NORGES GEOTEKNISKE INSTITUTT
Norwegian Geotechnical Institute

Internal Report

An experimental determination of the diffusion constant for high in-situ salt concentrations in Norwegian marine clays.

50703-2 June, 1973

FORSKNINGSVEIEN 1, OSLO 3 — TLF. 69 58 80

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I. INTRODUCTION

An earlier internal report has reviewed a number of field observations of salt concentration profiles in Scandinavian marine clays (Heiberg, 1972). The development of the observed salt concentration profiles were modeled by applying elementary concepts of salt diffusion superimposed on pore water flow. For a given elapsed time since the surface(s) became fresh, an observed salt concentration profile was consistent with only one value of each of the two physical parameters involved, namely the pore water velocity and the diffusion constant. The time elapsed since the top surface became fresh could be estimated from the data on isostatic uplift of the region. This allowed numerical values of pore water velocities and diffusion constants to be estimated from the salt concentration profiles. The estimates of the diffusion constants indicated that it varied within very narrow limits. It was found necessary to confirm this indication by measuring the diffusion constant under controlled conditions in the laboratory. One reason for this was that the times used in computing diffusion constants from field data could be in error if a considerable amount of clay compression had occurred after the surface first rose above sea level.

This report will present the results of the laboratory experiments. The experiments included:

(1) A study of the influence of method of salt extraction on the measured concentrations of Na^+, K^+, Mg^{++}, and Ca^{++} ions.

(2) A study of the soil profile at the site where the clay for the experiment was sampled.

(3) A study of the diffusion process in the two types of clays sampled as a function of temperature. Diffusion was allowed towards a fresh water reservoir in one end of the cylinder. The amount of Na^+, K^+, Mg^{++}, and Ca^{++} in the reservoir was recorded as a function of time. After completing the experiment, the concentration of Na^+, K^+, Mg^{++}, and Ca^{++} was recorded in the clay at

different distances from the fresh surface. These sets of measurements allowed independent computations of the diffusion constant to be made.

II. THE CLAYS STUDIED

It was decided to determine the diffusion constants in two clays which embraced the types of clays encountered in southern Norway. It was therefore natural to collect samples from a site in Drammen where NGI previously have taken numerous samples for a multitude of laboratory studies. The soil profile is given by Bjerrum (1967), Fig.19. The determinations carried out in this investigation on natural water content, Atterberg limits, and salt concentrations are given in Drawing 001. The soil profile consists of 4 m sand, underlain by plastic Drammen clay, a post-glacial clay with high clay content and a natural water content of 50%. This clay layer extends to a depth of 11 m. Below is a lean glacial clay with lower clay content and lower water content, 25-40%. This clay contains occasional layers of sand and silt. The salt concentrations increase with depth to about 9 meter below ground level. They remain practically constant below this depth. (The different methods used to extract the salt has a distinct influence on the value determined. So does the time of storage on the magnesium concentrations. This will be discussed separately later in the report). The porosities of the post-glacial plastic clay and of the glacial lean clay embrace those of the clays most frequently encountered in southern Norway.

III. THE EXPERIMENTAL SET-UP

The diffusion experiment was conducted on six undisturbed samples. Three were taken in the plastic clay, at a depth where the salt concentrations were constant with depth. Three were taken in the lean clay.

Two duplicate samples from each clay were tested at 7°C which corresponds to the ground temperature. One sample from each clay was tested at room temperature (approximately 22°C). The samples were taken in reinforced plastic cylinders and brought to the laboratory. The clay was flush with the bottom end of the cylinder. The clay at the bottom of the cylinder was capped with a thin filter paper and a sheet of gaz, Drawing 007. (This prevented soil to fall out without obstructing the diffusion path markedly).

The top end was sealed with wax and a rubber cap. The open end of the cylinder was then placed in approximately 700 ml of demineralized water. This water was changed regularly, and the quantity of salt removed was determined.

The distribution of salt concentration and of relative electrical conductivity in the cylinders was determined at the end of the experiment.

The determinations of salt concentration were made by measuring concentrations of Na^+, K^+, Mg^{++}, and Ca^{++} on a Perkin-Elmer atomic absorption spectrophotometer (model 290). The Ca^{++} determinations reported below were made using La_2O_3 as releasing agent, with the exception of the determinations reported in Drawings 005 and 013. The results shown in Drawing 005 are not entirely reliable and should be considered as an indication only. The results shown in Drawing 013 are probably reliable due to the low salt concentrations in the solutions analysed.

The data involving determinations of salt concentrations were recorded and analysed as explained in report 50703-1. The data sheets and the intermediate computations are on file, whereas the final computed results are included in the appendix of this report.

IV. THE INFLUENCE OF THE PROCEDURE OF SALT EXTRACTION ON DETERMINED SALT CONCENTRATIONS

The influence of the procedure used to extract the salts from the clay was studied on cylinder P2 after the diffusion experiment was terminated. The methods of extraction used were:

(1) To press the clay and determine the concentrations in the water thus produced.

(2) To stir approximately 25 g of clay with 25 ml of demineralized water, and to analyse the water phase after excluding the clay by centrifugation and filtration.

(3) As procedure 2, but now using 75 ml of demineralized water.

(4) To stir approximately 25 g of clay with 50 ml of a 1.0 molar $BaCl_2$ solution. The water phase is separated and the procedure

is repeated twice. The final volume of solution (approximately 150 ml) is diluted to 250 ml. The Ba^{++} ions will replace the ions of Na^{+}, K^{+}, Mg^{++}, and Ca^{++} adsorbed on the clay surfaces. The solution will therefore contain both the ions which normally are in the pore water and those which normally are adsorbed on the clay. These concentrations serve as reference concentrations for the concentrations determined by the other three methods. The first three methods are aimed at determining the salt concentrations in the free pore water only.

Samples of 6 cm length were homogenized and analysed. The natural water content of the clay varied little from 55%, as shown in Drawing 008. Diffusion had been allowed to take place for 205 days prior to the analysis. Drawings 002 to 005 show the concentrations Na^{+}, K^{+}, Mg^{++}, and Ca^{++} as determined by the different methods of extraction. Drawing 006 shows measured values of pH. The pH values reported from the pressed clay was measured in the pressed pore water. The other values were recorded in the clay suspension after stirring. Drawing 002 gives the values of relative electrical conductivities recorded.

The experimental results show that the different procedures of salt extraction from the free pore water influences the salt concentrations determined.

When the salt concentration in the free pore water is diluted, there occurs a change in the relative composition of the solution. The relative concentrations of the monovalent ions Na^{+} and K^{+} are increased, the relative concentrations of the divalent ions Mg^{++} and Ca^{++} are decreased and the pH is changed towards the basic side.

