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CONTRACT REPORT

DET NORSKE VERITAS

BLOCK 58, WEST DELTA AREA GULF OF MEXICO

LABORATORY REPORT

81222-2 18th JUNE. 1982

Norges Geotekniske Institutt

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TWO SAMPLES FROM 33.9 m AND 68 m DEPTH HAVE BEEN SUBJECTED TO CYCLIC TESTING WHICH WAS INTENDED TO SIMULATE THE FIELD CONDITIONS OF THE CLAY SURROUNDING THE PILES OF A TENSION LEG PLATFORM. THE TEST RESULTS HAVE BEEN COMPARED AND COINCIDE WELL WITH THE RESULTS FROM THE OTHER LABORATORIES INVOLVED IN THE PROJECT. COMPARISONS WITH NGI's EXTENSIVE EXPERIENCE WITH DRAMMEN CLAY INDICATE A CYCLIC BEHAVIOUR OF THE ACTUAL SOIL SIMILAR TO THE DRAMMEN CLAY WITH AN OCR BETWEEN 1 AND 4.

cont...

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The present report summarizes all the testing carried out at NGI on samples 65 and 133, Boring 5.

The following part of the report will describe in more detail the testing methods used and the results obtained. The results will also be discussed in view of the results obtained at the other laboratories involved and in light of the previous experience at NGI with cyclic testing on Drammen clay.

for the
NORWEGIAN GEOTECHNICAL INSTITUTE

Knut Schjetne

Fritz Nowacki

FN/mjs

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1. INTRODUCTION

The Norwegian Geotechnical Institute (NGI) is serving as consultants to Det norske Veritas, Norway, in connection with a Tension Pile Study carried out for Conoco Norway Inc.

NGI has received two 3-inch diameter sample cylinders from a soil sampling survey carried out by McClelland (1982) at a selected test site at Block 58, West Delta Area, Gulf of Mexico.

The scope of our laboratory work has mainly been to carry out a few cyclic simple shear tests in order to obtain some soil data about the behaviour of the clay when subjected to cyclic loading.

This report contains the results of the testing carried out at NGI's laboratory. The results are also, to some extent, discussed on the basis of and compared with NGI's previous experience. Comparison with the test results from the other laboratories involved in this project, have also been made.

2. LABORATORY PROGRAM

Appendix II gives a description of the procedures and the equipment used.

2.1 Classification and identification.

Attached to each simple shear specimen, the following tests were carried out on material close to the sample:

- water content
- Atterberg limits
- density
- density of solid particles
- salt content of pore water
- inorganic carbon content
- organic content
- particle size distribution
- fall cone shear strength

In addition to the classification testing, each sample was classified and described by a soil geologist during opening of the cylinder.

2.2 Consolidated constant volume simple shear tests.

One static test and two cyclic tests were carried out on specimens from each cylinder.

In order to simulate the loading of a soil element along a vertical pile, the axis of the specimen was oriented at a right angle to the cylinder wall. The horizontal plane on the built-in specimen thus coincide with the in situ horizontal plane, and the applied shear stress on the sample will coincide with the direction of the mobilized side friction on a vertical pile. It should, however, be noted that the horizontal stress in the simple shear apparatus is less than the in situ vertical effective stress which it should ideally be equal to.

During the first day, the specimen was axially consolidated in steps to an assumed in situ horizontal effective stress ($K_o' \; p_o'$). Standard NGI consolidation procedures were followed. The following day, a horizontal stress was applied to the sample in three steps under drained conditions. The sample was allowed to further consolidate over the following night. The horizontal consolidation shear stress was determined by the formula

$$\tau_{hc} = 0.35 \left(\frac{\tau_{hf}}{p_o'}\right) K_o' \, p_o' \qquad (1)$$

The idea was to apply a horizontal shear stress which was 35 per cent of the anticipated shear strength. There were two reasons for the selection of 35 per cent. Firstly, a rough analysis of a pile foundation for a TLP indicate an average tension of approximately 35 per cent of the failure load. Secondly, a few similar tests with this consolidation shear stress ratio were previously carried out as a part of a large research project dealing with repeated loading on clay, NGI (1975).

The third day, the cyclic testing and the static undrained test was carried out. The static shearing was carried out by increasing the shear stress in the same direction as the consolidation shear stress.

Some basic definitions and the shape of the shear stress pulses used in the cyclic testing are shown on Drawing 006.

More detailed test procedures are found in Appendix II.

2.3 Consolidation test.

Due to the uncertainty with respect to the in situ effective stress condition, it was decided during cylinder opening to perform one oedometer test on sample 65. This sample looked rather undisturbed.

The standard NGI oedometer procedure was followed, as described in Appendix II.

3. RESULTS OF LABORATORY TESTS

3.1 Classification tests.

The description of the samples and the classification test results are summarized in Drawings 001 and 002 respectively. A comparison with the results given in Refs. 2 and 3 gives reason to conclude that the index values all are close to the corresponding values found by Ertec, McClelland and NTH.

The grain size distribution curves are shown in Drawing 003.

The measured water content, soil density and density of solids was used to calculate the degree of saturation of the samples.

The result is presented in the table below:

Sample	Depth m	Range of calculated degree of saturation at atmospheric pressure (%)
65	33.9	87-91
133	68.0	97-100

The results indicate a content of gas in sample 65. Release and expansion of dissolved gas in the pore water during sampling and sample recovery may explain some of the sample disturbance which was experienced.

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3.2 Oedometer tests.

The test results are presented on Drawings 004 and 005 on a logarithmic and on a linear scale respectively.

The constrained deformation modulus, M, defined as $\Delta\sigma_a'/\Delta\varepsilon_a$, is shown on Drawing 005, which also shows estimates of the coefficient of consolidation, c_v. The c_v-values were calculated from the best estimate of the permeability of the samples and the modulus M.

The best estimate of the permeability was found by means of backcalculation from the time-settlement curves and by direct measurement on the sample.

It is in general difficult to determine the preconsolidation pressure from oedometer results. In this actual case, the sample disturbance seems to be significant, as the sample required more than 7% volumetric strain to reach the anticipated p_o' according to Ref. 2. We therefore do not recommend a preconsolidation pressure to be evaluated from these results.

The uncertainty with respect to the in situ effective stress conditions must be solved by means of direct pore pressure measurements in situ.

3.3 Simple shear test results.

The main test data and results are found in Table AIII-1.

Drawings 007 and 008 show the development of shear strain during consolidation for the horizontal shear stress. It is seen that the contribution from creep strain is significant for the final shear stress level in question.

Drawings 009 to 014 show the horizontal shear stress during all phases of the test versus shear strain in addition to the pore pressure during static loading versus shear strain. It may be of interest to note that the creep shear strain due to the constant horizontal consolidation stress is of the same order of magnitude as the permanent shear strain during cyclic loading.

For the cyclic phase, average pore pressure and the maximum and minimum shear strain values are shown against number of cycles on Drawings 015 to 018.

On Drawings 019 to 024, the effective stress paths are shown for the undrained phases of the tests.

A summary of the effective stress paths from the static phase is shown on Drawing 025.

4. DISCUSSION OF THE SIMPLE SHEAR TEST RESULTS

4.1 Consolidation stresses and cyclic shear stress level.

Based on the information provided in Ref. 4, it was assumed a ratio $\tau_{hf}/p_o' = 0.26$ when the horizontal consolidation shear stress was selected by means of equation (1).

As can be seen from Table AIII-1, Column 33, the measured ratio was approximately 0.33 and 0.29 for Sample 65 and Sample 133 respectively. Consequently, the ratio τ_{ha}/τ_{hf} was less than the value 0.35 which was planned. Due to the same reason, also the cyclic shear stress level became less than planned.

The assumed stress conditions both in situ and in the laboratory are summarized on Drawings 026 and 027 in Mohr diagrams. The in situ stresses are drawn for two alternatives. It is assumed that hydrostatic pore pressure conditions represent an upper effective stress limit, while the interpreted maximum past pressure on Plate 12A in Ref. 2, represents a lower limit.

The stress circles were constructed based on the following assumed K_o', taken from Brooker and Ireland (1965).

Sample	K_o'
65	0.63
133	0.70

The maximum stress circles at the first load cycle were based on the assumption of unchanged mean normal effective stress.

It is seen that the circles representing the laboratory tests are lying approximately midway between the in situ stress limits. Again, however, it should be noted that the principal stress directions are exchanged in the laboratory compared with the in situ conditions.

4.2 Comparisons with results from the other laboratories.

A comparison of the static simple shear tests are summarized in Table AIII-2.

The τ_{hf}/σ_{ac}'-values measured at NGI are somewhat high compared to the results from Refs. 2 and 4 and also somewhat higher than we would have expected for a true normally consolidated material. This may indicate that the tests described in the present report were carried out on a slightly overconsolidated soil, say OCR = 1.5.

In order to obtain the effective strength parameters (attraction = a = $c'/\tan\phi'$ and friction = $\tan\phi'$) and the undrained shear strength characteristics, a summary of the relevant static triaxial tests is shown in Table AIII-3. The a-$\tan\phi'$ results are indicated on the relevant simple shear test diagrams in this report, as these parameters cannot be directly measured from a simple shear test.

The scatter in the measured s_{uA}/σ_{ac}' values is significant. It is, however, of interest to note that the average values are approximately equal to the τ_{hf}/σ_{ac}' values measured by simple shear testing at NGI. We would normally have expected higher s_{uA}/σ_{ac}' ratios than τ_{hf}/σ_{ac}' and this supports the suspicion that our tests were carried out on a slightly overconsolidated material.

It is also of interest to note that the ratios of s_{uA}/σ_{ac}' obtained at NTH after cyclic loading are not lower, but on the contrary may be slightly higher than the values obtained by the other laboratories from pure static tests.

The present simple shear testing indicates an unchanged static shear strength of a sample subjected to cyclic loading of the actual intensity. Furthermore, the shear strain level when the maximum shear stress is reached seems to be unaffected by the previous cyclic loading. This is an interesting result which means that the secant shear modulus at failure shear stress may be unaffected by the cyclic load history of an element. Again this is valid for the actual cyclic loading history.

The permanent shear strain during cyclic loading has been interpreted by the shear strain resistance

$$R_\gamma = \frac{\Delta N}{\Delta\gamma_a} \qquad (2)$$

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The resistances versus number of cycles are shown on Drawings 028 and 029. The shear strain resistance was almost linearly increasing with the number of cycles. This made it possible to find a constant value of the resistance number $r_\gamma = dR_\gamma/dN$ for each cyclic test. The resistance number was plotted against cyclic shear stress level τ_{hcy}/τ_{hf} as shown on Drawing 030. It is seen from Drawing 030 that a dramatic increase in permanent cyclic strains may be expected if the cyclic shear stress level is exceeding 0.5. It should be noticed that the relationship between r_γ and τ_{hcy}/τ_{hf} also depends on the average shear stress level.

A comparison between the shear strain resistance and the axial strain resistance measured at NTH (Ref. 3) has been made. The theoretical relationship is

$$R_\varepsilon = \frac{3}{2} R_\gamma \qquad (3)$$

However, the numerical R_ε-results shown in Fig. 35 in Ref. 3 are valid for much higher τ_a/s_{uA}-ratios than the ratio used in the present tests. A systematic and quantitative comparison has not been possible to carry out because the R_ε-values in the same order of magnitude as the R_γ-values in the present report has not been presented in Ref. 3. A qualitative comparison indicates, however, that there is reasonable agreement between the permanent strains measured by the triaxial tests (NTH) and by the simple shear tests (NGI).

A quantitative comparison would probably require a coordinated planning of the testing procedures.

4.3 Comparisons with results from NGI s previous experience.

The basic experience at NGI is the extensive research work carried out on Drammen clay (e.g. Refs. 1 and 6).

One of the main objectives with the actual tests was to try to place the cyclic behaviour of the pertinent soil into this framework of experience.

