1943) theory of consolidation.

Hydraulic conductivity is given in cm/s and can be used to calculate the permeability in m^2. Permeability is a fluids ability to flow through a medium, the sediments determine the intrinsic permeability.

The Lomonosov Ridge divides the Amerasian basin and the Eurasian basin and stretches 1800 km from the New Siberian Islands to the Ellesmere Island of the Canadian Arctic Archipelago. The Integrated Ocean Drilling Program Expedition 302 Arctic Coring Expedition (ACEX) was the first serious attempt to core and retrieve sediments from the central Arctic Ocean. The ACEX project penetrated 428 m of Cenozoic sediments on the crest of the Lomonsov Ridge, and resulted in a total of 339.06 m core recovered. The upper 190 m of this record was composed of Neogene glaciomarine silty clays. A series of nine consolidation tests were performed by O'Regan et al. (2009) showing that the compaction characteristics and permeability of these sediments remained remarkably similar throughout this 190 m Neogene sequence.

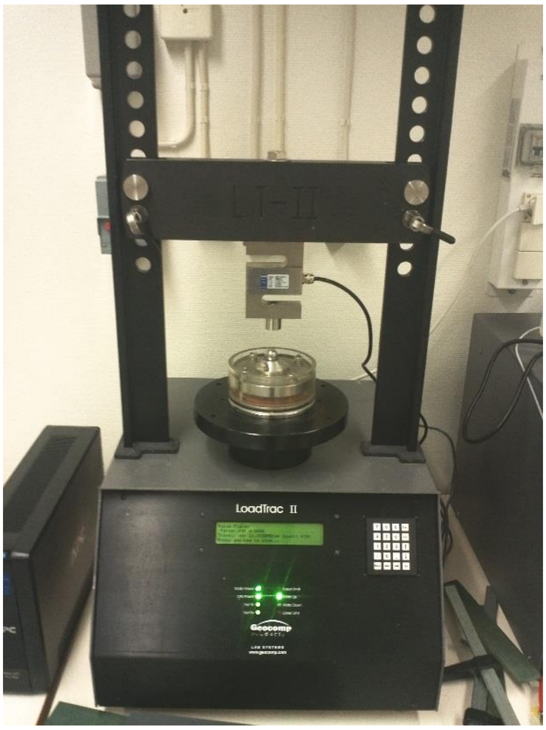
In 2012, the Oden returned to the Lomonosov Ridge as part of the joint Danish-Swedish LOMROGIII expedition (LR). 21 cores were retrieved during LR. 10 with a piston core and 11 with a trigger core. One of these cores, PC10, was not opened shipboard, and reserved for post cruise geotechnical testing.

The results from 3 consolidation tests on this core are compared to the results reported from ACEX to test whether Quaternary sediments from the Lomonosov ridge collected ~150km away from ACEX display similar compaction and permeability relationships, and if they can be used as input for regional modelling.

Method

Consolidation tests

One dimensional incremental load consolidation tests were performed on 3 samples. It is called one dimensional consolidation because the stress is only applied in the vertical direction, the sample is placed inside a confining ring and the pressure is exerted vertically. The steps are defined beforehand in the Loadtrac-II software. The Loadtrac-II system by Geocomp^{TM} (Geocomp Corporation) is a fully automated system. The consolidometer must be able to hold the same pressure while the sample is compacting, this is done by a micro stepper motor which raises the platen. The incremental load implies that the stress is exerted in a step by step procedure. The consolidation tests and sample preparation conformed to the American Society for Testing and Materials Standard D2435-04(ASTM International, 2007).



Picture 1. The picture shows the load frame and consolidation cell.

Sample preparation was done by taking a whole core cutting ~6cm off and trimming it to fit the confining ring. Once trimmed the wet mass of the sample and confining ring was recorded before the sample was transferred to the consolidation cell which was submerged in water. During the sample preparation a piece of trimmings were saved for grain density measurements. A second piece of each sample was saved and remolded to test how remolded characteristics compare to undisturbed.

The consolidometer was first calibrated with filter paper and porous stones in place to be able to correct for machine deformation during loading. A total of 18 applied stresses were performed on the Loadtrac. The selected steps was chosen so that the preconsolidation pressure was exceeded, with a load increment ratio of 1 beginning at 5kPa to 10240kPa. After maximum stress had been applied six steps of unloading was performed 5120kPa, 1280kPa, 640kPa, 160kPa, 40kPa, and 10kPa.

The Loadtrac determines when to end each loading step by the use of Terazaghi´s theory of consolidation, which is built upon seven assumptions (Table 1). During each step the software monitors the sample displacement and automatically determines when primary consolidation has ended. This is done by monitoring time-deformation data.

1. The clay is homogenous and the degree of saturation is 100%.

2. Drainage is provided at the top and or the bottom of a compressible layer.

3. Darcy´s law (v=ki) is valid.

4. The soil grains and the pore water are incompressible.

5. Both the compression and flow of water are one-dimensional.

6. The load increment results in small strains so that the coefficient of permeability k and the coefficient of compressibility a_v remain constant.

7. There is no secondary compression.

Table 1. Terazaghi`s seven assumptions which are applied to one dimensional consolidation tests.

Common errors associated with consolidation tests are; disturbance during trimming and sample preparation; poor fitting of the specimen in the confining ring; porous stones having to low permeability; friction between ring and specimen; improper loads and specimen height according to Rollings and Rollings (1996). These errors and disturbances can erase the preconsolidation pressure, as the change from elastic to plastic response in disturbed samples will be difficult to interpret. This can result in a lowering of the Cc slope and an increase in the Cr slope.

Grain Density

Grain density measurements were done on an Accupyc-II 1340™ (Micromeritics Instrument Corporation) helium displacement pycnometer. Dried samples were grinded with pestle and mortar and transferred to the measurement vial and then weighed. The pycnometer was set to measure over 5 steps, each step using 2 different pressures, through these steps the average volume and density was given with a standard deviation.

Initial Void Ratio E0, Compression Index Cc, Recompression Index Cr and Porosity

During consolidation testing, changes in sample height are used to calculate the porosity, or void ratio, at the end of each loading step. Porosity is commonly expressed in percentages of volume voids over the total volume of sample, and void ratio is easily converted to porosity. Porosity and void ratio controls the hydraulic conductivity which is a measurement of fluid flow through a given medium. Porosity and void ratio their relationship can be given through Day (2001), using the following equation:

$$\phi = \frac{e}{1 + e}$$

Where ϕ is porosity
e is void ratio

During each loading step, the void ratio is defined with the following equation:

$$e = \frac{V_V}{V_S} = \frac{1 - \left(\frac{\Delta h}{h_0}\right) - V_S}{V_S}$$

Were the V_V is volume void cm^3
V_S is volume solids cm^3
Δh is the change in height in cm
h_0 is initial height in cm

The Compression index (Cc) equation:

$$C_c = \frac{\Delta e}{\log\left(\frac{\sigma'_{vc2}}{\sigma'_{vc1}}\right)}$$

Where C_c is dimensionless
Δe is the difference in void ratio e_1-e_2 in decimal
σ_{vc1} and σ_{vc2} is the effective stress in kPa.

The values used to calculate the Cc were 320kPa, 640kPa, 1280kPa, 2560kPa.