The greatest change in milli-equivalents per litre occurs for Na^{+} and Mg^{++}. The change in percent of the total concentration is negligible for Na^{+}, however, due to the high concentration of this ion.

These results may be interpreted to reflect an exchange of ions between the free pore water and the phase adsorbed on the minerals. This exchange accompanies an expansion of the adsorbed phase. Whether the exchange is balanced, may not be determined with certainty as the Ca^{++} concentrations are not determined reliably.

The concentrations determined by extracting the salts by pressing the clay, and by washing approximately 25 g of clay with 75 g of water, may be com-

pared for the entire soil profile in Drawing 001. The discrepancies in the concentrations are negligible for Na^+ and quite marked for K^+ and Mg^{++}. Comparative determinations of Ca^{++} are not available. The Mg^{++} concentrations obtained by pressing after the end of the diffusion experiments show that a marked change has occurred upon storage of the samples.

The salt concentrations determined by pressing the clay are less scattered than those obtained by washing. The reason may well be that the amount of dilution was not the same in each sample washed. (The amount of clay to be washed was not the same in each sample, nor was the natural water content of the clay).

The diffusion process will lead to a dilution of the salt concentrations in the pore water of the samples. It may therefore be expected that the exchange of ions reported on above will interfere as a source of Na^+ and K^+ ions and a sink of Mg^{++} and Ca^{++} ions. As such sources and sinks are disregarded in the theory used to analyse the diffusion process, they may be expected to appear as "abnormal" behaviour, when the amount of salt which has left the cylinders is to be compared with the difference between the initial and final amounts in the sample. It will be seen that the exchange processes may be neglected when analysing the diffusion of bulk salt at the concentrations studied in this work. The reason is that the salt consists predominantly of NaCl, and only a very small fraction of Na^+ takes part in the exchange process. The exchange processes may complicate the diffusion considerably at low salt concentrations, however.

V. THE DIFFUSION CONSTANTS

The diffusion constants are computed from the rate of outflow of ions from the cylinders. The salt concentration profiles in the cylinders at the end of the experiment (after about 190 days of diffusion) are computed from the diffusion constants, and compared with the measured concentrations for Na^+, K^+, and Mg^{++} ions. The Ca^{++} ion did not conform with the behaviour expected for simple diffusion. The behaviour of this ion is discussed separately.

The results of significance in this study are the diffusion constants for Na^+. The computed value of this constant is 0.0122 ± 0.0003 m^2/year at 7°C. The corresponding value at room temperature (approximately 22°C) is 0.0217 ± 0.0003. These values are applicable to both the lean and the

plastic clays. This proves that diffusion at high salt concentrations is a predictable process, and that very detailed knowledge of the clay properties is not a prerequisite for predicting it.

The concentration profiles in the cylinders may be computed from knowledge of the diffusion constant by the equation:

$$\frac{C}{C_o} = \operatorname{erf}\left(\frac{z}{2\sqrt{Dt}}\right)$$

where

- C is the concentration
- C_o is the initial concentration
- z is the distance from the fresh surface
- D is the diffusion constant
- t is the elapsed time

A comparison between the computed and the measured concentration profile is presented in Drawing 009. The measured values confirm the computed ones. The measurements were performed by pressing slices of the test cylinder. Each slice was 2 cm thick.

The apparent diffusion constant for K^+ ions, computed from the amounts removed from the sample, were not in agreement with the concentration profiles measured at the end of the experiment.

The computed values of the diffusion constans were as shown below:

Clay	Sample No.	D in m^2/year at 7°C	D in m^2/year at 22°C
Plastic	P 1	.023	
Plastic	P 2	.028	
Lean	P 4	.034	
Lean	P 5	.034	
Plastic	P 3		.061
Lean	P 6		.068

The concentration profiles computed from diffusion constants of 0.027 m^2/year and 0.060 m^2/year are compared with the measured values in Drawing 010. The computed concentrations are much too low. The measured concentrations indicate that the diffusion constant for K^+ is nearly identical with the constant for Na^+.

The observation that more K^+ has left the sample than what is removed from the pore water is consistent with the observation in the above paragraph, that K^+ is brought out in solution in the pore water when the salt concentration in it is decreased.

The computed apparent diffusion constants for Mg^{++} are also in disagreement with the measured salt concentration profiles. The computed diffusion constants are:

Clay	Sample No.	D in m^2/year at 7°C	D in m^2/year at 22°C
Plastic	P 1	0.0061	
Plastic	P 2	0.0059	
Lean	P 4	0.0068	
Lean	P 5	0.0060	
Plastic	P 3		0.0083
Lean	P 6		0.0010

The salt concentration profiles computed from diffusion constants of 0.006, 0.008, and 0.010 m^2/year are compared with the measured values in Drawing 011. The computed concentrations are distinctly higher than the measured ones. This is again in agreement with the results presented in the above paragraph. There it was found that the amount of Mg^{++} ions in the pore water was decreased when the salt concentration was decreased. The measured values of Mg^{++} concentration are in better agreement with the values of diffusion constants for Na^+ than with those given above.

The experiments showed that Ca^{++} deviates significantly from the pattern expected from simple diffusion. The cumulative amount of Ca^{++} leaving a cylinder would be proportional to the square root of time if simple diffusion occurred. The curves shown in Drawing 013 are linear only in the initial phase. Midway through the experiment the curve steepens before it reaches a quasi-constant slope in the final stage. This slope is lower than the initial for the plastic clay and higher for the lean clay.

The presence of slightly soluble salts may well have an influence on this behaviour. If Ca^{++} in the reservoir is in equilibrium with for instance $CaCO_3$, the outflow curve would coincide roughly with what is described above as the initial range.

The measured Ca^{++} concentrations in the clay at the end of the experiment are shown in Drawing 012. At first sight the distribution of Ca^{++} is roughly equivalent to that of Na^{+}. A closer examination will reveal that the curves for all the samples are concave towards the concentration axes (not towards the distance axes as expected), and that this range of the curve culminates in an "abnormal" maximum value. The reason for, or the significance of the Ca^{++} behaviour cannot be assessed on the basis of the data collected in this investigation. It does not affect the process of bulk diffusion, as the Ca^{++} concentration is only a small fraction of the total salt concentration.

VI. CONCLUSIONS

The diffusion experiments described in this report have shown that the diffusion constant of Na^{+} is 0.0122 ± 0.0003 at $7^{\circ}C$ and 0.01217 ± 0.0003 at room temperature (approximately $22^{\circ}C$). The value of the diffusion constant was determined on marine clays from Drammen. The diffusion constant did not vary with the natural water content of the clay. Samples of natural water content ranging from 28 to 58 percent were tested. This covers the range encountered most frequently in southern Norway. The determinations were made at salt concentrations of the order of those encountered in sea water (30 g/l NaCl or 10,000 mg/l Na^{+}). The results prove that the diffusion of salt at these concentrations is a predictable process, and that very detailed knowledge of the clay properties is not required to predict it.