A comparison of the static test results with the static tests on Drammen clay is shown on Drawing 031. It should be noted that none of the static tests on Drammen clay was performed with horizontal shear stress consolidation and with the sample orientation as used in the actual tests. This comparison indicate, however, that the pertinent soils behave approximately equal to Drammen clay with OCR between 1 and 4. The somewhat less stiffer behaviour observed for sample 133 compared to sample 65 is reasonable due to the much higher plasticity.

A comparison of the accumulated average pore pressure build up during cyclic loading is shown in Drawing 032. The measured average pore pressures have been plotted into a pore pressure contour diagram valid for Drammen clay for OCR = 1 and $\tau_a = 0$. As can be seen from Drawing 032, the actual pore pressure build up is very similar to the test results on Drammen clay with OCR = 1.

In general, the cyclic as well as the average shear strains are functions of both cyclic and average shear stress levels. However, previous test results on Drammen clay indicate that the cyclic shear stress is the dominant parameter in governing the cyclic shear strain. Drawings 033 and 034 show the cyclic shear stress level plotted against the cyclic shear strain amplitude for 10, 100 and 1000 cycles. The Drammen clay data was based on triaxial and simple shear tests including several modes of cyclic loading. Also anisotropic consolidated tests were included, where the average shear stress during cycling was different from zero and thus in principle equal to the actual tests. These results from Drammen clay clearly indicate that the average shear stress was of minor importance for the development of cyclic shear strain. The results from the actual tests were also plotted on the diagrams on Drawings 033 and 034, valid for OCR = 1 and 4 respectively. It is seen that the actual test results fit very well to the cyclic shear strain amplitude measured on Drammen clay with an OCR = 4.

An attempt has also been made to compare the average shear strain during cyclic loading with the results from Drammen clay. The data base for tests with an average shear stress during cycling is, however, mainly concentrated on OCR = 4. In addition, a proper comparison would require a reinterpretation of the tests on Drammen clay. This was found to lie outside the scope of this project.

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APPENDIX I: LIST OF SYMBOLS

a	=	attraction
c'	=	cohesion
c_v	=	coefficient of consolidation
G	=	shear modulus
I_p	=	plasticity index
k	=	coefficient of permeability
M	=	modulus of deformation
N	=	number of cycles
OCR	=	overconsolidation ratio
p_o'	=	effective overburden pressure in situ
p_c'	=	vertical pre-consolidation pressure in situ
s_u	=	undrained shear strength
s_{uA}	=	active (compression) undrained shear strength
u	=	pore water pressure
u_f	=	pore water pressure at failure
u_N	=	pore water pressure after N cycles
w	=	water content
w_f	=	final water content
w_i	=	initial water content
w_p	=	plastic limit
w_L	=	liquid limit
ε_a	=	axial strain; average strain during cyclic loading
$\varepsilon_{N,a}$	=	axial strain after N cycles
ε_v	=	vertical strain

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ε_{ac} = axial strain after consolidation

ε_{af} = axial strain at failure

ε_{cy} = cyclic strain

ε_{vol} = volumetric strain

$\tan\phi'$ = internal friction

$\tan\rho$ = mobilized internal friction

γ = shear strain

γ_a = average shear strain during cyclic loading

$\gamma_{N,a}$ = average shear strain after N cycles

γ_c = consolidation shear strain

γ_{cy} = cyclic shear strain

γ_f = shear strain at failure

γ_h = horizontal shear strain

$\gamma_{N,cy}$ = cyclic shear strain after N cycles

ρ = density of soil

ρ_s = density of solids

ρ_w = density of water

σ_1' = effective major principal stress

σ_3' = effective minor principal stress

σ_r' = radial or horizontal effective stress

σ_{rc}' = radial or horizontal effective consolidation stress

σ_a', σ_v' = axial or vertical effective stress

σ_{ac}', σ_{vc}' = axial or vertical effective consolidation stress

τ = shear stress

τ_{cy} = cyclic shear stress

τ_a = average shear stress during cyclic loading

τ_h = horizontal shear stress

τ_{hcy} = cyclic horizontal shear stress

τ_{hf} = horizontal shear stress at failure

$\tau_{hf\ cy}$ = horizontal shear stress at failure after cycling.

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A P P E N D I X   II

DESCRIPTION OF LABORATORY PROCEDURES

1. CLASSIFICATION TESTS
2. CONSOLIDATION TESTS
3. SIMPLE SHEAR TESTS
4. PERMEABILITY TESTS

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DESCRIPTION OF LABORATORY PROCEDURES

This appendix contains a short description of the equipment and procedures used for the laboratory tests at NGI. For more details, see Andresen et al. (1979) (Ref. 7).

1. CLASSIFICATION TESTS

1.1 Water content (w)

Water content (w) is the mass of water in the sample expressed as a percentage of the mass of solids. It is found by weighing a representative part of the sample before and after 17-20 hours of oven drying at approximately 110°C.

1.2 Liquid limit (w_L) and plastic limit (w_P)

Liquid limit (w_L) and plastic limit (w_P) are the highest and lowest water contents, respectively, at which the remoulded soil material is in a plastic state. Standard methods, which correspond closely to the ASTM-procedures, are used to determine w_L and w_P.

1.3 Grain size distribution

The grain size distribution is determined by the following two procedures:

Samples that contain mainly sand and coarser material are subjected to an ordinary sieve analysis. On materials containing more than 10% silt and clay particles, a wet sieve analysis is performed.

On the samples that contain mainly silt or clay, the falling drop method is used. The falling drop method is primarily a sedimentation method based upon Stoke's law. A small sample of moist material is treated with water and hydrogen peroxide, washed through a 60 μ sieve and centrifuged before being poured into a sedimentation tube. Droplets from a certain depth in the sedimentation tube are sampled with a calibrated micropipette after certain time intervals and ejected into a glass column containing an organic liquid. The time required for each droplet to fall a certain distance in the glass column is measured. The concentration of suspended particles in each droplet can then be read from a calibration chart.

1.4 Density

Density, ρ, of a soil specimen is determined by measuring its diameter and length and then weighing it.

1.5 Density of solid particles

Density of solid particles, ρ_s, is measured by means of a density bottle according to standard soil testing procedures.

1.6 Carbon content and organic content

Inorganic carbon as calcite is determined by treating dry samples with HCl in a closed vessel. By a manometric measurement of the evolved carbondioxide, the amount of calcite can be calculated.

The organic carbon as organic content is determined in the same apparatus by treating the sample with chromic acid and subtacting the inorganic carbon from the total (Moum, 1967).

1.7 Undrained shear strength determination by fallcone

The fallcone apparatus is produced by Geonor A/S. It measures the penetration of a cone into the specimen when the cone is released from an initial stationary position with the tip of the apex at the surface of the specimen. Cones with different apex angles and masses are used. For the hard clays from the North Sea a 400 g cone with an apex angle of 30^{o} is most often used.

2. CONSOLIDATION TESTS

This test is designed to find the compressibility of the specimen tested. On "undisturbed" specimens the test may also indicate the maximum pressure that the specimens have ever been subjected to. This pressure is called the preconsolidation pressure and is denoted p_c'.

A cylindrical specimen with a cross-sectional area of 20 or 50 cm^2 and height 2 cm is placed within a steel ring which prevents radial deformation. An axial (vertical) stress is applied on the top of the specimen. The stress is increased in steps. For each step the axial deformation is measured at certain time intervals until the compression more or less stops. The specimen is allowed to drain freely at top and bottom.

For overconsolidated clays, which may have a high negative pore pressure, dry filter stones are used at the beginning of the test to prevent the specimen from swelling. To avoid evaporation of moisture from the specimen, all openings from the filterstones are covered with silicon grease or sealed with O-rings.

Two loading procedures are used, depending on whether the preconsolidation pressure, p_c', is determined before the test or not. For North Sea clays p_c is usually evaluated before the test using a relationship between s_u/p_c' and I_p. The specimen is first loaded to this p_c-value. Then the porous stones are saturated with salt water of approximately the same salt concentration as the pore water of the clay. The specimen is then unloaded to the present vertical effective stress p_o' and thereafter reloaded to about 9 times p_c'.

If p_c' is not determined before the test, the specimen is loaded to a pressure which is about two times higher than the pressure where the stress-strain curve has a maximum curvature. Then the porous stones are saturated with salt water, the specimen unloaded to p_o' and reloaded as described above.

3. SIMPLE SHEAR TESTS

3.1 Static, consolidated, constant volume tests (static CCV-tests)

The apparatus for this test is described by Bjerrum and Landva (1966) (Ref. 8) and Andresen et al. (1979) (Ref. 7).

A cylindrical specimen with cross-sectional area 20, 35 or 50 cm and height 16 mm is placed within a reinforced rubber membrane which prevents radial deformation, but allows the specimen to be deformed in simple shear.

Clay specimens are mounted with dry porous stones to prevent swelling at low pressures. The axial (vertical) stress is then increased in steps to the estimated effective preconsolidation pressure p_c'. The porous stones are then saturated with water of approximately the same salt concentration as the pore water of the clay. After saturation the horizontal consolidation stress is increased in steps.

After the consolidation the specimen is sheared by applying a horizontal shear stress to it.

The specimens are sheared at constant volume. The volume is kept constant by increasing or decreasing the axial stress during shearing.

The constant volume test theoretically gives the same result as an undrained test. The change in the axial stress for a constant volume test is equal to the change in pore pressure for an undrained test where the total axial stress is kept constant. The reason for doing a constant volume instead of an undrained test is that drainage cannot be completely prevented and back pressure cannot be applied in the simple shear device. (Triaxial tests are sometimes also performed as constant volume tests if it is difficult to saturate the specimen sufficiently by application of a back pressure. The cell pressure is then adjusted to keep the volume of the specimen constant).

3.2 Cyclic, consolidated constant volume tests (Cyclic CCV)

For cyclic shear testing a pneumatic loading device is connected to the simple shear apparatus. The shape of the shear stress pulses and some definitions are shown on Drawing 006. The period of the cycles is usually 10 seconds.

The consolidation procedure for a cyclic test is the same as for a static test.

A cyclic horizontal shear stress is applied such that the horizontal shear stress varies between $\tau_{ha} + \tau_{hcy}$ and $\tau_{ha} - \tau_{hcy}$. The average cyclic shear stress is τ_{ha}. The volume of the specimen is kept constant during the cyclic loading.

The cyclic phase continues until 2 000 cycles or to a shear strain of +3%, whichever occurs first. After the cyclic phase a static, constant volume test is performed as described above. No volume change is permitted between the cyclic and the static shearing.

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4. PERMEABILITY TESTS

4.1 Permeability tests on specimens in the oedometer cell

The coefficient of permeability of an oedometer specimen may be measured at any of the loading steps where the porous stones are saturated with water. A constant water pressure gradient, i, is then applied over the specimen and the resulting rate of flow, v, measured. Usually, no back pressure is used. The coefficient of permeability, k, is then computed from Darcy's law: $v = ki$.