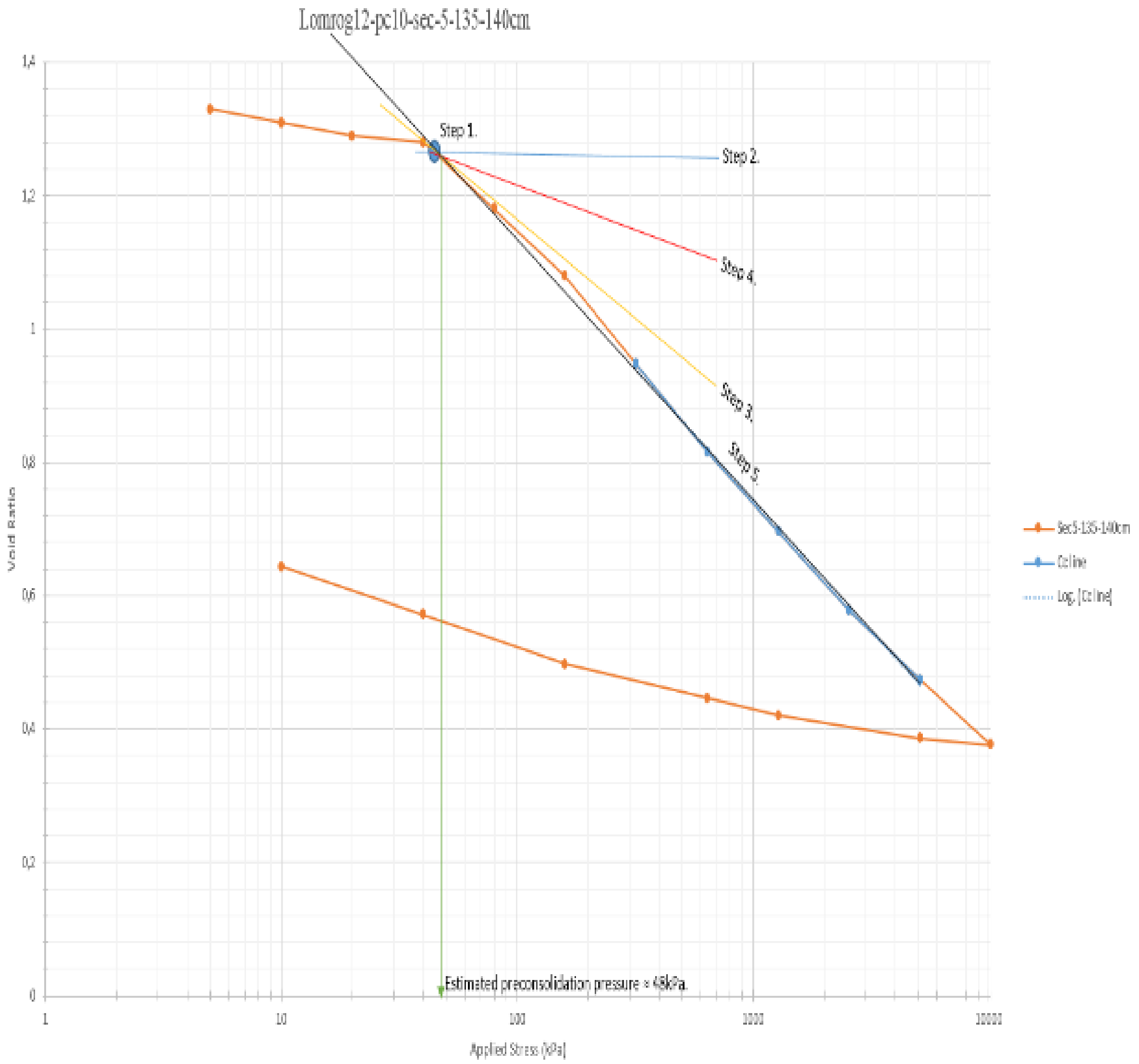
Initial void ratio e_0 is calculated using a regression analysis with values from the Cc curve and setting the y intercept to 1kPa.

The Recompression index (Cr) is defined as:

$$Cr = \frac{\Delta e}{\log\left(\frac{\sigma'_{vc2}}{\sigma'_{vc1}}\right)}$$

Where C_r is dimensionless
Δe is the difference in void ratio e1-e2 in decimal
σ_{vc1} and σ_{vc2} is the effective stress in kPa

The values used to calculate the Cr were 5120kPa, 1280kPa, 640kPa, 160kPa, 40kPa.



Preconsolidation Pressures

The maximum past pressure also known as the pre-consolidation pressure was calculated with the Casagrande construction technique (Casagrande, A., 1936) this method is done by five steps (Figure 4).

(1) Find a point of maximum curvature (large blue dot).

(2) Draw a horizontal line from the blue dot (thin blue line).

(3) Draw a tangent to the curve (yellow line).

(4) Bisect the angle made by step 2 and 3 (red line).

(5) Extend the virgin compression curve with a line until it meets the line created in step 4 (black line).

Figure 3. Is showing step by step how the Casagrande method interprets preconsolidation pressure. Done on an actual sample from the Lomonosov Ridge.

Permeability and Hydraulic conductivity

The relationship between hydraulic conductivity (k) and permeability (K_i), which is known as intrinsic permeability, is given by the following equation:

$$K_i = \frac{k\mu}{\rho g}$$

Where K_i is in m^2
k = hydraulic conductivity m/s
g = gravity constant 9,81m/s^2
μ = absolute or dynamic viscosity, Pa-s,
ρ = fluid density, kg/m^3

Hydraulic conductivity is calculated using the following equation:

$$k = C_v * M_v * \gamma_w$$

Where C_v is the Coefficient of consolidation
M_v is the Coefficient of Volume Compressibility
γ_w is the unit weight of water at 20°C, 9,80665kN/m^3
k is hydraulic conductivity measured in cm/s

The effective stress calculations was performed on high resolution bulk density data acquired post cruise on the multi sensor core logger at Stockholm University.

Effective stress (σ'_{v1}) calculation:

$$\sigma'_{v1} = (\mathrm{P}B - \mathrm{P}W) * g * z$$

Where PB = Bulk density g/cm^3
σ'_{v1} = Effective stress kPa
PW = Density of water (assumed to 1,024g/cm^3)
g = Gravity 9.81m/s^2
z = Depth in meters below sea floor

Stress History

The overconsolidation describes the stress history of sediments and can be calculated through overconsolidation ratio (OCR):

.

$$OCR = \frac{\sigma'_{vm}}{\sigma'_{v1}}$$

Where $\sigma`_{vm}$ is the same as preconsolidation pressure P_c given by Casagrande method in kPa.
$\sigma`_{v1}$ Current in situ effective stress in kPa.

The stress history can be one of three cases either under-consolidated (OCR < 1), normally-consolidated (OCR = 1), or over-consolidated (OCR > 1).

Under-consolidated sediments is not fully consolidated as the present pore water pressure is in excess. This is a common feature were high sedimentation rates are present, and there hasn't been enough time for the sediment to consolidate.

Normally-consolidated sediments are fully consolidated to the current overburden and has never been exposed to a greater pressure.

Over-consolidated sediments have been subjected to a higher effective stress than is currently present. This is common in high erosional environments.

Quantifying the OCR will provide a useful parameter to interpret the past applied stress for the sediments. If the OCR is higher than 1 our sediments have been subjected to a higher stress than is present, and if lower than 1 it will tell us that the sediments have not yet been able to consolidate fully. The process of consolidation is largely dependent on permeability.

Results

The LR calculations of e_0 is done by using the intercept of y, and the calculation of Cr and Cc is done by using the slope function y over 320kPa to 2560kPa.