The diffusion experiments, and a series of dilution experiments showed that there is an increase of the monovalent ions and a decrease of divalent ions in solution in the free pore water when the salt concentration in the pore water is reduced. This exchange will influence the process of bulk diffusion at concentrations of the order of a few grams per litre NaCl. At higher concentrations, the process of diffusion of K^{+}, Mg^{++}, and Ca^{++} is affected, but not in a way which invalidates the diffusion constants quoted above. The amount of salt removed from the clays by diffusion indicates diffusion constants for K^{+}, Mg^{++} which differ from the values given, whereas the distribution of salt concentration determined by pressing the clay in the test cylinders after the experiments confirm the values given. The behaviour of Ca^{++} is not as expected from simple diffusion.

The processes which complicate the elementary process of salt diffusion is without practical significance at high concentrations. Na^{+} behaves

according to the elementary process. The concentrations of the other ions are minor in comparison with the Na^+ concentration.

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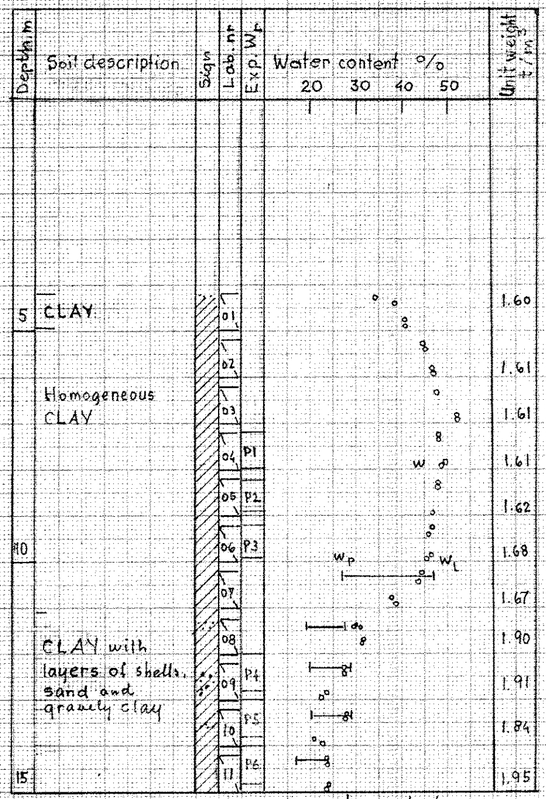
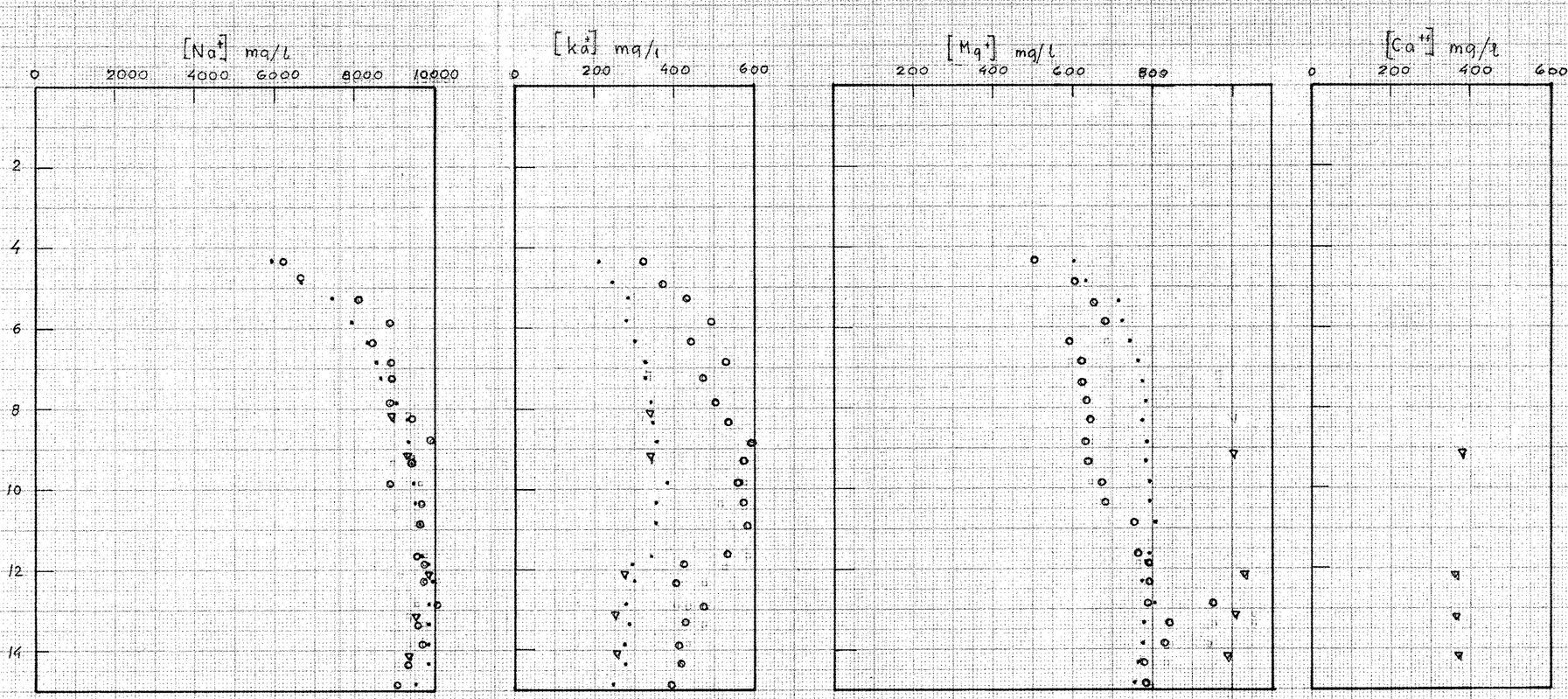


w = water content
w_p = plastic limit
w_L = Liquid limit



LEGEND

METHOD OF SALT EXTRACTION

- • By pressing clay from steel sampling tubes
- o By washing ~25g of clay from steel sampling tubes with 75 ml H_2O La_2O_2 used as releasing agent in analysis
- ▽ By pressing water from clay outside the range of diffusion in the diffusion experiment tubes. Mg^{++} and Ca^{++} values are determined using La_2O_3 as releasing agent.