SUMMARY OF CCV SIMPLE SHEAR TESTS

BORING NO	SAMPLE NO	DEPTH	INDEX PROPERTIES: w_i	w_f	w_l	w_p	I_p	2	*) Fall cone s_u	*) Pock. pen. s_u	$K_o P_o'$	CONSOLIDATION, VERTICAL: $\sigma_{ac\,max}$	**) $\varepsilon_{ac\,max}$	OCR	HORIZONTAL: τ_{hc}	γ_{hc}	$\Delta\varepsilon_{ac}$	CYCLIC LOADING: τ_{hcy}	$\frac{\tau_{hcy}}{\tau_{hf}}$	N At end of test	$\gamma_{N_{cy}}$	$u_{N_{cy}}$	$\frac{u_{N_{cy}}}{\tau'_{ac}}$	τ_{ha}	$\frac{\tau_{ha}}{\tau_{hf}}$	***) $\gamma_{N,a}$	$u_{N,a}$	$\frac{u_{N,a}}{\tau'_{ac}}$	STATIC LOADING: τ_{hf} or τ_{hfcy}	γ_f	u_f	$\frac{\tau_{hf}}{\tau'_{ac}}$ or $\frac{\tau_{hfcy}}{\tau'_{ac}}$
		m	%						kPa				%		kPa	%		kPa			%	kPa		kN/m²		%	kPa		kPa	%	kPa	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
5	65B	33.9	37.6	35.9	55.1	23.9	31	38	40.2		142	138.2	6.9	1	12.6	0.59	0.37												43.8	10.8	44	0.32
	65D		38.6	36.9	54.1	21.0	33	30	35.3		142	137.7	7.9	1	12.6	0.62	0.31	12.71	0.29	2000	0.17	0.7	~ 0	12.65	0.29	0.70	39.9	0.29	45.3	10.8	49	0.33
	65E		38.6	36.6	53.4	24.0	39	38	31.7		142	138.0	8.5	1	12.5	1.17	0.70	16.61	0.39	2000	0.40	14.0	0.10	12.55	0.29	1.59	58.1	0.42	44.5	8.4	46	0.32
	133-C	68.0	52.6	46.8	93.2	34.9	58	62	58.2		342	333.4	11.8	1	30.2	1.50	0.72												98.0	14.2	99	0.29
	133-B		56.9	53.0	92.4	31.8	61	55	71.3		342	333.3	12.6	1	30.2	1.25	0.74	30.37	0.31	2000	0.30	4.21	0.01	30.29	0.31	0.92	71.4	0.21	97.7	12.9	105	0.29
	133-D		55.3	47.8	99.4	35.9	63	61	55.5		342	332.5	12.6	1	30.2	2.00	0.91	43.30	0.44	2000	0.78	6.64	0.02	30.31	0.31	3.74	124.1	0.37	101.3	12.4	122	0.30

*) Before building in

**) Used correction for false deformation results in too high values

***) Accumulated during cyclic loading

Table no. A III - 1

Project no: 81222

Client: CONOCO/DNV

Location: BLOCK 58. W. DELTA AREA. GULF OF MEXICO

Report: 81222-2

COMPARISON OF STATIC SIMPLE SHEAR TESTS

Boring sample	Depth	w_L	w_p	I_p	ρ	w_i	w_f	σ_{ac}'	OCR	τ_{hf}	γ_f	τ_{hf}/σ_{ac}'	Shear strain rate	Stratum	Company
	m		%		Mg/m^3	%		kPa	-	kPa	%	-	%/hour		
5-76	39.02	45*	21*	24*	1.76/ 1.84	36	31	275.9	1.0	58.1	10.6	0.211	12.4	II	ERTEC
5-42	21.0	64	27	37		73	58	179.0	1.0	56.7	14.1	0.317		Transition to Zone I	McClelland
5-85	45.5	54	24	30		36	29	448.0	1.0	123.0	13.8	0.275		II	McClelland
5-65B	33.9	55	24	31	1.74	38	36	138.2	1.0	43.8	10.8	0.317	10.9	II	NGI
5-133C	67.8	99	36	63	1.70	53	47	333.4	1.0	98.0	14.2	0.294	11.5	III	NGI
6-62	64.24					55	45	503.5	1.0	114.2	15.6	0.226	7.9	III	ERTEC
5-138	69.7	83	51	32		63	44	683.0	1.0	158.0	19.2	0.231		III	McClelland

* Not from the sample itself?

TABLE NO. AIII-2

SUMMARY OF RELEVANT STATIC TRIAXIAL TESTS CARRIED OUT BY OTHER LABORATORIES

Sample	Depth	Index properties w_i	w_f	w_L	w_p	I_p	Consolidation σ_{rc}'	σ_{ac}'	OCR	$\tan\phi$	a	s_{uA}	s_{uA}/σ_{ac}'	ε_{af}	Stratum	Company
	m			%			kPa					kPa		%		
5-61	32.4	45.8	33.4				103.4	103.4	1.0	0.43	0	34.8	0.34	16.6		ERTEC
6-16	25.0	39.2	32.0				196.5	283.0	1.0	0.58	0	88.0	0.31	7.2		ERTEC
5-69	34.9	42.0	30.0	64	27	37	434.0	711.0	1.0	0.53	0	193.0	0.27	4.4	II	McClelland
5-71	35.4						136.0	226.0	1.0	0.52	20	83.0	0.37	8.8		NTH CON1. Post cyclic
5-71	35.4	44.0		65	35	30	125.0	219.0	1.0	0.55	15	60.0	0.27	4.4		NTH CN102. Post cyclic
5-71	35.4	40.0					98.0	212.0	1.0	0.54	25	54.0	0.26	11.4		NTH CN103. Post cyclic
6-45	49.2	52.9	41.4				358.6	358.6	1.0	0.47	0	105.2	0.29	7.5		ERTEC
6-62	64.3	49.3	43.4				503.3	503.3	1.0	0.46	0	133.1	0.26	10.0		ERTEC
6-53	55.0	56.4	43.0				361.3	480.5	1.0	0.46	0	127.0	0.26	6.2	III	ERTEC
5-110	57.7	54.0	36.0	89	36	53	765.0	968.0	1.0	0.35	0	226.5	0.23	5.5		McClelland
5-119	62.7	(51.0)					199.0	371.0	1.0	0.50	20	137.0	0.37	10.8		NTH CON10. Post cyclic
5-119	62.7			98	40	58	224.0	384.0	1.0	0.49	20	138.0	0.36	11.5		NTH CON11. Post cyclic

TABLE NO. AIII-3

NGI

LOCATION: MEXICO GULF

PROJECT: 81222

BORING: 5
SAMPLE: 65
DEPTH: 33.66-34.14 m

DESCRIPTION	DEPTH (m)	SAMPLE	TEST	w	w_L	w_P	$C_{inorg.}$	Org cont.	$< 2\mu$	ρ	ρ_s	FALL CONE UND.	FALL CONE REM.	SALT CONT.
				PER CENT						t/m³		kPa		g/l
	33.7	NOT USED												
CLAY, a little silty, homogeneous, fine horizontal parting with spacing less than 1 mm. Dark grey, Hue 5Y 4/1.	33.8	e	SST	38.6	53.4	24.0	0.4	0	38	1.75	2.73	31.7		18
	33.9	d	SST	38.6	54.1	21.0	0.4	0.2	30	1.74	2.74	35.3		24
		c	OED	39.6						1.72				
	34.0	b	SST	37.6	55.1	23.9	0.5	0.2	38	1.74	2.80	40.2		20
		a		38.4								41.8	30.5	
	34.1	REMOVED												

BLOCK 58 - W. DELTA AREA. GULF OF MEXICO.

SAMPLE OPENING SHEET.

Sample: 65

Date	Drawn by
18.06.82	[signature]
Approved	[signature]
Project no.	81222-2
Drawing no.	001

Norwegian Geotechnical Institute

NGI

LOCATION: MEXICO GULF

PROJECT: 81222

BORING: 5
SAMPLE: 133
DEPTH: 67.66-68.12 m

DESCRIPTION	DEPTH (m)	SAMPLE	TEST	w	w_L	w_P	$C_{inorg.}$	Org cont.	$< 2\mu$	ρ	ρ_s	FALL CONE UND.	FALL CONE REM.	SALT CONT.
				PER CENT						t/m³		kPa		g/l
	67.7	NOT USED												
	67.8													
CLAY, homogeneous, random fissured (fissure surfaces like broken glass), dark grey Hue 5Y 4/1.	67.9	d	SST	55.3	99.4	35.9	0.5	0.31	63	1.69	2.81	55.5		26
	68.0	c	SST	52.6	93.2	34.9	0.5	0.2	58	1.695	2.80	58.2		24
		b	SST	56.9	92.4	31.8	0.5	0.4	61	1.68	2.74	71.3		26
	68.1	a		54.2								66.7	35.0	

BLOCK 58 - W. DELTA AREA. GULF OF MEXICO.

SAMPLE OPENING SHEET.

Sample: 133

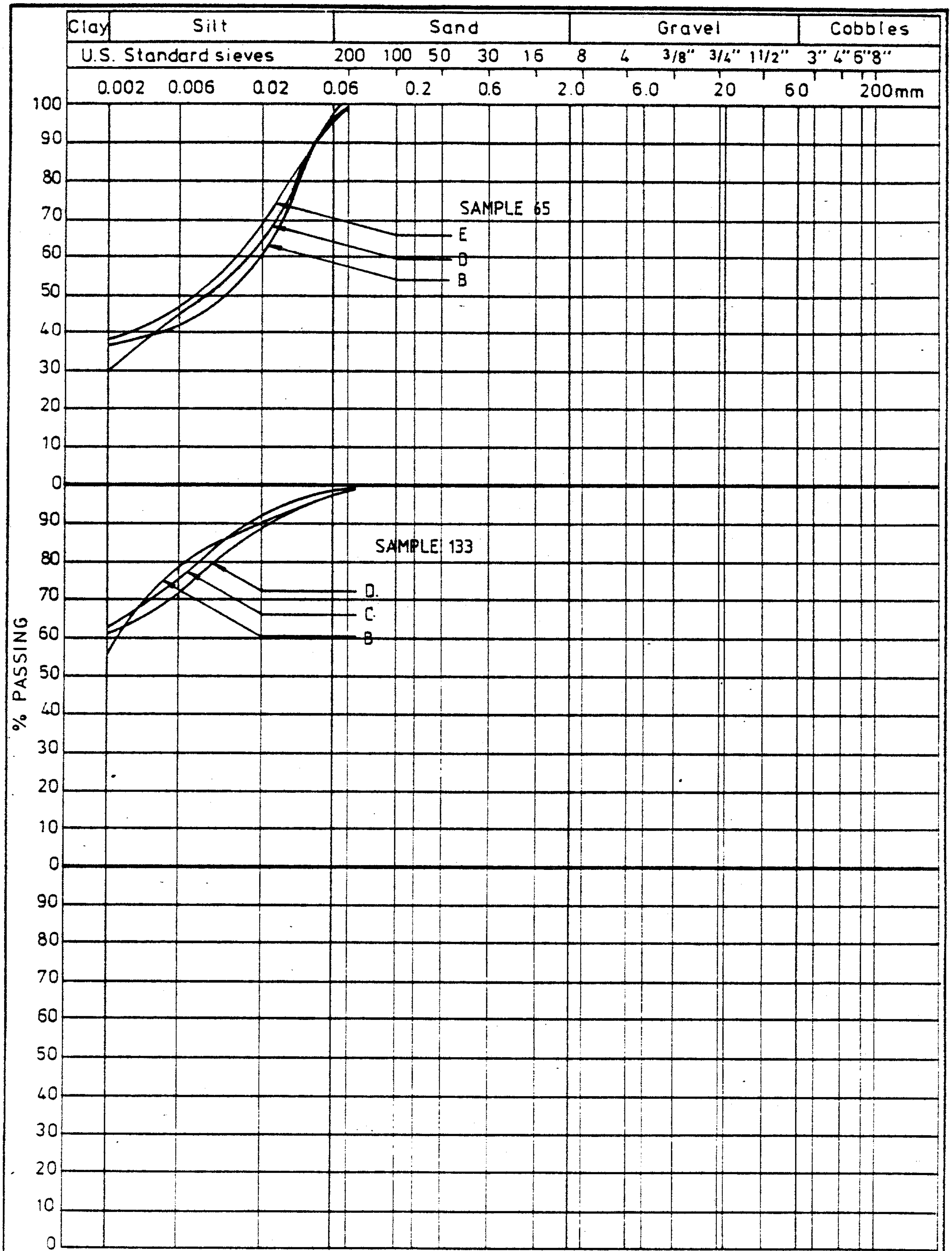
Date 18.06.82 | Drawn by [signature]

Approved [signature]