Sample	**Sample Depth meters below sea floor (mbsf)**	**Grain Density (g/cm³)**	**e_o**	**Cr**	**Cc**
LOMROG12-PC10-SEC-1	0.905	2.7133	1.590	0.052	0.310
LOMROG12-PC10-SEC-1-REMOLDED	0.905	Standard deivation Sec1 =0.0030	1.310	0.062	0.267
LOMROG12-PC10-SEC-3	3.897	NM Assumed to 2.71	1.900	0.071	0.371
LOMROG12-PC10-SEC-3-REMOLDED	3.897	NM Assumed to 2.71	1.570	0.075	0.305
LOMROG12-PC10-SEC-5	6.806	2.7339	1.960	0.088	0.408
LOMROG12-PC10-SEC-5-REMOLDED	6.806	Standard deviation Sec5 =0.0026	1.480	0.086	0.274
ACEX-M0003A-3H3-A	18.62	NM Assumed to 2.71	1.990	0.107	0.433
ACEX-M0003A-3H3-B	18.67	NM Assumed to 2.71	1.883	0.107	0.405
ACEX-M0002A-10X1-A	42.98	NM Assumed to 2.71	1.764	0.095	0.375
ACEX-M0002A-10X1-B	43.02	NM Assumed to 2.71	1.639	0.086	0.341
ACEX-M0002A-20X1-A	87.61	NM Assumed to 2.71	1.790	0.086	0.360
ACEX-M0002A-20X1-B	87.66	NM Assumed to 2.71	1.764	0.104	0.353

Table 2 Lomrog12-PC10 and ACEX sample results of e_0, C_r, C_c, and Grain Density. NM = Not measured.

The values from Lomrog12 and ACEX are all in similar range with no outliers (Table2).

Pearson Correlation Coefficient					
Sec1		Sec3		Sec5	
Cc	0.999	Cc	0.999	Cc	0.999
Cr	0.982	Cr	0.998	Cr	0.978
Sec1 Remolded		Sec3 Remolded		Sec5 Remolded	
Cc	0.999	Cc	0.999	Cc	0.998
Cr	0.977	Cr	0.989	Cr	0.967

Table 3. The Pearson correlation coefficient for all LR samples tested.

The Pearson Correlation Coefficient is describing how close the values are to the line plotted. It is the same as the R^2 plotted on graphs. It is basically saying how good the estimations are. Where 1 is perfect and all data points are plotted on the line, a low value would indicate outliers.

Sample	Pc (kPa)	OCR	In situ effective stress (kPa)
LOMROG12-PC10-SEC-1	48	7.02	6.84
LOMROG12-PC10-SEC-3	42	1.47	28.63
LOMROG12-PC10-SEC-5	49	1.23	48.11

Table 4. Lomrog12-PC10-Sec1-Sec5 Calculated preconsolidation, overconsolidation ratio, and Effective stress.

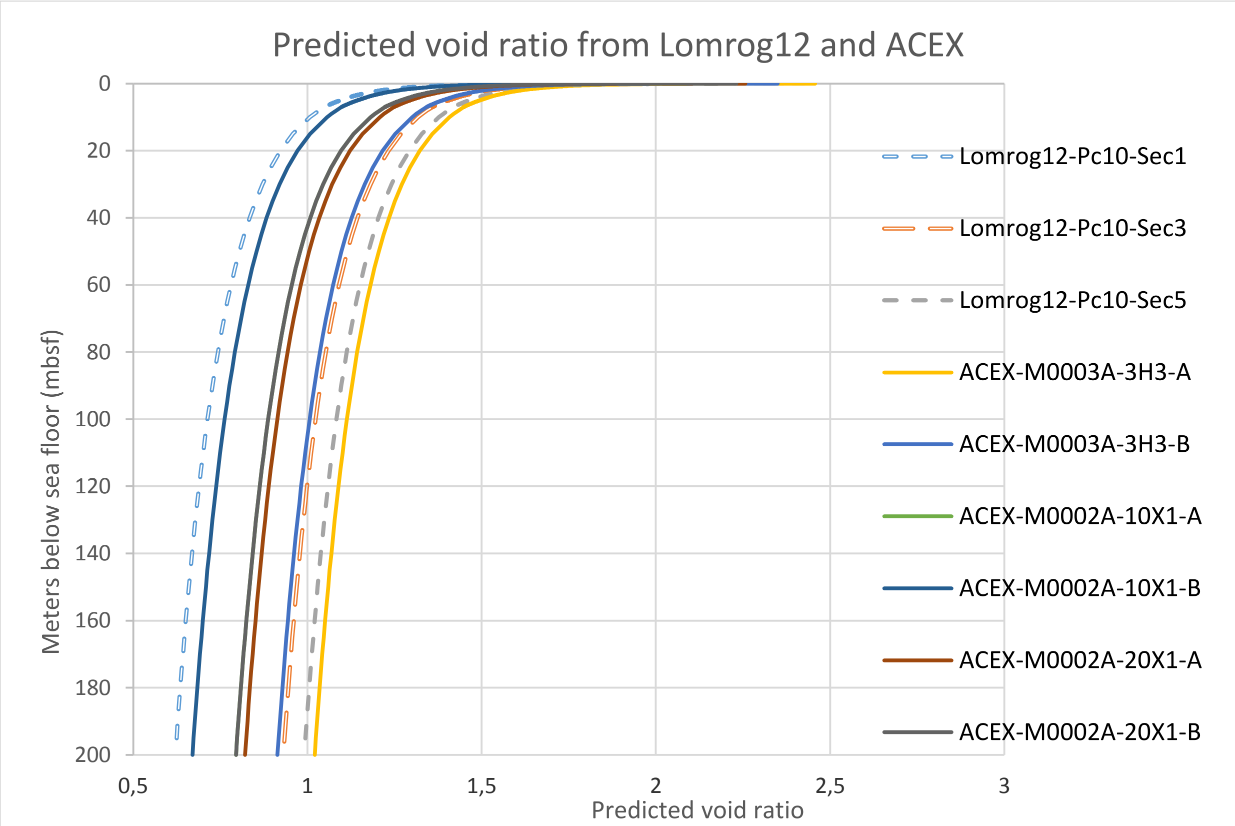


Figure 4. Prediction of void ratio from LR and ACEX.

The predicted void ratio from LR and ACEX shows that two of the LR samples plot within the ACEX predictions of void ratio.

Predicted Void ratio at 200mbsf	
ACEX-M0003A-3H3-A	1,021
Lomrog12-PC10-Sec5	0.991
Lomrog12-PC10-Sec3	0.931
ACEX-M0003A-3H3-B	0.914
ACEX-M0002A-20X1-A	0.821
ACEX-M0002A-20X1-B	0.795
ACEX-M0002A-10X1-A	0.795
ACEX-M0002A-10X1-B	0.670
Lomrog12-PC10-Sec1	0.621

Table 5. The predicted void ratio at 200mbsf in decreasing order from top to bottom.