SALT DIFFUSION IN MARIN CLAY	Dato 6/6-73	Tegner
THE SOIL PROFILE AT DANNEVIKS 16, DRAMMEN.	Godkjent	
	Oppdr nr. 50703-2	
Norges geotekniske institutt	Tegn. nr. 001	

SALT DIFFUSION IN MARINE CLAYS	Date 6/6-73	Drawn by
The determination of Na^+ concentrations by different procedures of salt extraction.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 002	

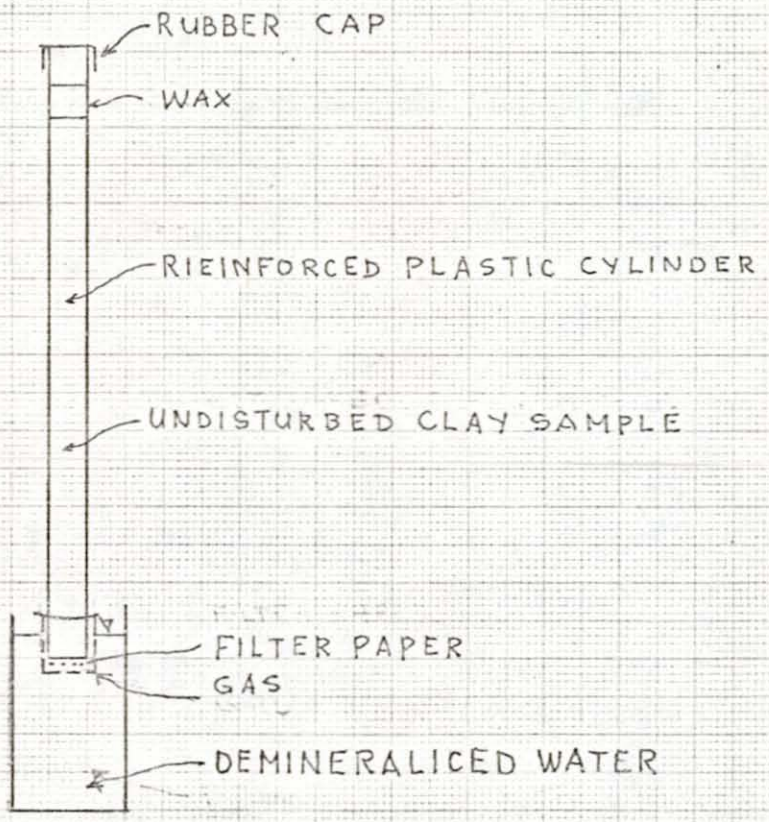
SALT DIFFUSION IN MARINE CLAYS	Date 6/5 - 73	Drawn by
The determination of K^+ concentrations by different methods of salt extraction.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 003	

SALT DIFFUSION IN MARINE CLAYS	Date 6/6 -93 | Drawn by
The determination of Mg^{++} concentrations by different methods of salt extraction.	Approved
	Project no 50703-2
Norwegian geotechnical institute	Drawing no 004

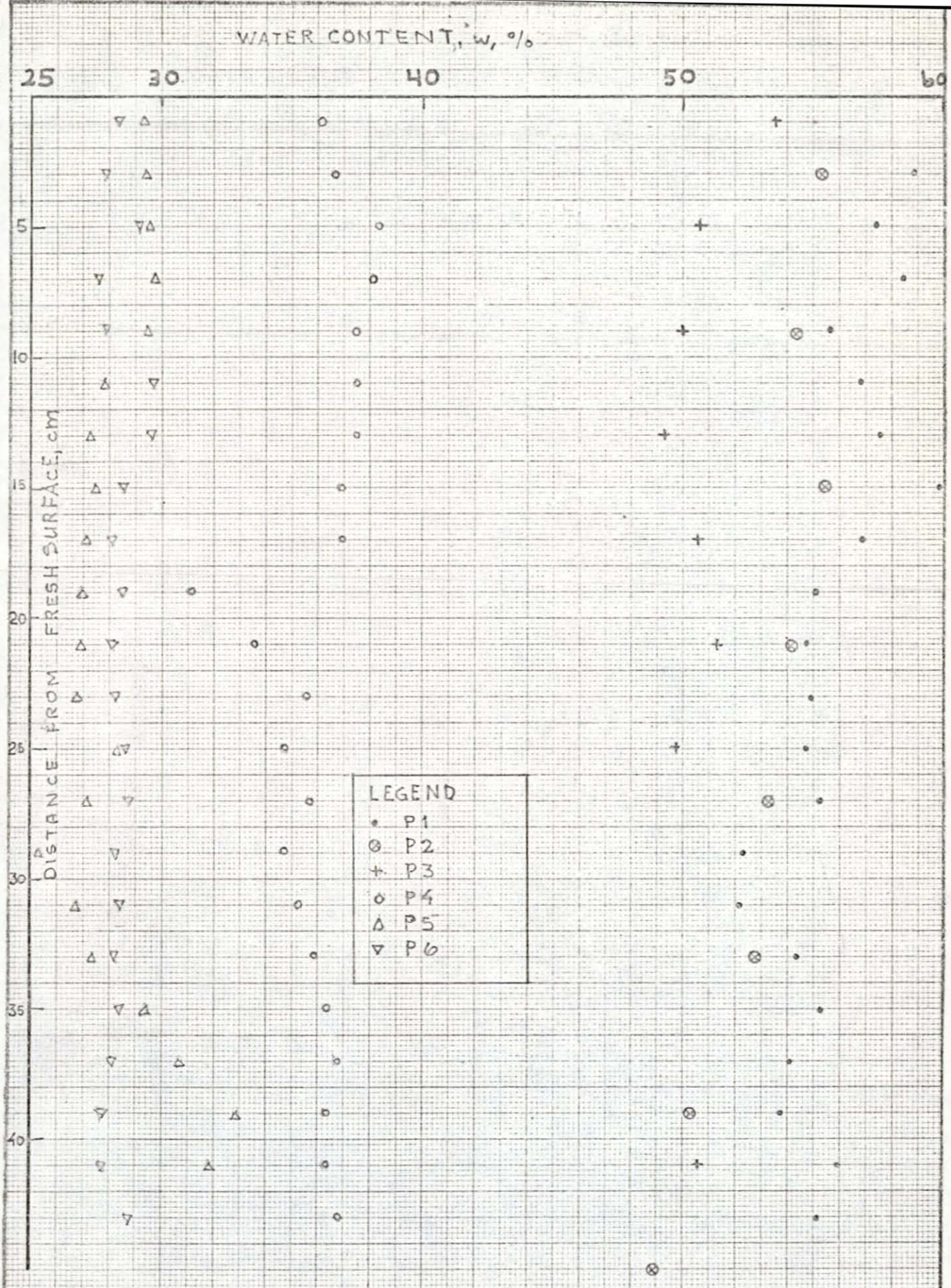
These determinations are made without the use of the releasing agent La_2O_3 and are therefore not reliable.