Project no. 81222-2

Drawing no. 002

Norwegian Geotechnical Institute

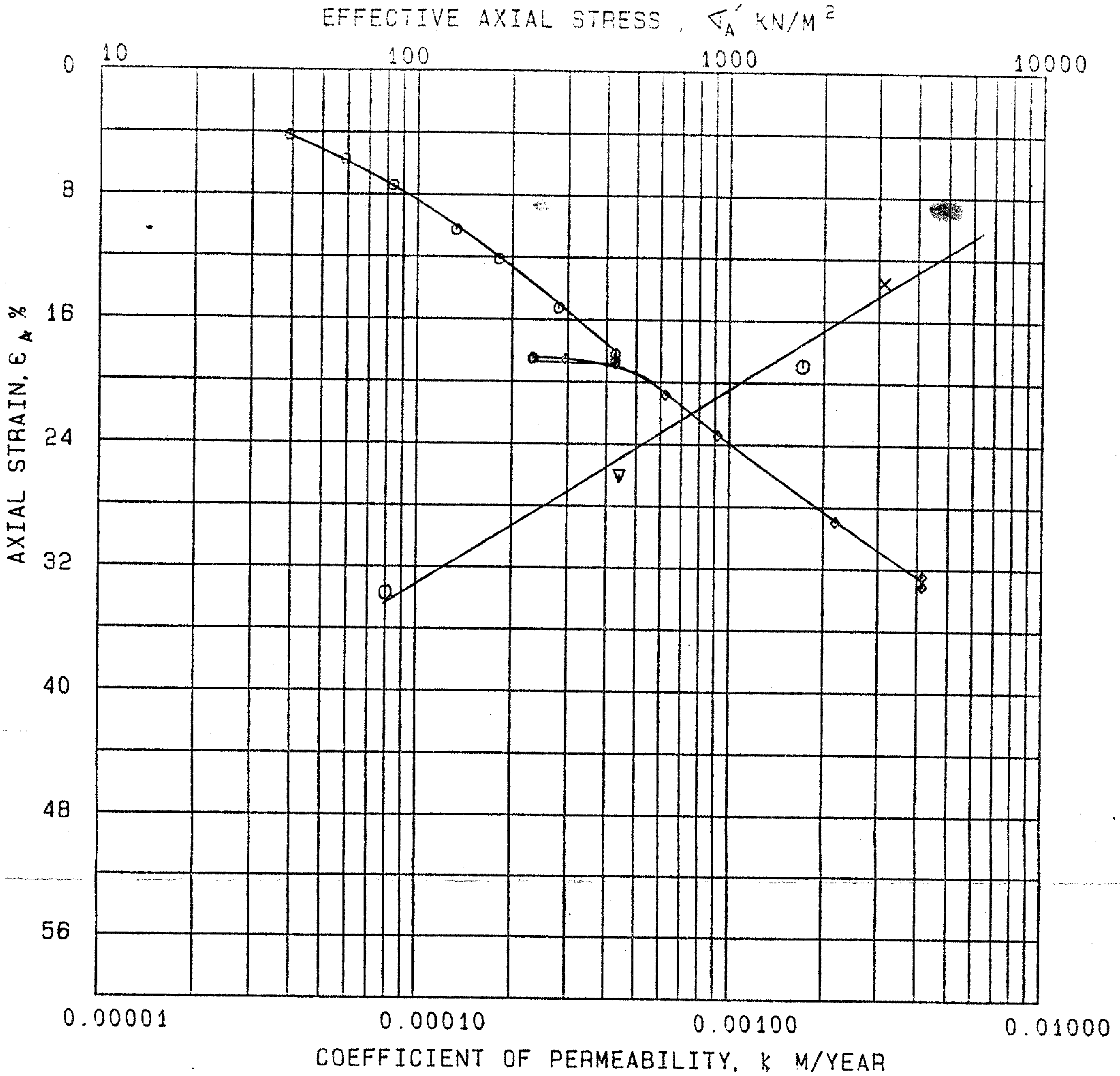


BLOCK 58 - W. DELTA AREA. GULF OF MEXICO.

Grain size distribution curves

Date 18.06.82	Drawn by QQk.
Approved	
Project no. 81222-2	
Drawing no. 003	

Norwegian Geotechnical Institute



× CALCULATED K, 1ST. LOADING — FROM TIME/COMPRESSION CURVES

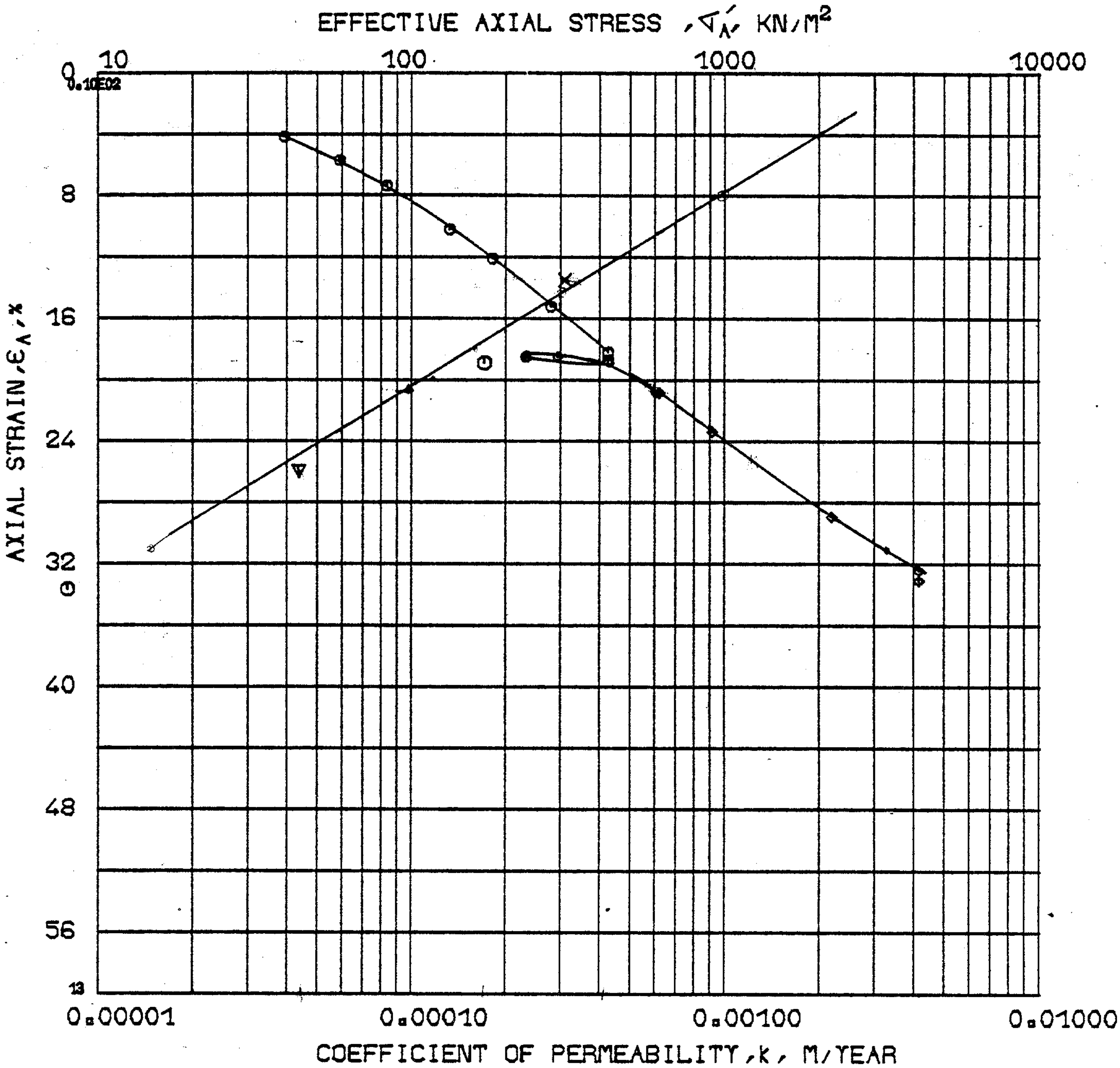
∇ CALCULATED K, RELOADING — FROM TIME/COMPRESSION CURVES

⊙ MEASURED K

⊙ 1ST. LOADING — REFERENCE-TIME T= 150 MIN.

◇ RELOADING — REFERENCE-TIME T= 150 MIN.

BLOCK 58-W.DELTA AREA.GULF OF MEXICO		DATE 01.02.84	DRAWN BY
OEDOMETER TEST SEMILOGARITHMIC PLOT	DEPTH = 33.96 M	APPROVED ABye.	
	P_0' = 232.5 KN/M²		
BORING: 5 LAB: 65C	W_I = 39.58 %	PROJ. NO. 81222	
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAWING NO. 004A	



× CALCULATED K, 1ST. LOADING
▽ CALCULATED K, RELOADING
} FROM TIME/COMPRESSION CURVES

⊙ MEASURED K

⊙ 1ST. LOADING
◆ RELOADING
} REFERENCE-TIME T= 150 MIN.