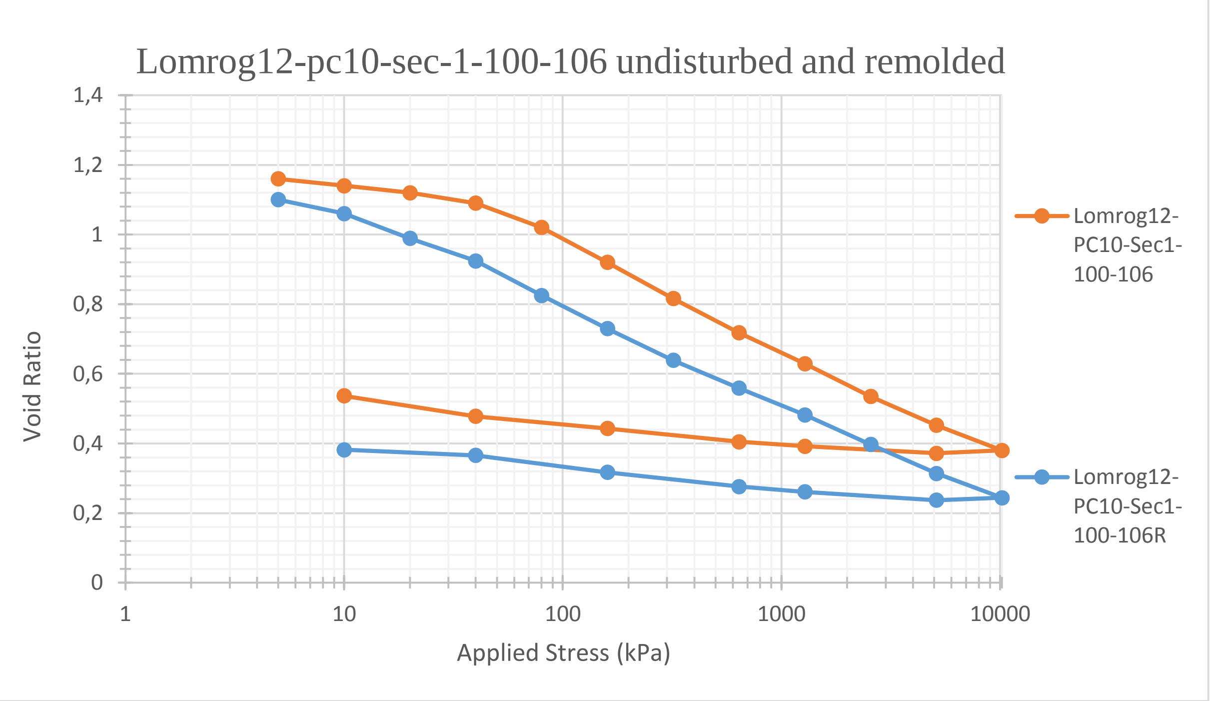


Figure 5. Lomrog12-Pc10-Sec1 Remolded and undisturbed samples consolidation curve.

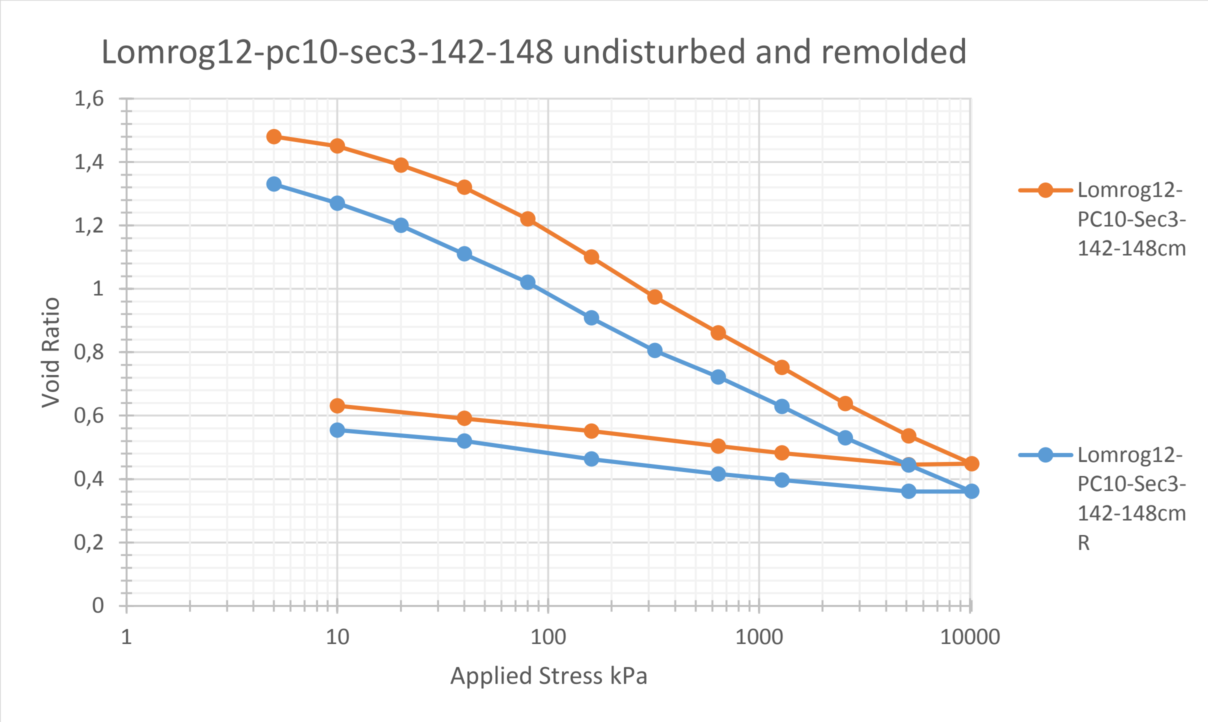


Figure 6. Lomrog12-Pc10-Sec3 Remolded and undisturbed samples consolidation curve.

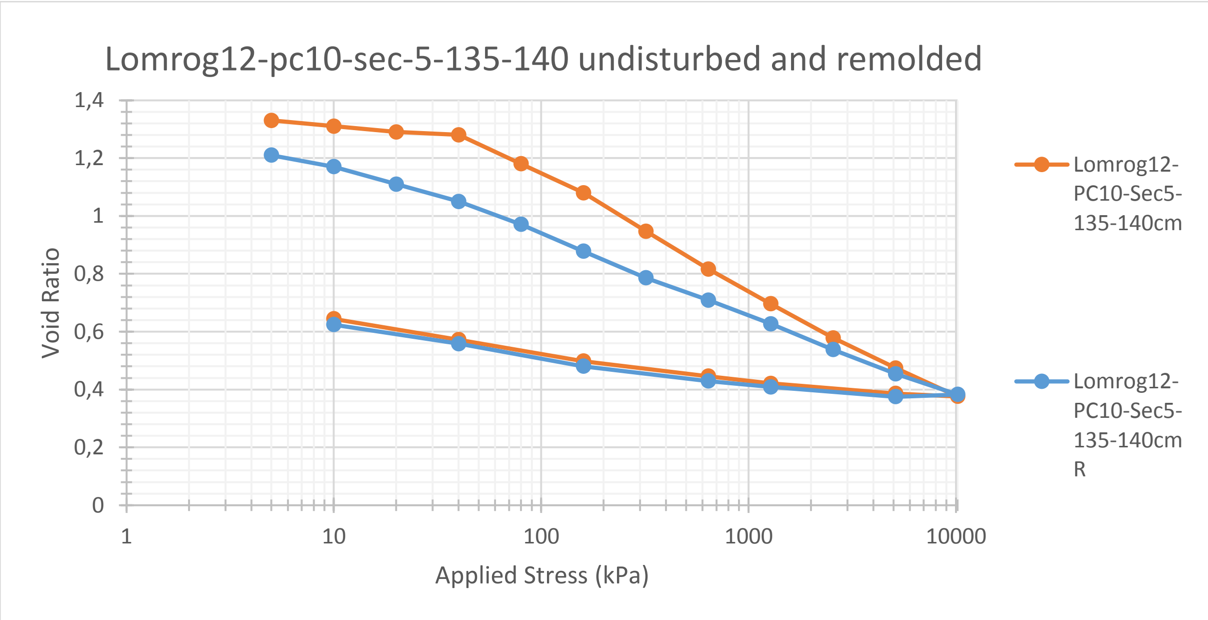


Figure 7. Lomrog12-Pc10-Sec3 Remolded and undisturbed samples consolidation curve.

All remolded sediments are showing a similar trend compared to the undisturbed samples. The Cc is lower and the Cr increases in all but Sec5, but compared to the Cc values the Cr values are significantly higher for remolded sediments.