SALT DIFFUSION IN MARINE CLAYS	Date 6/6 -73	Drawn by
The determination of relative Ca^{++} concentrations by different methods of salt extraction.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 005	

SALT DIFFUSION IN MARINE CLAYS	Date 6/5 - 73	Drawn by
The determination of pH in the water extracted from clays by different methods.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 006	



SALT DIFFUSION IN MARINE CLAYS	Date 6/6 - 73	Drawn by
Schematic drawing of the diffusion experiment equipment.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 007	



SALT DIFFUSION IN MARINE CLAYS.	Dato 6/6-73	Tegner
Natural water content distribution in the test cylinder.	Godkjent	
	Oppdr. nr. 50703-2	
Norges geotekniske institutt	Tegn. nr. 008	

SALT DIFFUSION IN MARINE CLAYS.	Dato 6/5 - 73	Tegner
Normalized Na^+ concentrations; measured and computed values, and normalized electrical conductivities.	Godkjent	
	Oppdr. nr. 50703-2	
Norges geotekniske institutt	Tegn. nr. 009	

SALT DIFFUSION IN MARINE CLAYS.	Dato 6/6-73	Tegner
Normalized K^+ concentrations. Measured and computed values.	Godkjent	
	Oppdr. nr. 50703-2	
Norges geotekniske institutt	Tegn. nr. 010	

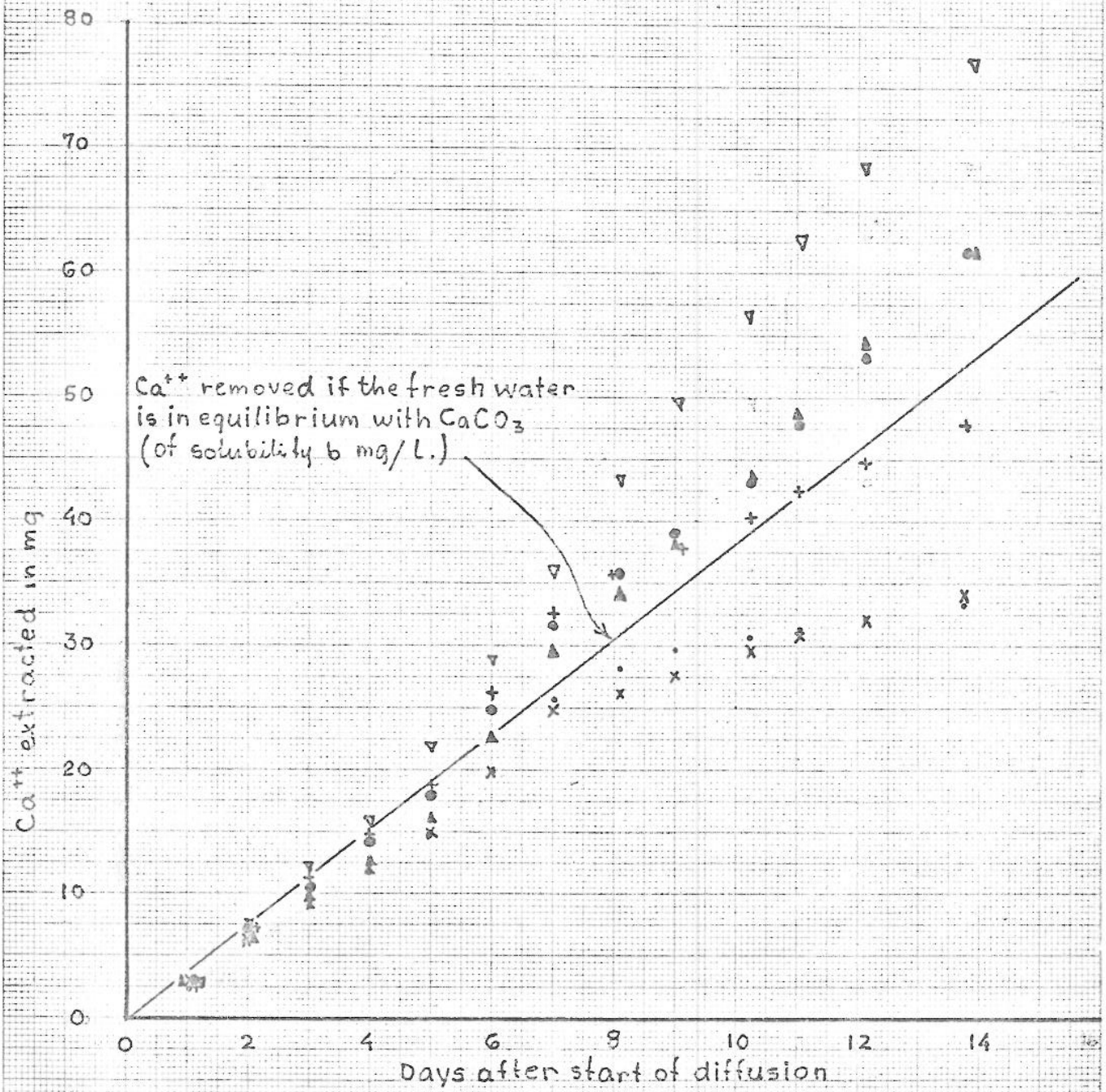
SALT DIFFUSION IN MARINE CLAYS.

Normalized Mg^{++} concentrations. Measured and computed values.

Norges geotekniske institutt

Dato	Tegner
6/5 - 73	
Godkjent	
Oppdr. nr. 50703-2	
Tegn. nr. 011	

SALT DIFFUSION IN MARINE CLAYS.	Date 6/6-73	Drawn by
Normalized Ca^{++} concentrations. Measured values.	Approved	
	Project no 50703-2	
Norwegian geotechnical institute	Drawing no 012	



LEGEND

Symbol	Sample	Temp °C	Clay
•	P1	7	Plastic
×	P2	7	Plastic
+	P3	22	Plastic
●	P4	7	Lean
▲	P5	7	Lean
▽	P6	22	Lean

These concentrations were measured without the use of the La_2O_2 releasing agent

SALT DIFFUSION IN MARINE CLAYS.

Extracted Ca^{++} by diffusion as a function of the square root of time.