BLOCK 58-W. DELTA AREA. GULF OF MEXICO

DATE 21.06.82

DRAWN BY

OEDOMETER TEST
SEMILOGARITHMIC PLOT

DEPTH = 33.96 M
P_0' = 232.5 KN/M²
W_I = 39.58 %

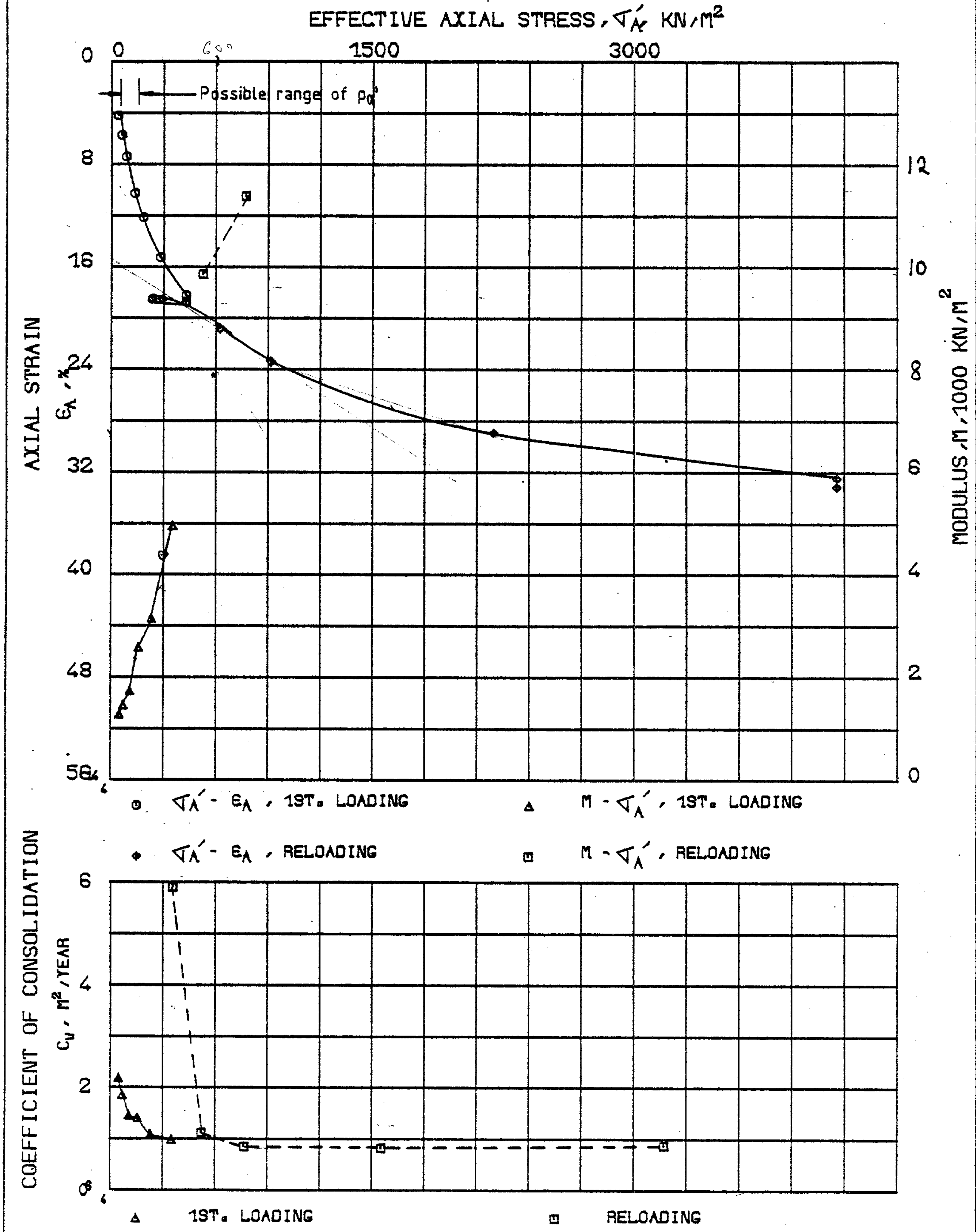
APPROVED

BORING: 5 SAMPLE: 65C

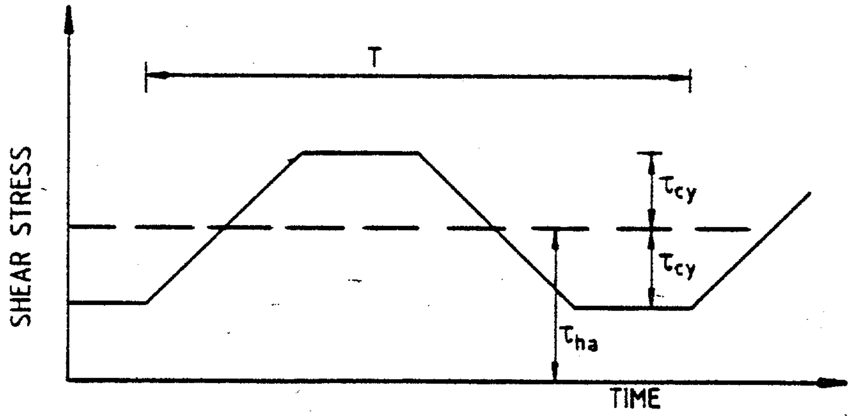
PROJ. NO. 81222-2

NORWEGIAN GEOTECHNICAL INSTITUTE

DRAWING NO. 004



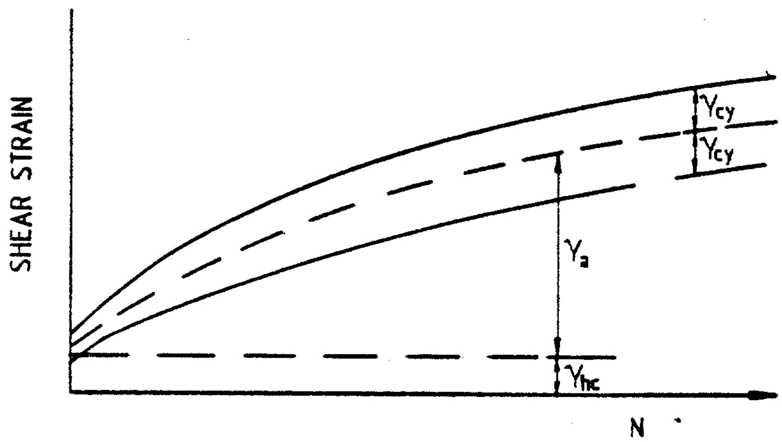
BLOCK 58-W. DELTA AREA. GULF OF MEXICO	DATE 21.06.82	DRAWN BY
OEDOMETER TEST LINEAR PLOT	DEPTH =33.96 M Po' =232.5 KN/M² Wi =39.58 %	APPROVED
BORING: 5 SAMPLE: 65C		PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAWING NO. 005



τ_{cy} = cyclic shear stress.

τ_{ha} = average horizontal shear stress during cyclic loading.

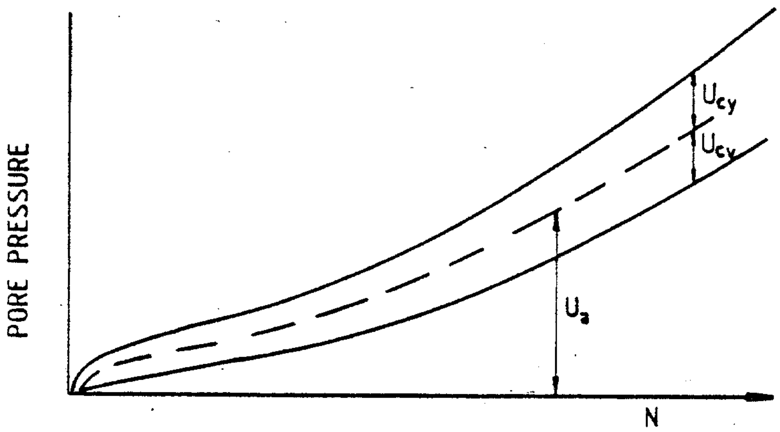
T = load period



γ_{cy} = cyclic shear strain.

γ_a = average shear strain during cyclic loading.

γ_{hc} = shear strain during consolidation.

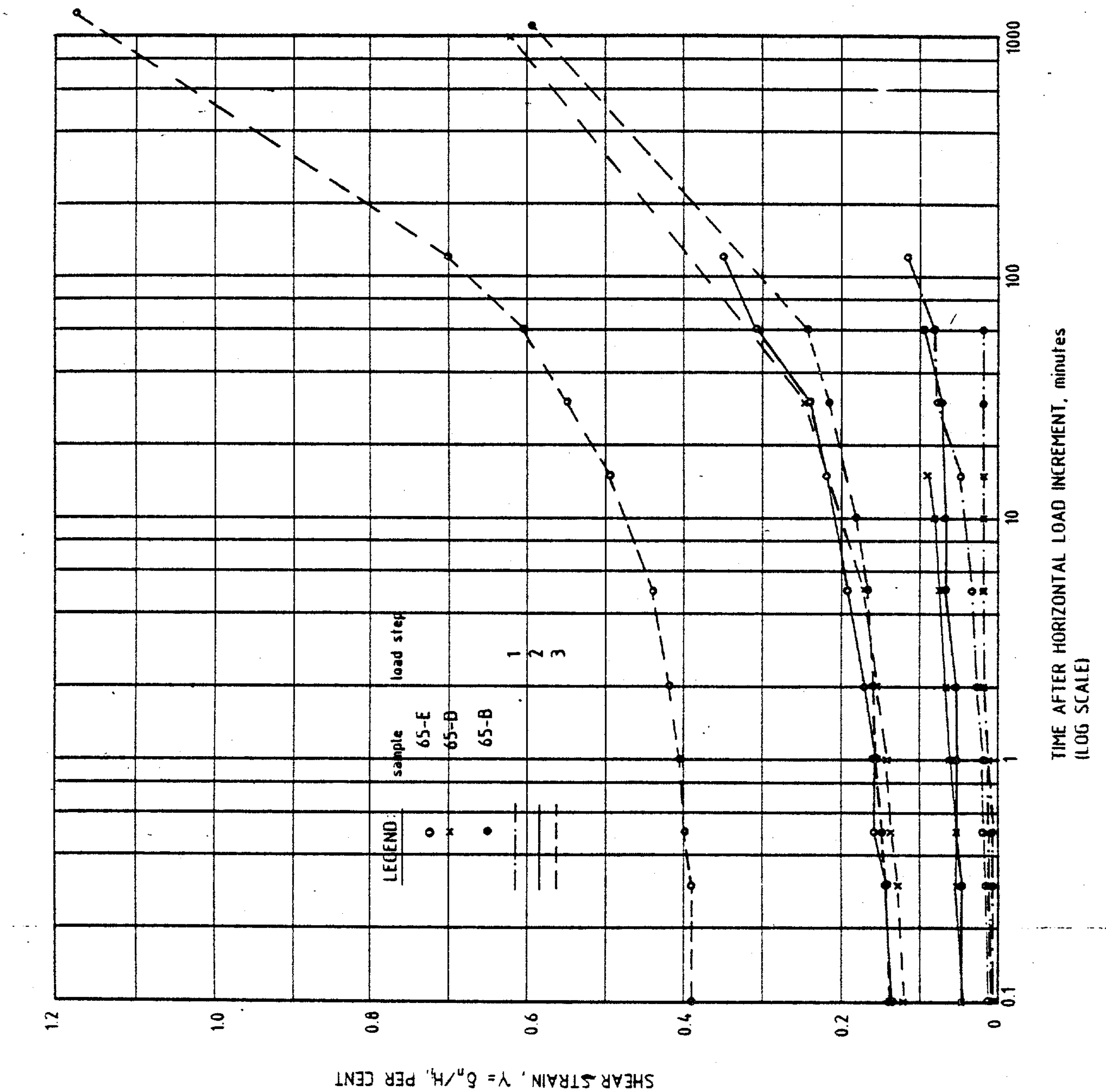


U_{cy} = cyclic pore pressure.

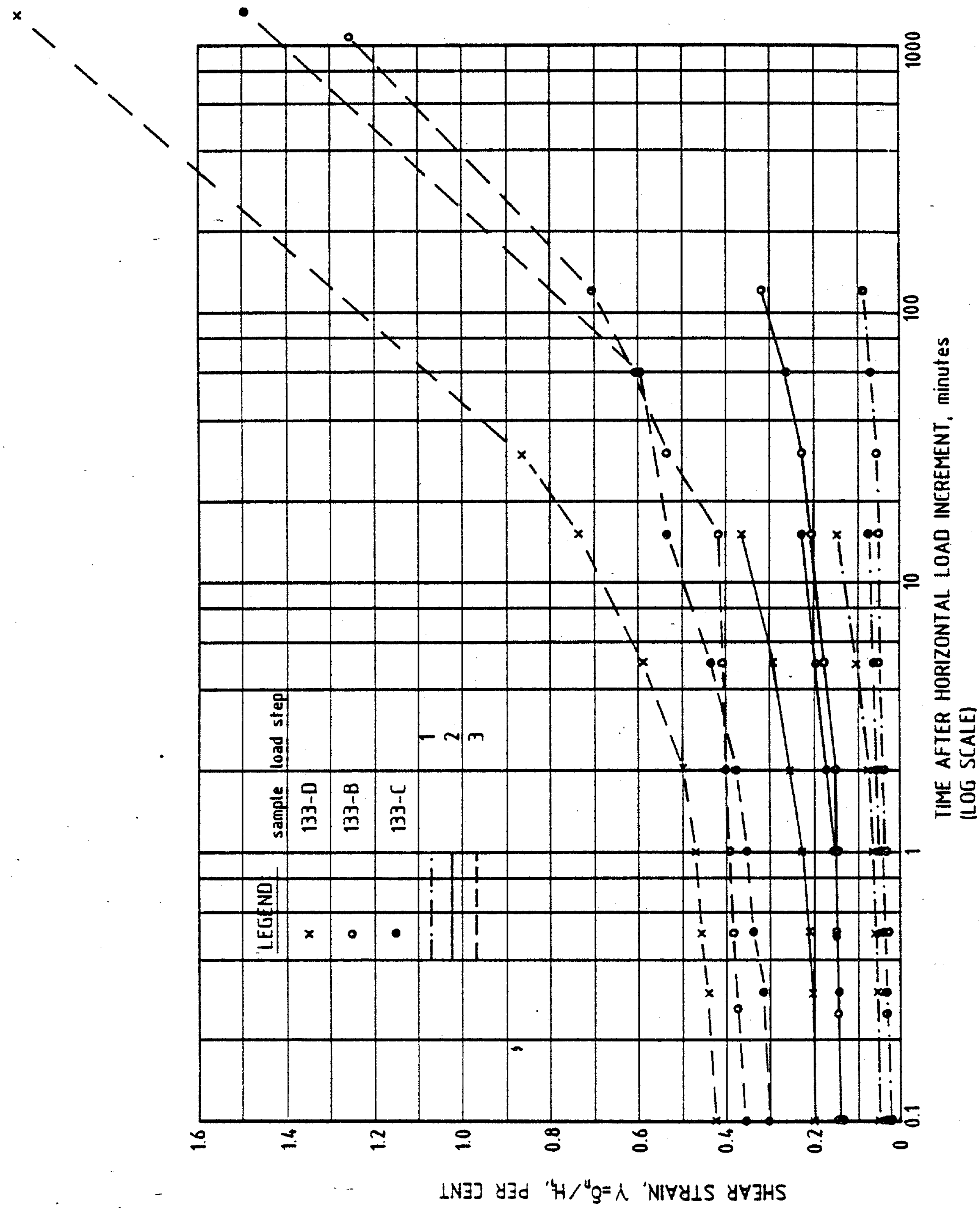
U_a = average pore pressure during cyclic loading.