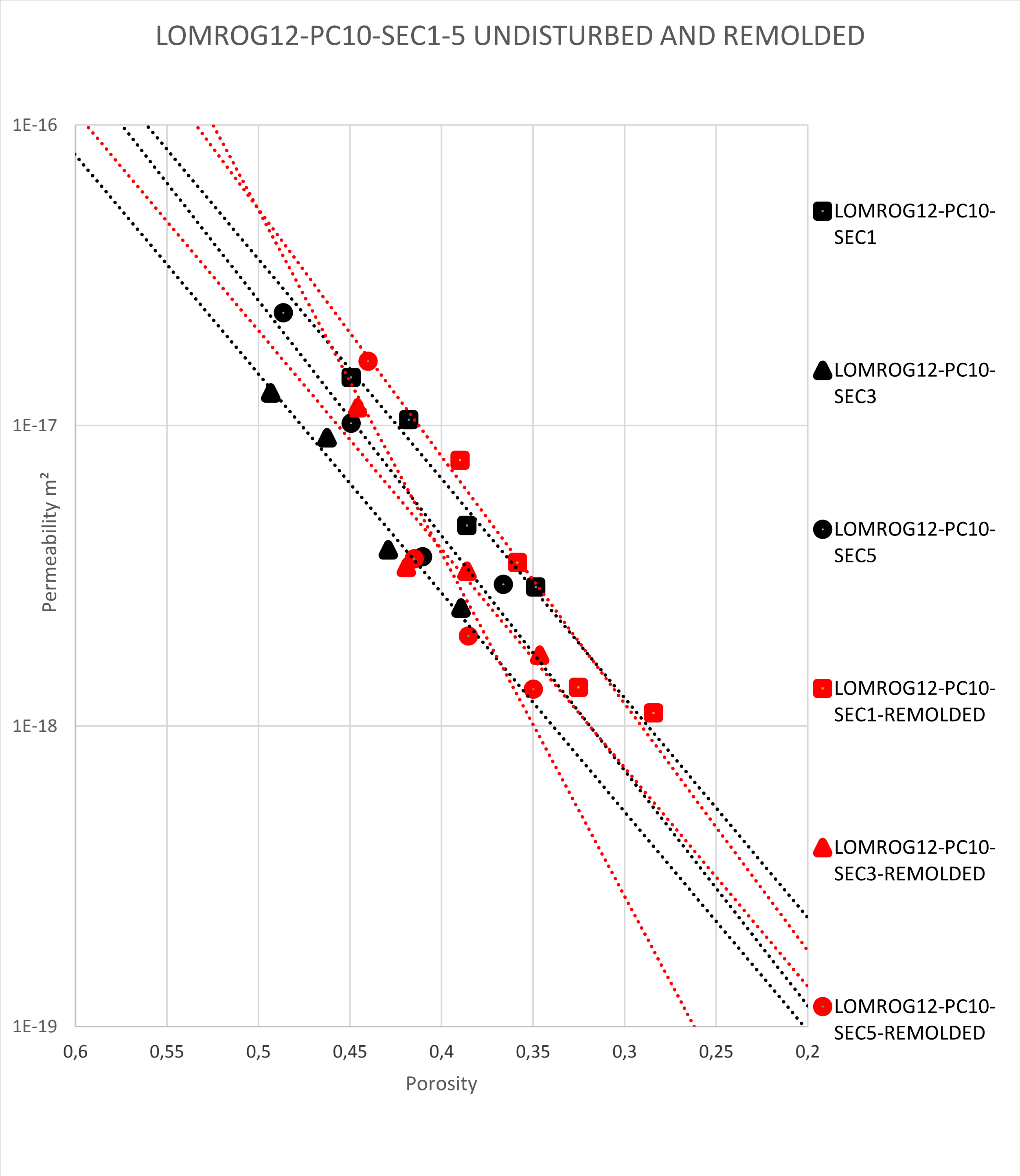


Figure 8. Lomrog12-PC10-Sec1-Sec3-Sec5 Remolded and undisturbed samples plotted with permeability and porosity data.

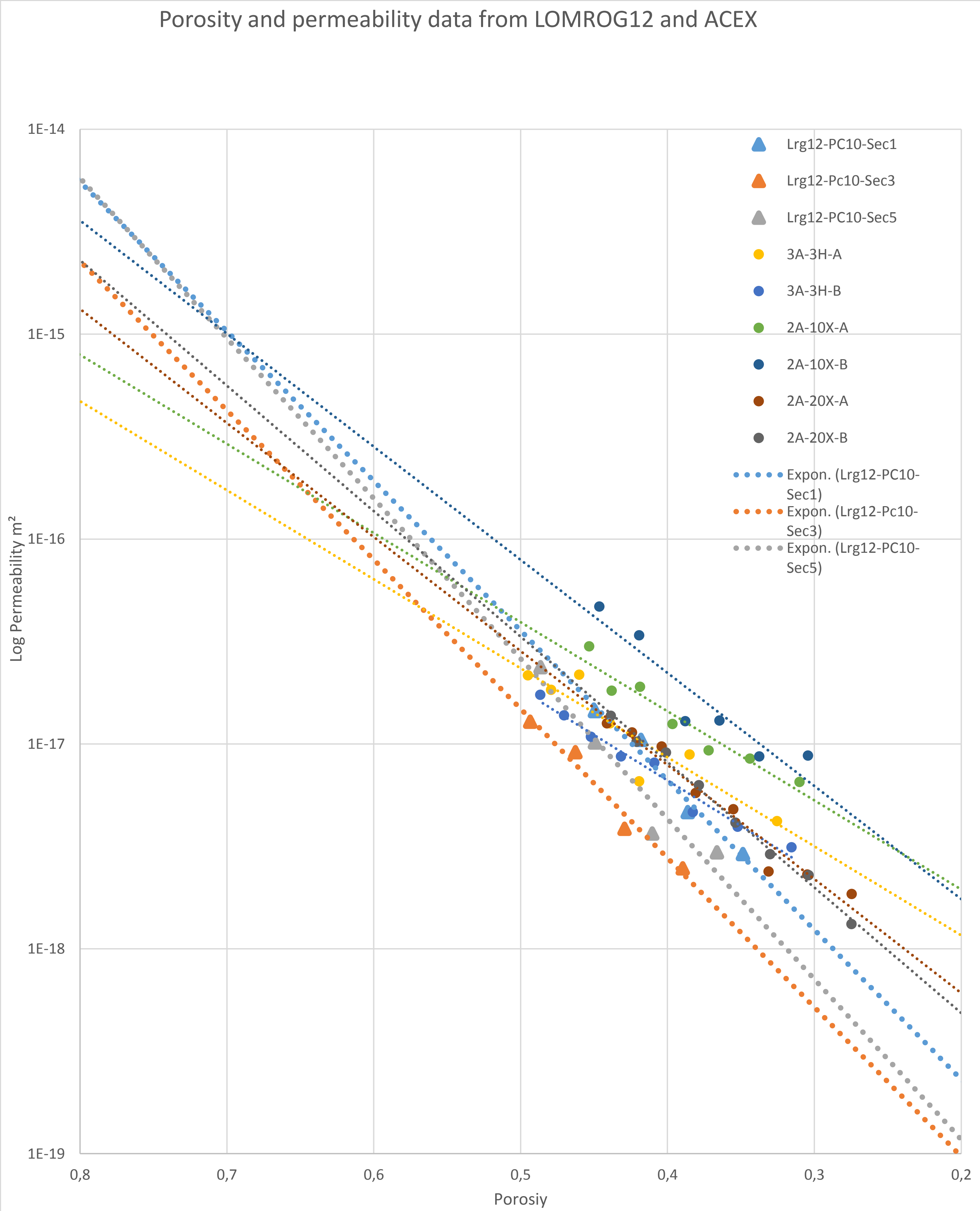


Figure 9. Lomrog12-PC10-Sec1-Sec3-Sec5, And ACEX samples plotted on permeability and porosity parameters.