Norwegian geotechnical institute

Date 6/6·73 | Drawn by

Approved

Project no 50703-2

Drawing no 013

APPENDIX

Tables of experimental results

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RESULTATER

50703 DANNEVIKSGATE 16 DRAMMEN. ANALYSE AV DIFFUSJONSPROFIL I PLASTSYLINDRE

NO	PRØVE NO.	~~DYBDE~~ AVSTAND FRA FERSK FLATE M	VANN INNHOLD PST	NA MG/L	K MG/L	MG MG/L	CA MG/L
1	101	.01	55.81	590.91	26.16	69.81	78.13
2	102	.03	58.90	1789.47	75.58	150.94	83.33
3	103	.05	57.43	2877.36	125.00	274.53	114.58
4	104	.07	58.45	3349.06	179.05	443.40	158.73
5	105	.09	55.61	4858.49	189.19	533.96	218.75
6	106	.11	56.45	5613.21	216.22	670.21	306.03
7	107	.13	57.52	6524.39	239.86	769.98	452.59
8	110	.19	55.19	7887.80	293.92	914.89	744.93
9	301	.01	53.49	1092.91	40.51	94.34	95.83
10	303	.05	50.63	2657.89	123.55	273.58	135.42
11	305	.09	50.00	4103.77	102.16	426.42	177.08
12	307	.13	49.15	5613.21	212.84	548.94	301.72
13	309	.17	50.57	7439.02	256.76	829.79	310.34
14	311	.21	51.21	8048.78	273.65	888.30	336.21
15	313	.25	49.72	8780.49	293.92	966.09	370.69
16	322	.29	51.21	9390.24	314.19	1020.20	379.31
17	401	.01	36.17	7012.20	212.84	806.51	289.79
18	404	.07	38.01	1227.27	49.42	132.08	62.50
19	407	.13	37.41	4056.60	135.14	443.40	171.88
20	410	.19	30.54	8902.44	246.62	978.72	431.03
21	413	.25	34.76	9390.24	260.14	1042.55	643.62
22	416	.31	35.17	9756.10	266.89	1042.55	370.69
23	419	.37	36.62	9634.15	266.89	1053.19	362.07
24	422	.43	36.80	9878.05	277.66	1231.91	362.07
25	501	.01	29.25	1227.27	40.51	122.64	182.29
26	504	.07	29.68	4622.64	141.89	514.15	203.13
27	507	.13	27.21	7195.12	195.95	808.51	310.34
28	510	.19	26.99	8780.49	230.49	957.45	349.14
29	513	.25	25.49	~~6087.56~~	~~182.43~~	~~639.39~~	~~267.42~~
30	516	.31	25.25	9146.34	240.62	978.72	375.00
31	519	.37	29.39	9390.24	253.38	1000.00	375.00
32	522	.43	31.84	9512.19	253.38	1010.64	362.07
33	601	.01	28.33	1181.82	42.15	113.21	64.58
34	604	.07	27.69	3349.06	107.56	377.36	370.09
35	607	.13	29.60	6219.51	182.43	691.49	315.52
36	610	.19	28.55	7926.83	219.59	850.36	336.21
37	613	.25	28.27	~~3401.69~~	~~116.36~~	~~748.06~~	~~265.67~~
38	616	.31	28.40	9146.34	246.62	957.45	357.76
39	619	.37	28.05	9390.24	256.76	989.36	379.31
40	622	.43	28.51	9390.24	256.76	994.68	370.69

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RESULTATER

50703 DANNEVIKSGATE 16. DRAMMEN. ANALYSE AV DIFFUSJONSSYLINDER P2

NO	PRØVE NO.	DYBDE M	VANN INNHOLD PST	NA MG/L		K MG/L	MG MG/L	CA MG/L
1	211	.03	55.26	~~1340,19~~	1850	78.95	163.46	38.05
2	221	.09	54.02	~~5165,24~~	8050	193.33	551.72	110.00
3	231	.15	55.34	~~6750,63~~	7000	260.00	755.21	160.42
4	241	.21	54.29	~~7941,18~~	8160	304.35	869.79	185.42
5	251	.27	53.32	~~8571,43~~	8800	710.87	937.50	195.83
6	261	.33	52.76	~~8743,58~~	8880	717.39	963.54	200.00
7	271	.39	50.31	~~8888,48~~	8920	717.39	953.13	195.83
8	281	.45	48.89	~~8758,48~~	8950	736.96	963.54	187.75
9	212	.03	55.26	2053.03		122.91	77.36	23.01
10	222	.09	54.02	5470.70		306.36	323.48	68.77
11	232	.15	55.34	7757.55		395.39	495.10	112.97
12	242	.21	54.29	8997.74		430.30	518.74	148.00
13	252	.27	53.32	9236.16		452.03	743.39	159.35
14	262	.33	52.76	9484.06		459.12	739.56	167.41
15	272	.39	50.31	9567.49		485.07	768.08	160.64
16	282	.45	48.89	9516.07		481.06	772.54	156.74
17	213	.03	55.26	2121.71		197.24	92.14	7.82
18	223	.09	54.02	4790.88		305.80	165.20	27.06
19	233	.15	55.34	7639.43		455.96	341.43	59.36
20	243	.21	54.29	9321.46		547.28	430.32	84.41
21	253	.27	53.32	9112.83		544.92	460.23	89.78
22	263	.33	52.76	9555.21		546.79	467.23	100.78
23	273	.39	50.31	9580.36		577.14	469.88	89.70
24	283	.45	48.89	9353.07		526.54	479.26	91.73
25	214	.03	55.26	2750.42		1869.49	1400.45	834.67
26	224	.09	54.02	5738.83		2781.71	1959.42	929.61
27	234	.15	55.34	8215.58		2355.89	1738.30	949.11
28	244	.21	54.29	9780.37		2657.33	1867.52	1078.78
29	254	.27	53.32	9842.42		2761.23	1848.86	1038.52
30	264	.33	52.76	9866.52		2807.55	1881.02	1103.92
31	274	.39	50.31	10067.72		2563.09	1922.70	1121.09
32	284	.45	48.09	9822.80		2491.45	1836.86	1121.67

	Dato	Tegner
Salt concentrations in the cylinders of the diffusion experiment at the end of the diffusion process.	Godkjent	
	Oppdr. nr. 50703-2	
Norges geotekniske institutt	Tegn. nr.	