N = number of cycles.

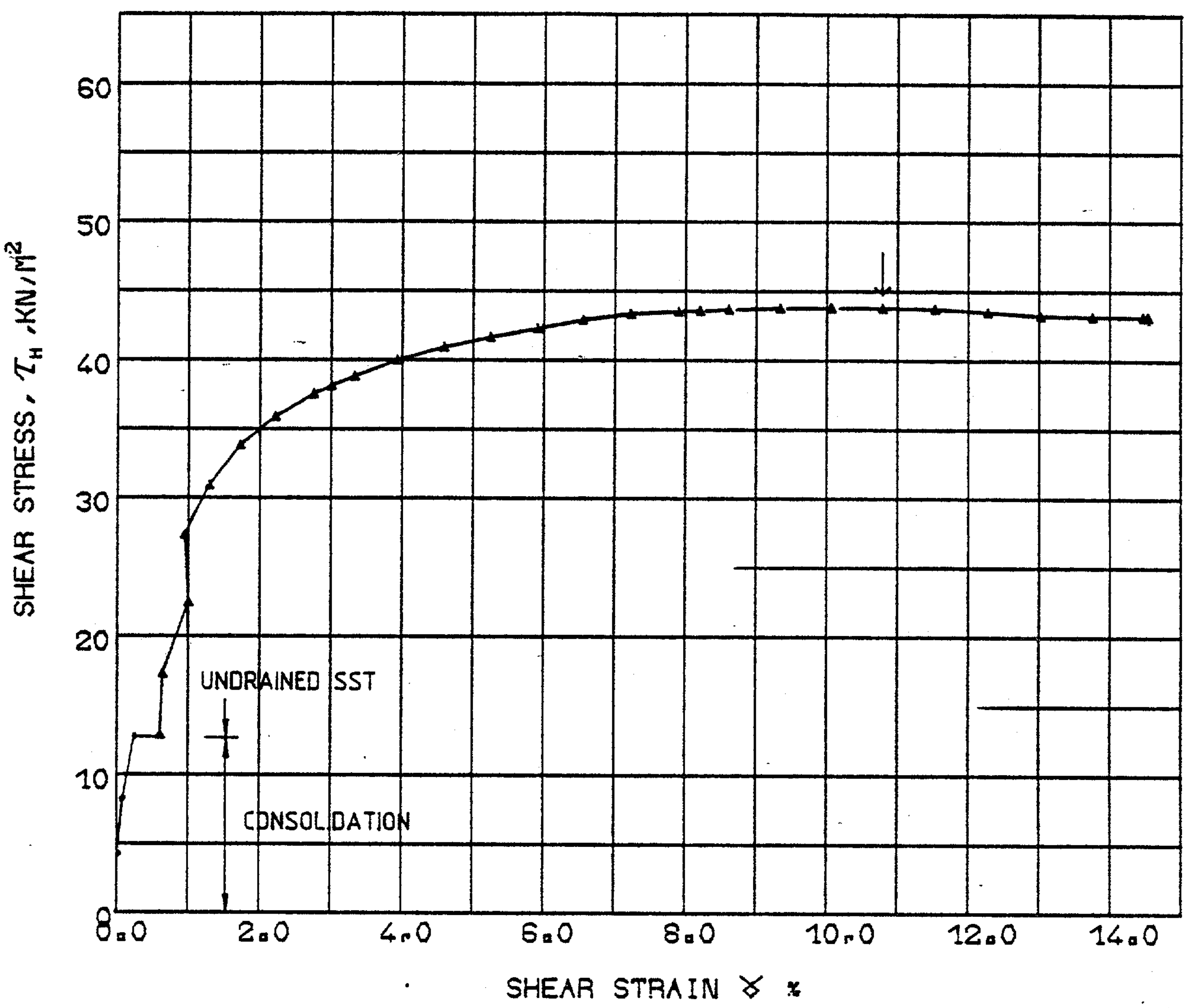
BLOCK 58 - W. DELTA AREA. GULF OF MEXICO.	Date 18.06.82	Drawn by RAK.
CCV SIMPLE SHEAR TEST Cyclic load pulse and basic definitions.	Approved [signature]	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 006	

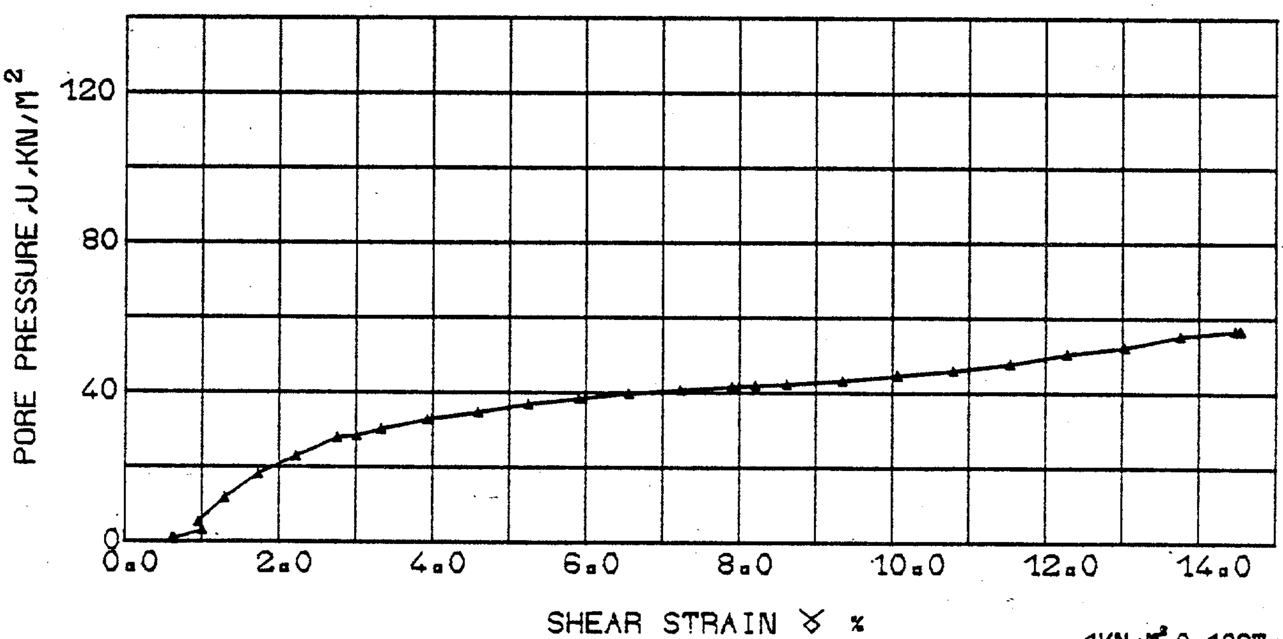


BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by Aak.
Consolidation shear strain versus time	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 007	



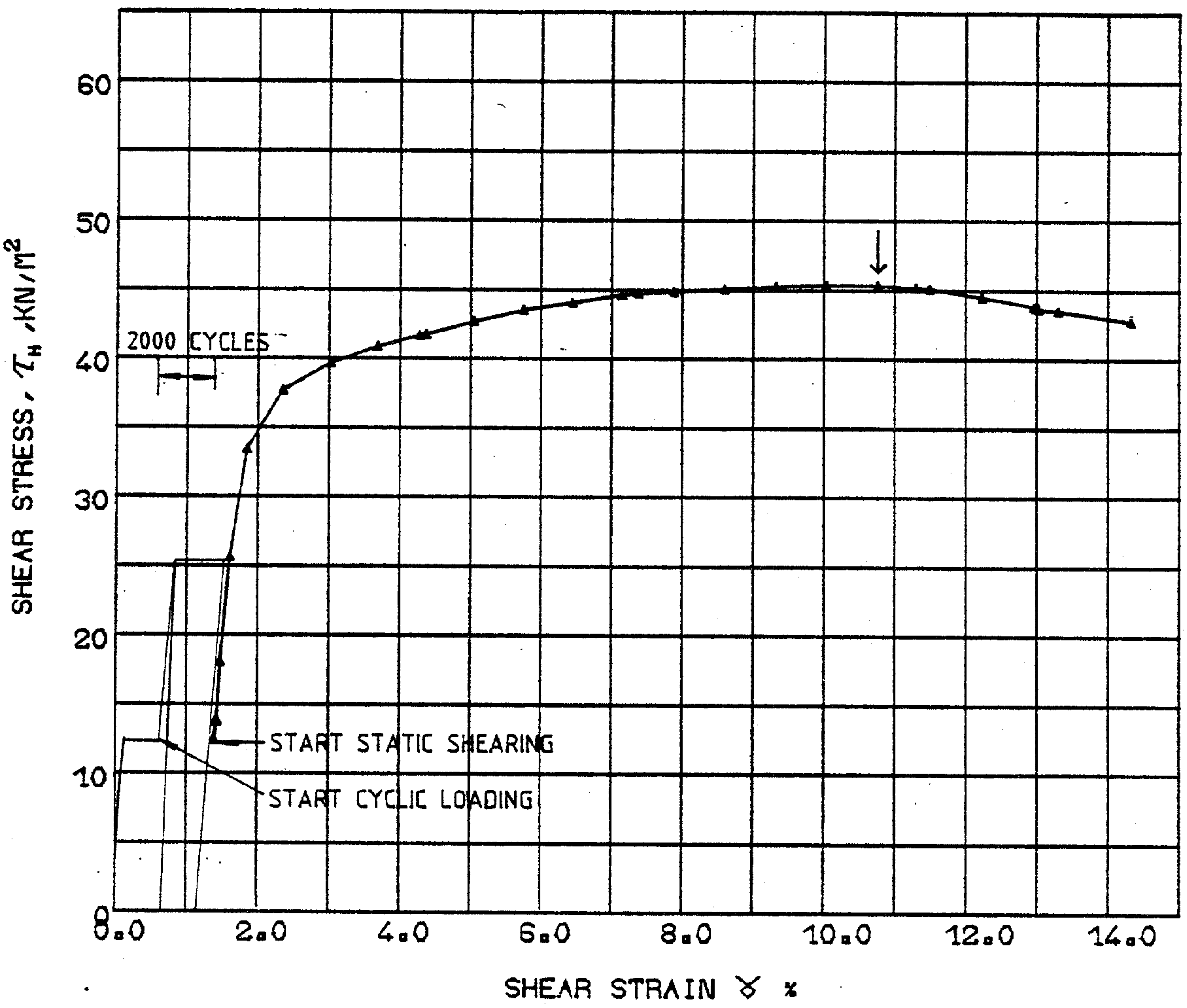
BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by
Consolidation shear strain versus time	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 008	