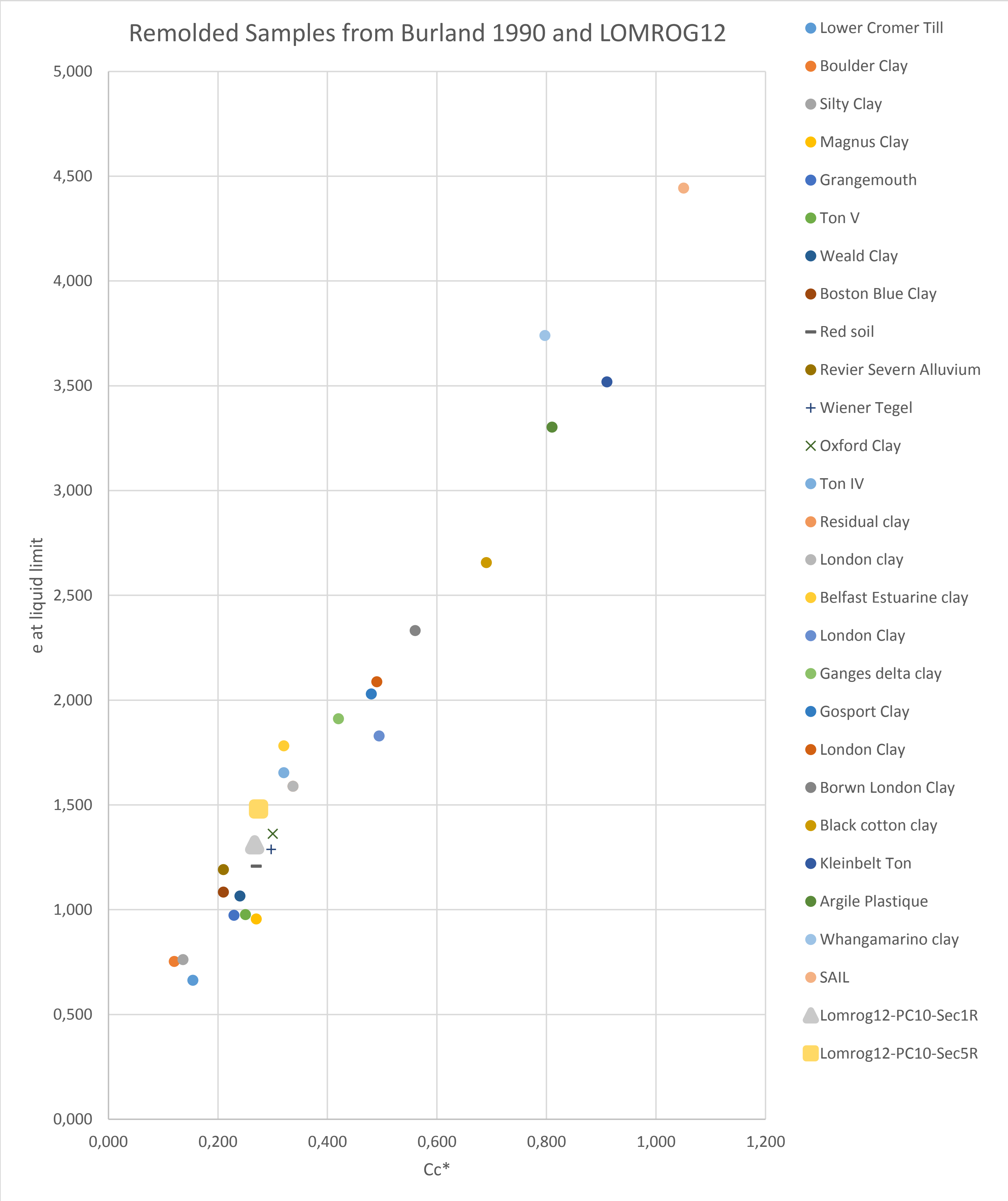


Figure 10. Showing Lomrog12-PC10 Sec1 and Sec5, compared to samples from Burland 1990.

Discussion

Six consolidation tests were run on 3 samples on the LOMROG12-PC10 sections all were from shallow depths 0.91-6.81mbsf, the previous studies from ACEX were from deeper depths 18.62-87.66mbsf. The calculated e_0 is increasing in the LR samples while in the ACEX there is a general decreasing trend. At shallow depths e_0 is expected to be higher if the sediments are homogenous and not overconsolidated. The Cr is increasing downward in the LR samples and decreasing in the ACEX samples. An increase in Cr coupled with a decrease in the Cc could indicate that the samples are disturbed. The samples from LR and ACEX display similar consolidation values. The changes could be because different intervals were chosen for Cc Cr and e_0, this could also be because of sample preparation that was done differently. The lowest Cc value reported was from Lomrog12-PC10-Sec1 which also was the shallowest of all samples (Table 2).

The estimated preconsolidation pressures from Lomrog12-PC10 were 48kPa, 42kPa, 49kPa, all these values are very close to the same and might actually be the same as the error margin of the estimations by the Casagrande technique is rough. The calculated overconsolidation ratio for the 3 undisturbed Lomrog samples generated Sec1 sample as strongly overconsolidated and sec3 and sec5 moderately to slightly overconsolidated (Table 4). There are a few possible interpretations for the present overconsolidation either the seafloor has eroded due to currents and the overburden has been transported away, or this erosion could have been caused by previous ice ages.
According to Jakobsson, (1999) the data evidence from Chirp Sonar bottom profiling suggests erosion on the Lomonosov Ridge. The most plausible theory presented by Jakobsson, (1999) is grounded ice-sheets or icebergs. If this can explain the present overconsolidaition at Lomrgon12-PC10 is however uncertain, a closer look at the bathymetry data from the expedition would be ideal.

The Lomrog12-PC10 void ratio predictions seem to fall on both the low end and close to the high end in void ratio at 200mbsf with the ACEX predictions showing the highest predicted values. The Lomrog12-PC10-Sec3 and Sec5 predictions at 200mbsf are close to the same as ACEX-M0003A-3H3-A. The prediction for Lomrog12-PC10-Sec1 is showing the lowest void ratio value at 200mbsf (Table 5). The Lomrog12-PC10-Sec1 is the shallowest of the three Lomrog12 samples tested.

The presented values from LOMROG12-PC10 of porosity and permeability are in similar range as those from ACEX however the general differences could be from grain size or mineralogical changes. The trends in porosity and permeability on the Lomrog12 samples are showing a clear difference when compared to the ACEX sample (Figure 9).

Porosity and permeability from Lomrog12-PC10 comparison between remolded and undisturbed samples (Figure 8). The permeability at a set porosity is not significantly different between remolded and undisturbed samples. The remolded samples seem to be following a steeper trend than the undisturbed samples.

The remolded Lomrog12 samples are aligning very nicely with the other remolded clays and sediments from Burland, (1990). Remolding destroys the physio-chemical bonds between individual clay particles (Burland et al., 1990). This seems to be a plausible cause for the change in compaction characteristics, but this is not seen in the permeability porosity from undisturbed and disturbed sediments.

Possible errors

During the preparation there are many possible errors. If we begin with a perfect sample without any disturbances during the preparation and cutting of the core no disturbance is allowed. The trimming to fit the confining ring must be done quickly so that no water can escape the sediment. During the trimming to fit the confining ring it is imperative to not overwork the sample as it might get disturbed from the motion of molding the sediment to fit the confining ring. If sample preparation is done correctly there is also the cutting of filter paper that must be precise, if not some sediments might be able to escape through the porous stones which would be a catastrophe. There are also many assumptions done with the methods, sediments are considered to be perfectly elastic and that water is incompressible.

Conclusion

The Quaternary sediments (LR and ACEX) from the Lomonosov ridge results indicate similar compaction behavior, however the porosity and permeability data suggest a difference. The difference is most likely due to mineralogical or grain size changes. Void ratio predictions are showing high values for LR section 3 and section 5. Also the lowest values reported is from LR section 1. Further studies of sediments from the Lomonosov Ridge is suggested to test the rigidity of this hypothesis especially grain size and chemical composition comparison.