NORWEGIAN GEOTECHNICAL INSTITUTE FOR INDUSTRIAL RESEARCH

RESULTATER

50703 DANNEVIKSGATE 16, DRAMMEN . ANALYSE AV PRESSET PORE VANN

NO	PRØVE NO.	DYBDE M	VANN INNHOLD PST	NA MG/L	K MG/L	MG MG/L	CA MG/L
1	01A	4.35	42.66	5911.76	213.23	631.66	222.99
2	01B	4.82	46.36	6697.78	284.19	636.00	205.45
3	02A	5.35	48.76	7460.00	285.48	714.50	223.95
4	02B	5.82	49.18	7895.56	280.32	724.31	220.21
5	03A	6.35	51.16	8331.11	300.97	743.94	223.95
6	03B	6.82	55.81	8568.89	328.33	763.56	228.35
7	04A	7.35	52.50	8766.67	328.33	773.37	206.10
8	04B	7.82	51.47	9038.89	340.00	783.19	210.87
9	05A	8.35	54.38	9311.11	305.83	773.37	209.10
10	05B	8.82	51.13	9365.56	351.67	783.19	212.74
11	06A	9.35	50.56	9420.00	345.83	783.19	209.10
12	06B	9.82	52.54	9479.44	360.83	793.00	212.74
13	07A	10.35	47.25	9528.89	357.50	793.00	205.76
14	07B	10.82	42.51	9637.78	351.67	802.81	212.74
15	08A	11.62	34.72	9637.78	345.83	793.00	209.10
16	08B	11.82	36.75	9848.75	290.65	783.19	228.33
17	09A	12.30	32.66	9930.00	305.97	773.37	228.73
18	09B	12.85	29.95	9726.25	280.32	802.81	231.96
19	10A	13.35	33.60	9787.50	265.48	778.26	253.82
20	10B	13.82	27.54	9787.50	275.16	773.37	230.29
21	11A	14.35	28.66	9848.75	275.16	763.56	227.15
22	11B	14.82	29.13	9542.50	249.35	753.75	228.73

NORWEGIAN GEOTECHNICAL INSTITUTE FOR INDUSTRIAL RESEARCH

RESULTATER

50703 DANNEVIGSGATE 16,DRAMMEN . ANALYSE AV VASKET PORE VANN

NO	PRØVE NO.	DYBDE M	VANN INNHOLD PST	NA MG/L	K MG/L	MG MG/L	CA MG/L
1	01A	4.35	41.15	6233.68	323.45	504.57	275.76
2	01B	4.82	45.20	6688.06	371.47	608.84	185.74
3	02A	5.35	41.94	8124.60	435.71	652.55	420.32
4	02B	5.82	51.20	8953.63	490.60	680.34	215.99
5	03A	6.35	52.40	8377.60	441.24	597.48	187.53
6	03B	6.82	56.60	8341.62	530.82	622.93	189.09
7	04A	7.35	52.91	8951.02	475.20	629.80	202.59
8	04B	7.82	53.21	8909.50	501.08	639.61	211.15
9	05A	8.35	52.65	9399.36	535.79	648.74	214.03
10	05B	8.82	51.56	9949.24	591.77	634.15	220.96
11	06A	9.35	51.17	9404.54	573.92	642.80	241.79
12	06B	9.82	50.71	8953.59	515.06	677.11	227.56
13	07A	10.35	47.75	9617.05	543.68	683.75	207.05
14	07B	10.82	42.96	9676.94	586.09	753.09	225.87
15	08A	11.62	34.93	9538.69	531.88	767.20	395.26
16	08B	11.82	36.53	9750.50	424.69	732.76	374.21
17	09A	12.30	32.19	9755.92	409.52	793.84	381.13
18	09B	12.85	27.84	10082.84	475.33	955.54	421.12
19	10A	13.35	32.73	9597.27	432.33	844.56	356.34
20	10B	13.82	26.55	9749.83	419.76	837.42	408.10
21	11A	14.35	28.78	9366.15	412.56	780.51	375.80
22	11B	14.82	29.43	9069.45	397.02	798.11	343.13

	Dato	Tegner
In-situ salt concentrations determined by extracting the salts by pressing and by washing the clay.	Godkjent	
	Oppdr. nr.	50703-2
Norges geotekniske institutt	Tegn. nr.	

BEREGNINGSRESULTATER

50703 BESTEMMELSE AV DIFFUSJONSKONSTANTER I PLASTISK OG MAGER DRAMMENSLEIRE

PRØVE NO.: 1

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.02	61.1	.0084	2.9	.0153	3.7	.0031	2.8	.0106
3	3.9	1.97	136.1	.0111	7.7	.0284	8.6	.0045	6.0	.0135
4	9.0	3.00	213.2	.0118	11.4	.0268	13.8	.0050	9.0	.0130
5	16.0	4.00	287.9	.0121	15.3	.0269	18.9	.0053	11.8	.0128
6	24.9	4.99	361.5	.0122	18.7	.0259	23.7	.0054	14.7	.0127
7	36.2	6.02	433.3	.0121	21.9	.0244	29.2	.0056	19.9	.0159
8	49.2	7.01	501.4	.0119	25.4	.0242	34.6	.0058	25.7	.0195
9	64.8	8.05	584.9	.0123	29.4	.0247	39.9	.0059	28.1	.0178
10	81.0	9.00	653.1	.0123	32.5	.0241	45.0	.0060	29.6	.0157
11	105.0	10.25	747.4	.0124	37.0	.0241	51.2	.0060	31.4	.0137
12	122.9	11.09	812.8	.0125	40.0	.0240	56.0	.0061	32.9	.0129
13	147.1	12.13	887.6	.0125	43.5	.0237	61.3	.0061	34.4	.0117
14	~~152.9~~	~~12.36~~	978.7	~~.0146~~	48.0	~~.0278~~	69.9	~~.0076~~	36.5	~~.0127~~
	188.9	13.74								

PRØVE NO.: 2

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.02	61.8	.0085	3.3	.0202	3.6	.0031	3.0	.0137
3	3.9	1.97	131.5	.0103	7.8	.0303	8.3	.0045	6.2	.0160
4	9.0	3.00	206.7	.0110	11.6	.0265	13.2	.0049	9.1	.0148
5	16.0	4.00	279.9	.0113	15.6	.0291	18.0	.0051	12.0	.0144
6	24.9	4.99	350.7	.0114	19.1	.0280	22.7	.0052	14.8	.0142
7	36.2	6.02	422.1	.0114	22.7	.0272	27.9	.0054	19.8	.0174
8	49.2	7.01	490.3	.0113	26.8	.0280	33.1	.0056	24.8	.0201
9	64.8	8.05	569.3	.0116	31.3	.0289	38.3	.0057	26.3	.0172
10	81.0	9.00	648.6	.0120	34.8	.0286	43.1	.0058	27.7	.0152
11	105.0	10.25	742.4	.0121	39.2	.0280	49.0	.0058	29.5	.0134
12	122.9	11.09	808.7	.0123	42.5	.0282	53.5	.0059	30.9	.0125
13	147.1	12.13	882.1	.0122	46.3	.0280	58.5	.0059	32.1	.0112
14	~~153.9~~	~~12.41~~	988.9	~~.0141~~	51.6	~~.0319~~	67.9	~~.0073~~	34.4	~~.0119~~
	183.9	13.58								
15	264.9	14.31	1077.0		53.3		70.9		41.4	