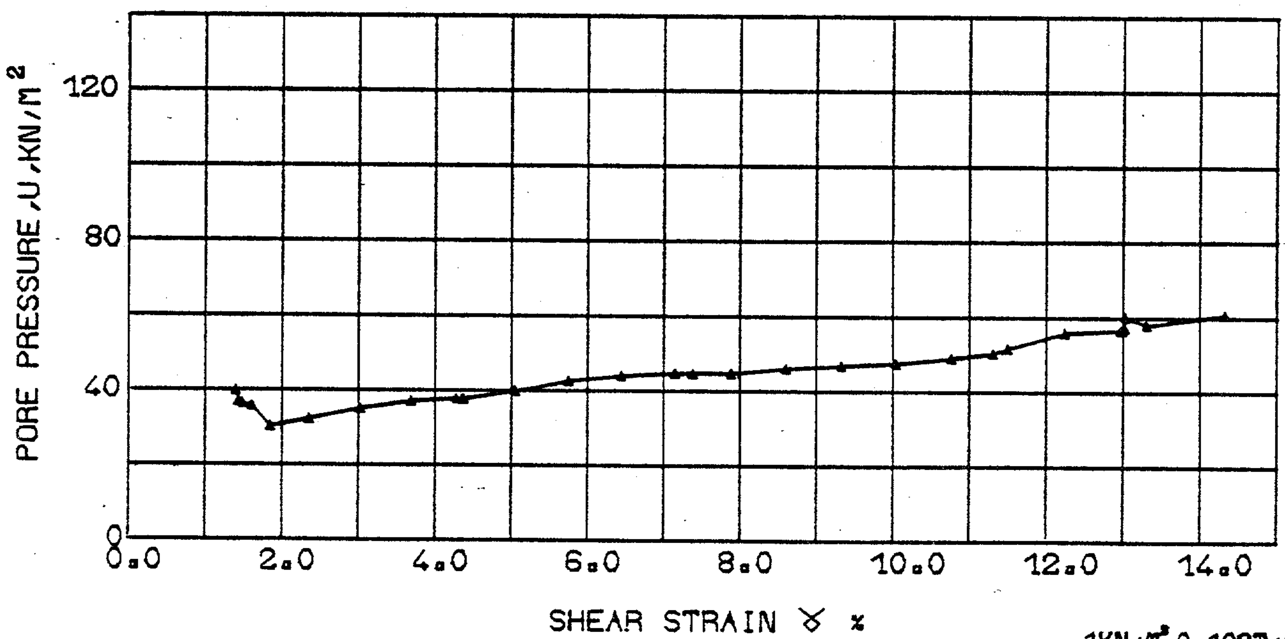




1KN/M^2=0.102T/M^2

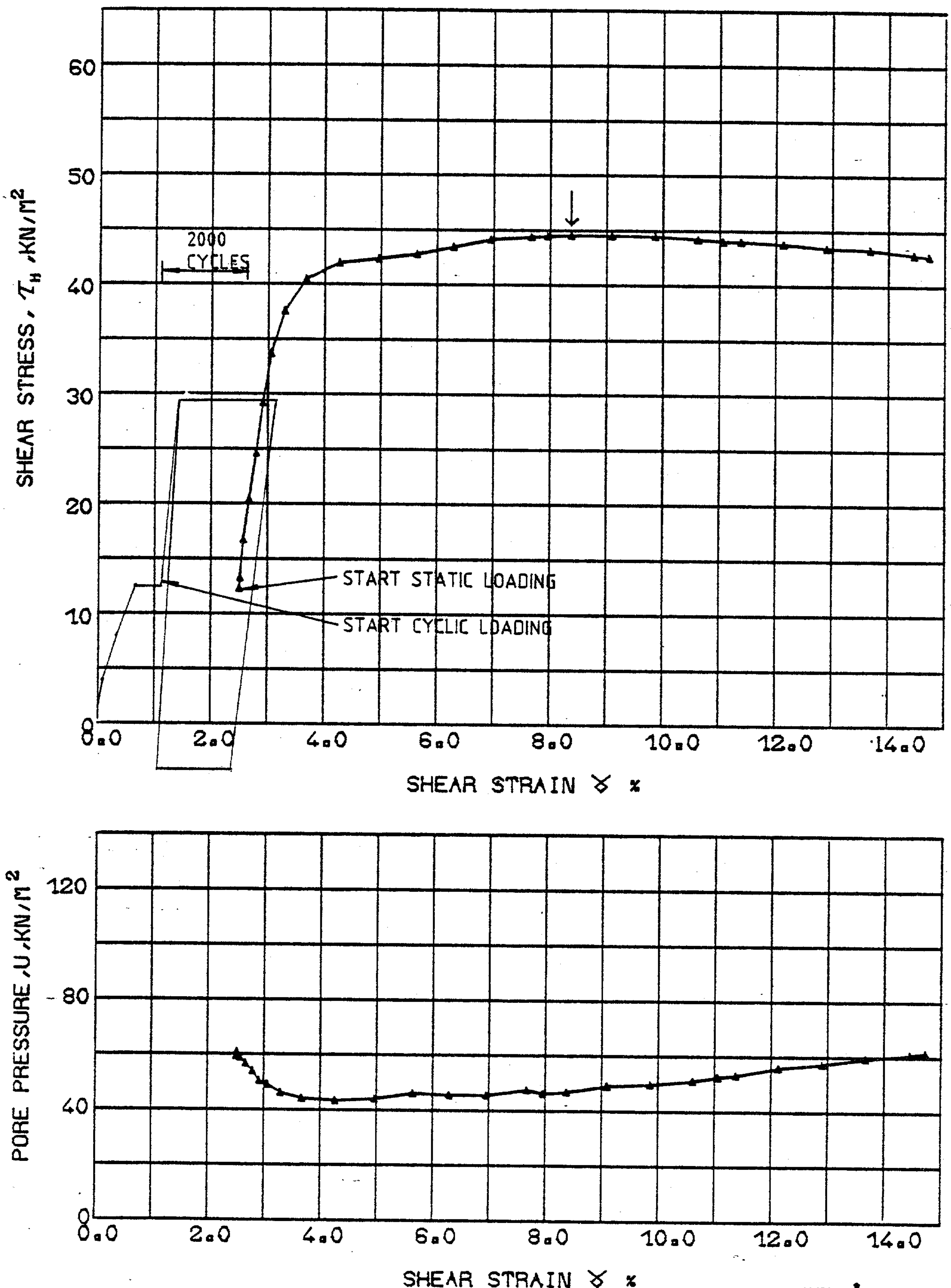
BLOCK 58-W. DELTA AREA. GULF OF MEXICO	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 33.90 M; σ'_{AC} =138.2 KN/M^2; BORING: 5 SAMPLE: 65- -B; W_I = 37.61 %	APPROVED	
	PROJ. NO. 81222 -2	
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 009	





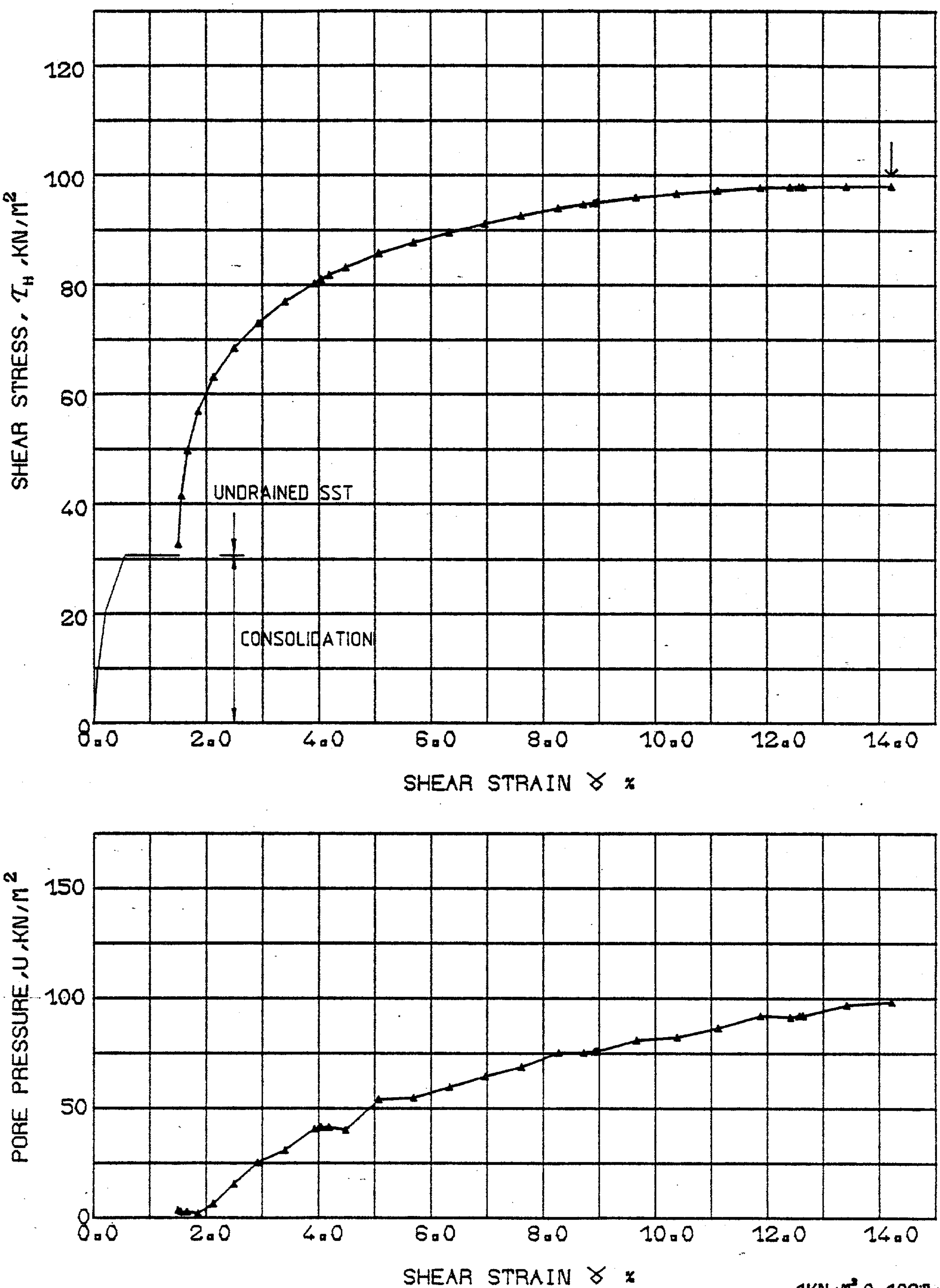
1KN/M² = 0.102T/M²

BLOCK 58-W. DELTA AREA GULF OF MEXICO.		DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST	DEPTH = 33.90 M σ_{AC} = 137.7 KN/M² W_I = 38.58 %	APPROVED	
BORING: 5 SAMPLE: 65- - D		PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 010	