Acknowledgment

I would like to thank Matt O´Regan for setting up this project and his patience listening to my questions and answering them in a logic way, I am very thankful for all the help during the writing of this thesis.

References:

Articles:

Burland, J. B. 1990. Geotechnique 40, No. 3, 329-378

Jakobsson, M., 1999. First high-resolution chirp sonar profiles from the central Arctic Ocean reveal erosion of Lomonosov Ridge sediments. Marine Geology, 158, 111-123. Elsevier

O'Regan, M., Moran, K., Baxter, C. D. P. Cartwright J., Vogt, C., and Kölling, M., 2010. Towards ground trothing exploration in the central Arctic Ocean: a Cenozoic compaction history from the Lomonosov Ridge. Basin Research, 22, p215-235.

Rollings, M. P., and Rollings, R. S. 1996. Geotechnical Materials in Construction. McGraw-Hill, New York.

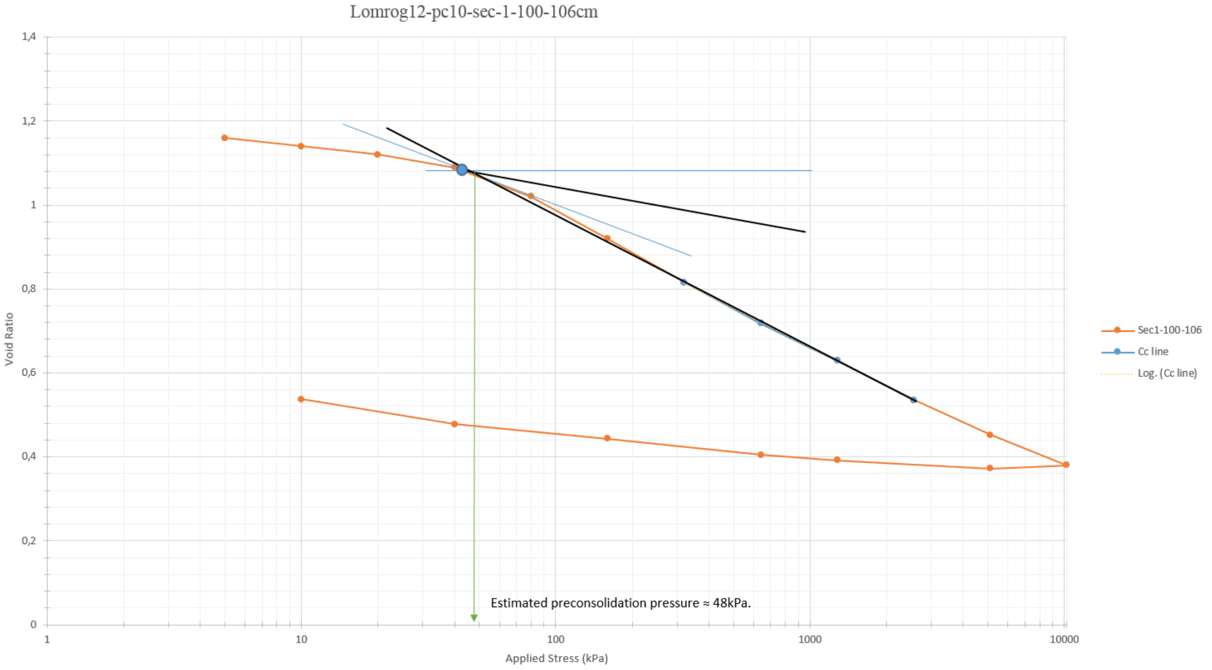
Litterature:

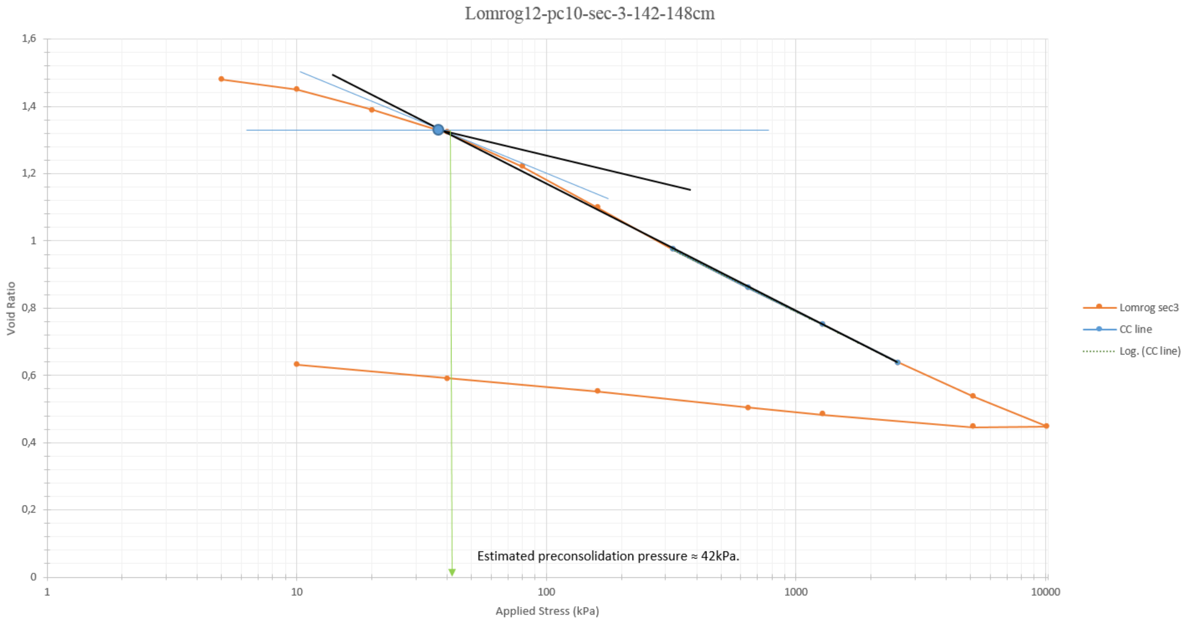
Casagrande, A., 1936. The determination of pre-consolidation load and its practical significance. *In* Casagrande, A., Rutledge, P.C., and Watson, J.D. (Eds.), *Proc. 1st Int. Conf. Soil Mech. Found. Eng.* Am. Soc. Civ. Eng., 3:60–64.