PRØVE NO.: 4

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.01	59.3	.0098	3.0	.0319	4.2	.0053	3.4	.0245
3	3.9	1.97	123.8	.0113	6.6	.0421	8.9	.0063	7.1	.0282
4	9.0	3.00	191.0	.0110	9.5	.0378	13.7	.0065	10.5	.0267
5	16.0	4.00	256.2	.0117	12.9	.0367	18.5	.0066	14.2	.0270
6	24.9	4.99	320.7	.0118	15.5	.0357	23.1	.0066	17.9	.0276
7	36.2	6.02	387.0	.0118	18.2	.0338	27.9	.0067	24.8	.0366
8	49.2	7.01	450.8	.0116	21.0	.0334	32.8	.0067	31.7	.0440
9	64.8	8.05	514.7	.0117	24.2	.0335	37.6	.0067	35.9	.0428
10	81.0	9.00	573.8	.0116	26.9	.0333	41.8	.0067	39.0	.0405
11	105.0	10.24	655.0	.0117	30.5	.0330	47.4	.0066	43.2	.0383
12	122.9	11.09	715.2	.0119	33.5	.0340	52.0	.0068	47.8	.0401
13	147.1	12.13	781.8	.0119	36.9	.0343	57.1	.0068	53.3	.0415
14	~~159.9~~	~~12.64~~	862.3	~~.0130~~	40.6	~~.0343~~	65.4	~~.0085~~	60.8	~~.0511~~
	192.0	13.86								

ANTALL FORSØK ER: 6

UTGANGSDATA

PRØVENS TVERRSNITTAREAL: 19.871CM**2

PRØVE	DATO	KL	N	NA Mg/L	K Mg/L	MG Mg/L	CA Mg/L
1	721002	1300.	.62	9000.00	320.00	890.00	360.00
2	721002	1315.	.59	9500.00	330.00	910.00	360.00
4	721002	1325.	.51	9878.00	274.00	950.00	360.00
5	721002	1325.	.45	9510.00	253.00	1000.00	360.00
3	721002	1340.	.59	9390.00	340.00	950.00	360.00
6	721002	1340.	.445	9390.00	259.00	980.00	360.00

Porøtall

PRØVE NO.: 5

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.01	51.5	.0104	2.6	.0360	3.5	.0044	3.0	.0237
3	3.9	1.97	106.1	.0115	5.8	.0486	7.8	.0056	6.4	.0289
4	9.0	3.00	165.7	.0121	8.3	.0431	11.9	.0057	9.4	.0274
5	16.0	4.00	224.6	.0125	11.2	.0439	16.1	.0058	12.5	.0271
6	24.9	4.99	282.6	.0127	13.3	.0401	20.0	.0058	16.0	.0283
7	36.2	6.02	340.3	.0127	16.0	.0396	24.3	.0059	22.7	.0393
8	49.2	7.01	397.0	.0127	18.5	.0389	28.5	.0059	29.8	.0501
9	64.8	8.05	452.9	.0125	21.2	.0387	32.8	.0060	34.3	.0502
10	81.0	9.00	502.6	.0124	23.2	.0372	36.7	.0060	38.1	.0497
11	105.0	10.25	569.3	.0122	26.0	.0360	41.7	.0059	43.7	.0504
12	122.9	11.09	617.3	.0123	28.2	.0362	45.4	.0060	48.6	.0533
13	147.1	12.13	671.8	.0122	30.6	.0355	49.6	.0060	54.1	.0549
14	~~159.9~~	~~12.66~~	739.4	~~.0146~~	33.5	~~.0367~~	56.3	~~.0078~~	61.9	~~.0684~~
	190.8	13.81								

PRØVE NO.: 3

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.00	65.3	.0101	4.3	.0330	4.0	.0036	3.3	.0174
3	3.9	1.96	167.2	.0172	11.3	.0601	10.0	.0060	7.3	.0222
4	9.0	3.00	278.6	.0205	18.2	.0663	16.5	.0070	11.1	.0219
5	16.0	4.00	376.2	.0209	24.4	.0672	22.2	.0071	14.7	.0219
6	24.9	4.99	473.0	.0213	29.7	.0638	28.1	.0073	18.7	.0226
7	36.2	6.02	581.7	.0221	36.0	.0644	35.4	.0080	26.2	.0305
8	49.2	7.01	675.7	.0220	42.1	.0650	41.8	.0082	32.5	.0345
9	64.8	8.05	773.9	.0219	48.1	.0644	48.0	.0082	35.6	.0315
10	81.0	9.00	864.1	.0218	53.3	.0633	53.7	.0082	37.6	.0281
11	105.0	10.24	974.8	.0214	59.8	.0616	61.0	.0082	40.3	.0249
12	122.9	11.09	1061.3	.0217	64.9	.0619	66.5	.0083	42.4	.0236
13	147.1	12.13	1157.3	.0215	70.7	.0614	72.8	.0083	44.8	.0219
14	~~164.8~~	~~12.96~~	1281.3	~~.0252~~	92.3	~~.0098~~	82.5	~~.0103~~	47.9	~~.0246~~
	189.8	13.78								

PRØVE NO.: 6

	TID DØGN	SQRT(T)	QNA MG	DNA M2/AR	QK MG	DK M2/AR	QMG MG	DMG M2/AR	QCA MG	DCA M2/AR
2	1.0	1.00	53.0	.0119	3.0	.0509	3.5	.0049	3.2	.0303
3	3.9	1.96	124.2	.0170	6.6	.0631	8.6	.0075	7.5	.0420
4	9.0	3.00	206.7	.0202	10.6	.0693	14.2	.0088	12.1	.0475
5	16.0	4.00	277.4	.0204	14.6	.0741	19.4	.0092	16.9	.0519
6	24.9	4.99	350.7	.0210	17.8	.0710	24.6	.0095	21.9	.0558
7	36.2	6.02	431.8	.0219	21.9	.0739	30.4	.0100	28.9	.0668
8	49.2	7.01	501.8	.0218	24.9	.0704	35.6	.0100	35.6	.0744
9	64.8	8.05	575.2	.0217	28.8	.0713	40.8	.0100	43.1	.0850
10	81.0	9.00	642.5	.0217	31.1	.0669	45.6	.0100	49.2	.0864
11	105.0	10.24	732.4	.0217	35.5	.0669	52.0	.0101	56.5	.0881
12	122.9	11.09	796.6	.0220	38.7	.0682	56.5	.0102	62.7	.0924
13	147.1	12.13	863.6	.0216	41.9	.0668	61.1	.0099	68.6	.0926
14	~~155.8~~	~~12.46~~	959.1	~~.0254~~	64.4	~~.0469~~	69.4	~~.0121~~	77.2	~~.1108~~
	191.8	13.78								

Initial data and time readings of salt quantities removed by diffusion. Average diffusion constants computed from this.

Norges geotekniske institutt

Dato

Godkjent

Tegner

Oppdr. nr. 50703-2

Tegn. nr.