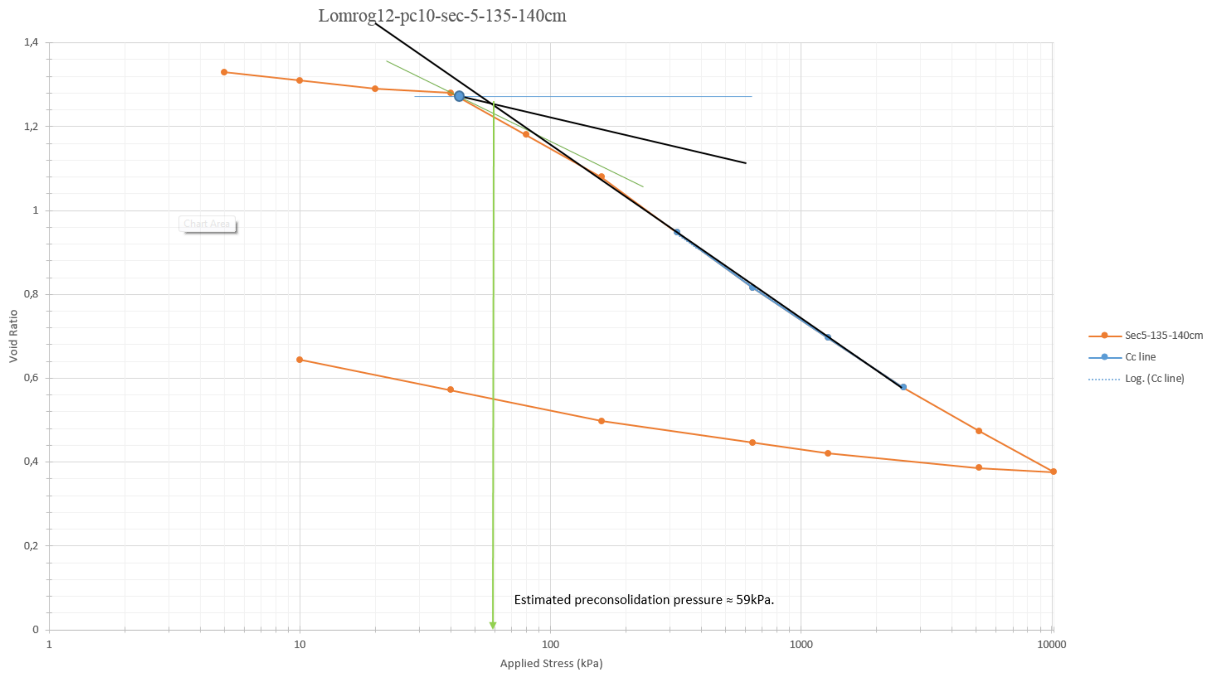
Day, W. R., 2001, Soil Testing Manual, McGraw-Hill

Holtz, R.D., and Kovacs, W.D., 1981. *An Introduction to Geotechnical Engineering:* Englewood Cliffs, NJ (Prentice-Hall).

Appendix


Lomrog12-pc10-sec-1-100-106cm
Void Ratio
Applied Stress (kPa)
Estimated preconsolidation pressure ≈ 48kPa.
Sec1-100-106
Cc line
Log. (Cc line)
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1
10
100
1000
10000


Lomrog12-pc10-sec-3-142-148cm
Void Ratio
Applied Stress (kPa)
Estimated preconsolidation pressure ≈ 42kPa.
Lomrog sec3
CC line
Log. (CC line)
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1
10
100
1000
10000


Lomrog12-pc10-sec-5-135-140cm
Void Ratio
Applied Stress (kPa)
Estimated preconsolidation pressure ≈ 59kPa.
Sec5-135-140cm
Cc line
Log. (Cc line)
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1
10
100
1000
10000

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec1—100-106cm

Date: 7/4-2014

File Name: Lrg12-PC10-1-100-106

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,277g
Sample + Ring (g):	129,469g
Calculated void ratio:	1,16

Notes:

Before Test: Trimmings

Tare weight (g):	24,023g
Wet weight + Tare (g):	51,23g
Dry weight + Tare (g):	42,734g
Grain density (pycnometer):	NM

Notes: NM= Not Measured assumed to same Grain density as End test measurement.

End Test -Sample

Sample + ring weight (g):	118,122g
Sample height(cm):	
Tare weight (g):	13,165g
Wet weight sample + Tare (g):	69,821g
Dry weight sample + Tare (g):	59,254g
Grain density (pycnomter):	2,7133g/cm^3
Calculated void ratio:	0,537

Notes: Standard deviation for Pycnometer = ±0,0030g/cm^3

NM= NOT MEASURED

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec1-100-106 REMOLDED

Date: 09/04 2014

File Name: Lrg12-PC10-Sec1-100-106R

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,279g
Sample + Ring (g):	133,358g
Calculated void ratio:	1,1

Notes:

Before Test: Trimmings

Tare weight (g):	13,058g
Wet weight + Tare (g):	37,010g
Dry weight + Tare (g):	28,920g
Grain density (pycnometer):	NM

Notes:

End Test -Sample

Sample + ring weight (g):	118,686g
Sample height(cm):	
Tare weight (g):	13,118g
Wet weight sample + Tare (g):	70,275g
Dry weight sample + Tare (g):	59,816g
Grain density (pycnomter):	NM
Calculated void ratio:	0,382

Notes: Grain density assumed to be the same as undisturbed test 2,7133g/cm^3

NM= NOT MEASURED

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec3-142-148

Date: 29/5 2014

File Name: Lrg12-PC10-Sec3-142-148

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,281g
Sample + Ring (g):	126,256g
Calculated void ratio:	1,48

Notes:

Before Test: Trimmings

Tare weight (g):	23,936g
Wet weight + Tare (g):	53,613g
Dry weight + Tare (g):	43,648g
Grain density (pycnometer):	NM

Notes: Grain density assumed to 2.71g/cm^3 NM= NOT MEASURED

End Test -Sample

Sample + ring weight (g):	113,20g
Sample height(cm):	
Tare weight (g):	24,005g
Wet weight sample + Tare (g):	75,744g
Dry weight sample + Tare (g):	64,936g
Grain density (pycnomter):	NM
Calculated void ratio:	0,631

Notes: Grain density assumed to 2.71g/cm^3

NM= NOT MEASURED

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec3-142-148 Remolded

Date: 30/05-2014

File Name: Lrg12-PC10-Sec3-142-148R

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,28g
Sample + Ring (g):	127,574g
Calculated void ratio:	1,33

Notes:

Before Test: Trimmings

Tare weight (g):	24,022g
Wet weight + Tare (g):	61,313g
Dry weight + Tare (g):	48,613g
Grain density (pycnometer):	NM

Notes:

End Test -Sample

Sample + ring weight (g):	114,979g
Sample height(cm):	
Tare weight (g):	0,718g
Wet weight sample + Tare (g):	53,607g
Dry weight sample + Tare (g):	42,972g
Grain density (pycnomter):	NM
Calculated void ratio:	0,554

Notes:

NM= NOT MEASURED

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec5-135-140

Date: 2/4-2014

File Name: Lrg12-PC10-Sec5-135-140

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,28g
Sample + Ring (g):	128,075g
Calculated void ratio:	1,33

Notes:

Before Test: Trimmings

Tare weight (g):	13,145g
Wet weight + Tare (g):	33,916g
Dry weight + Tare (g):	27,224g
Grain density (pycnometer):	NM

Notes:

End Test -Sample

Sample + ring weight (g):	116,590g
Sample height(cm):	
Tare weight (g):	13,114g
Wet weight sample + Tare (g):	68,061g
Dry weight sample + Tare (g):	56,314g
Grain density (pycnomter):	2,7339g/cm^3
Calculated void ratio:	0,644

Notes: Standard deviation on Grain density 0,0026g/cm^3

NM= NOT MEASURED

1-D Consolidation Test

Sample: Lomrog12-PC10-Sec5-135-140 Remolded

Date: 4/4-2014

File Name: Lrg12-PC10-Sec5-135-140R

Test Type: One dimensional incremental load (Loadtrac-II)

Initial Sample Conditions

Sample diameter (cm):	5,0cm
Sample height(cm):	1,9cm
Ring weight (g):	61,28g
Sample + Ring (g):	128,407g
Calculated void ratio:	1,21

Notes:

Before Test: Trimmings

Tare weight (g):	24,021g
Wet weight + Tare (g):	52,240g
Dry weight + Tare (g):	43,227g
Grain density (pycnometer):	NM

Notes:

End Test -Sample

Sample + ring weight (g):	117,277g
Sample height(cm):	
Tare weight (g):	23,882g
Wet weight sample + Tare (g):	79,528g
Dry weight sample + Tare (g):	68,114g
Grain density (pycnomter):	2,7339g/cm^3
Calculated void ratio:	0,624

Notes: Standard deviation on Grain density 0,0026g/cm^3 From Sec5 undisturbed.

NM= NOT MEASURED