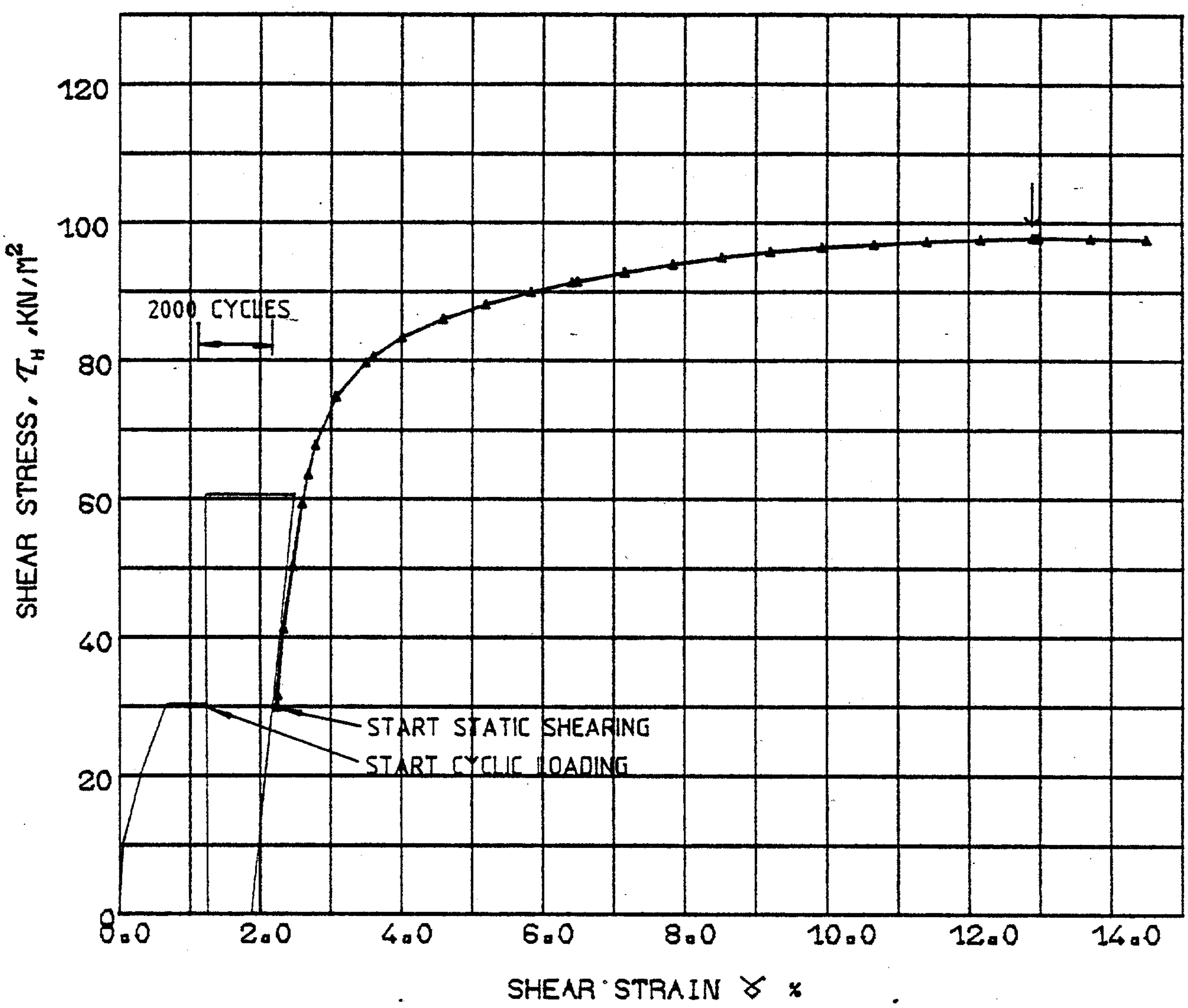
1KN/M²=0.102T/M²

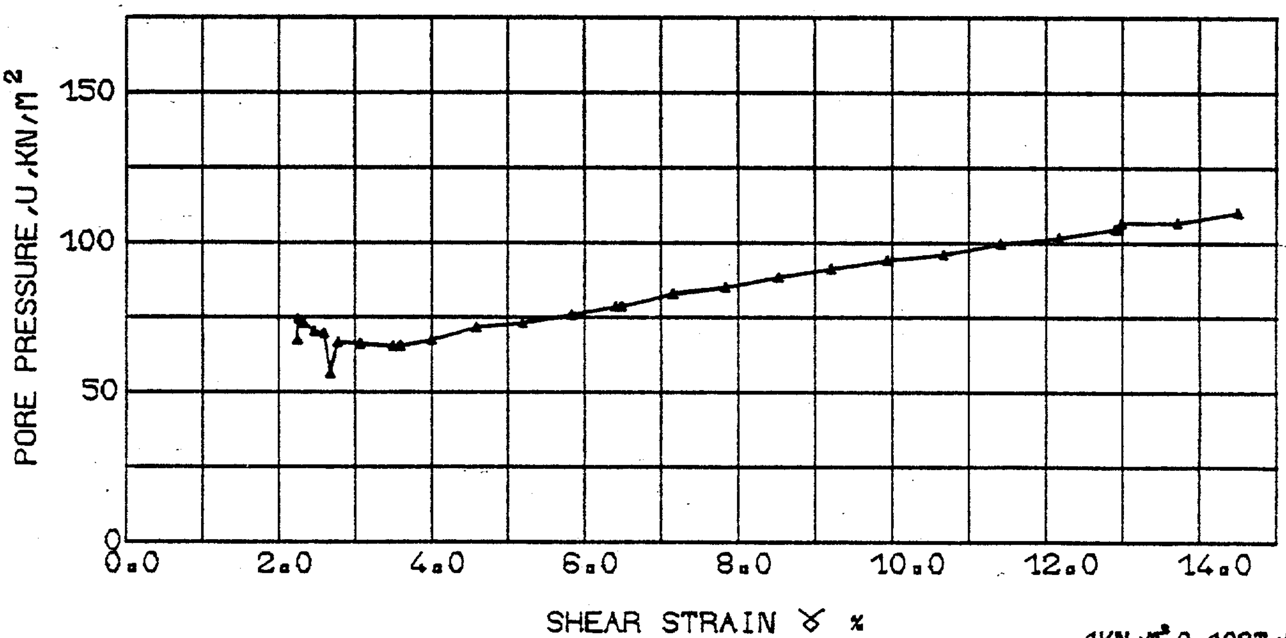
BLOCK 58-W.DELTA AREA.GULF OF MEXICO.	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 33.90 M; σ_{AC} =138.0 KN/M²; W_I = 36.60 %; BORING: 5 SAMPLE: 65- - E	APPROVED	
	PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 011	



1KN/M² = 0.102T/M²

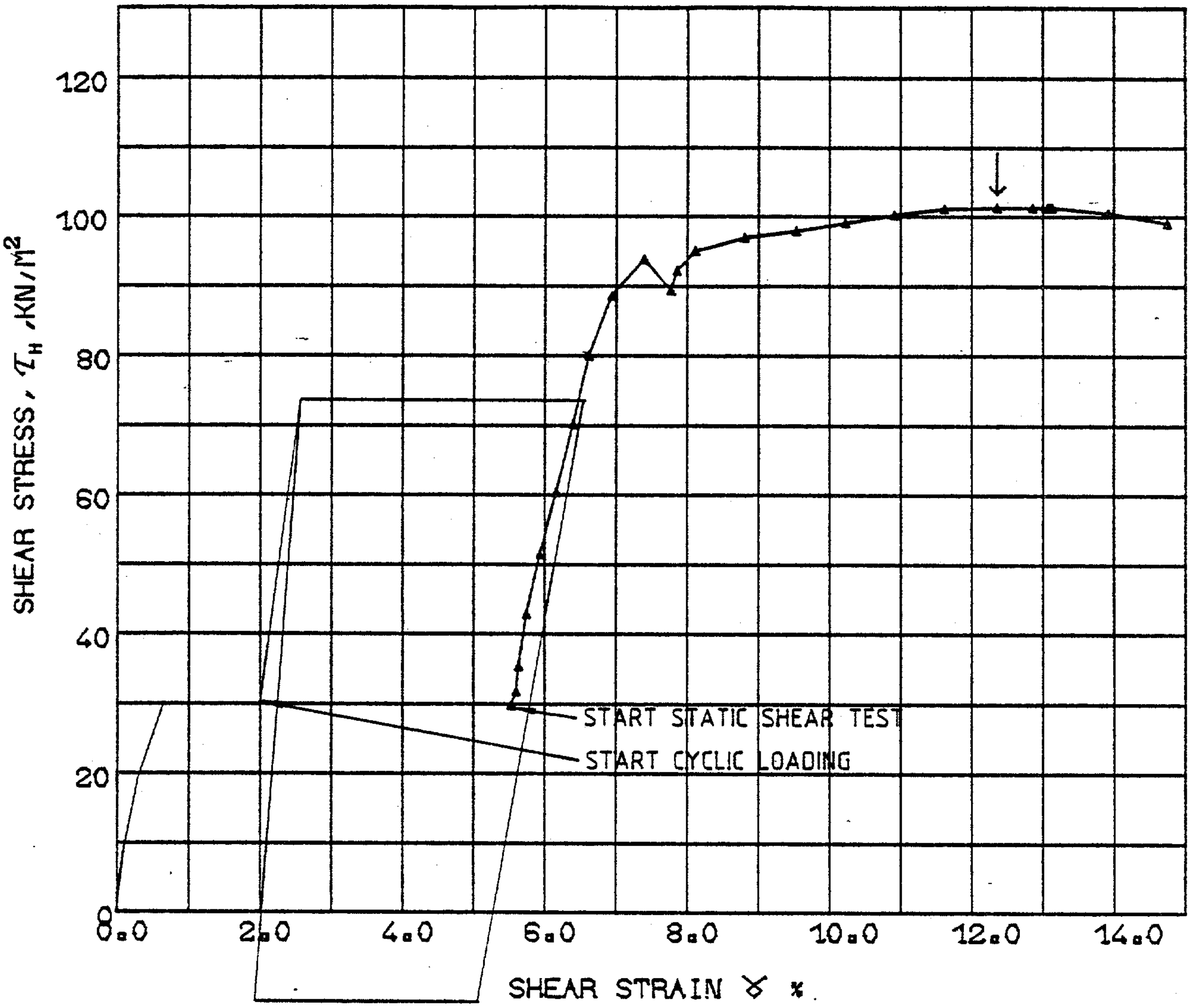
BLOCK 58-W. DELTA AREA. GULF OF MEXICO.		DATE 11. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST	DEPTH = 68.00 M σ'_{AC} = 333.4 KN/M²	APPROVED	
BORING: 5 SAMPLE: 133- - C	W_I = 52.61 %	PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 012	

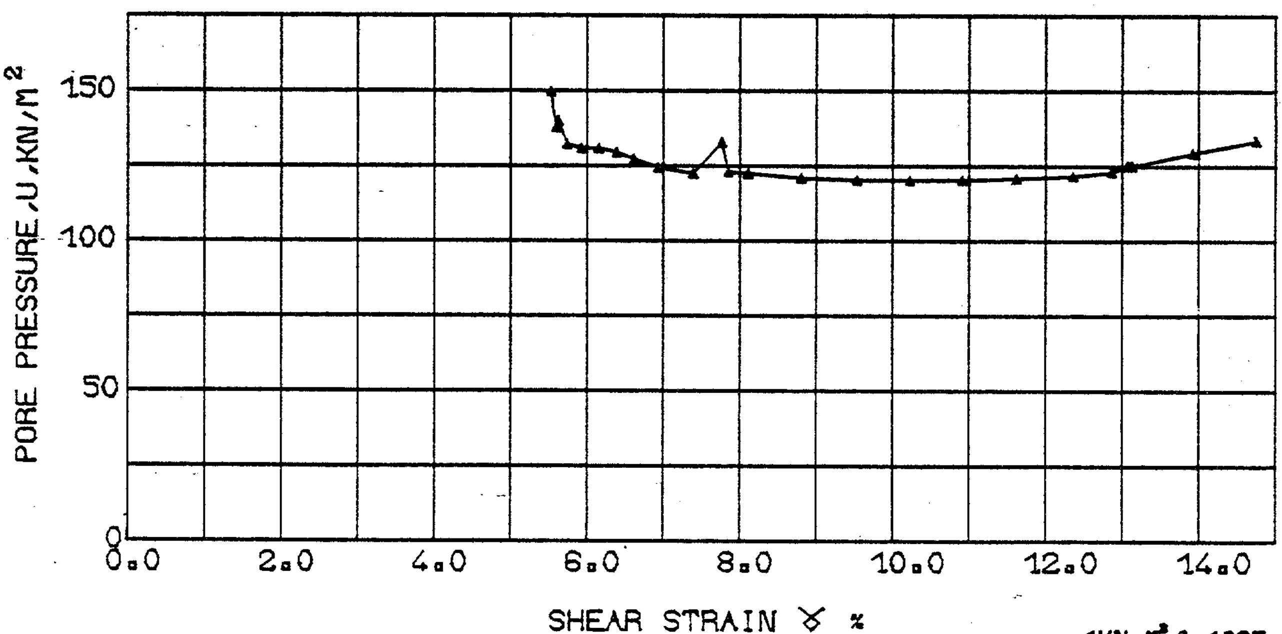




1KN/M² = 0.102T/M²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.		DATE 11. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST	DEPTH = 68.00 M	APPROVED	
	σ'_{ac} = 333.3 KN/M²		
BORING: 5 SAMPLE: 133- -B	W_I = 56.86 %	PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 013	





1KN/M²=0.102T/M²

BLOCK 58-W.DELTA AREA.GULF OF MEXICO.

DATE 11. 5. 82 DRAWN BY

CCV SIMPLE SHEAR TEST

DEPTH = 68.00 M

σ_{AC} =332.5 KN/M²

BORING: 5 SAMPLE: 133- - D

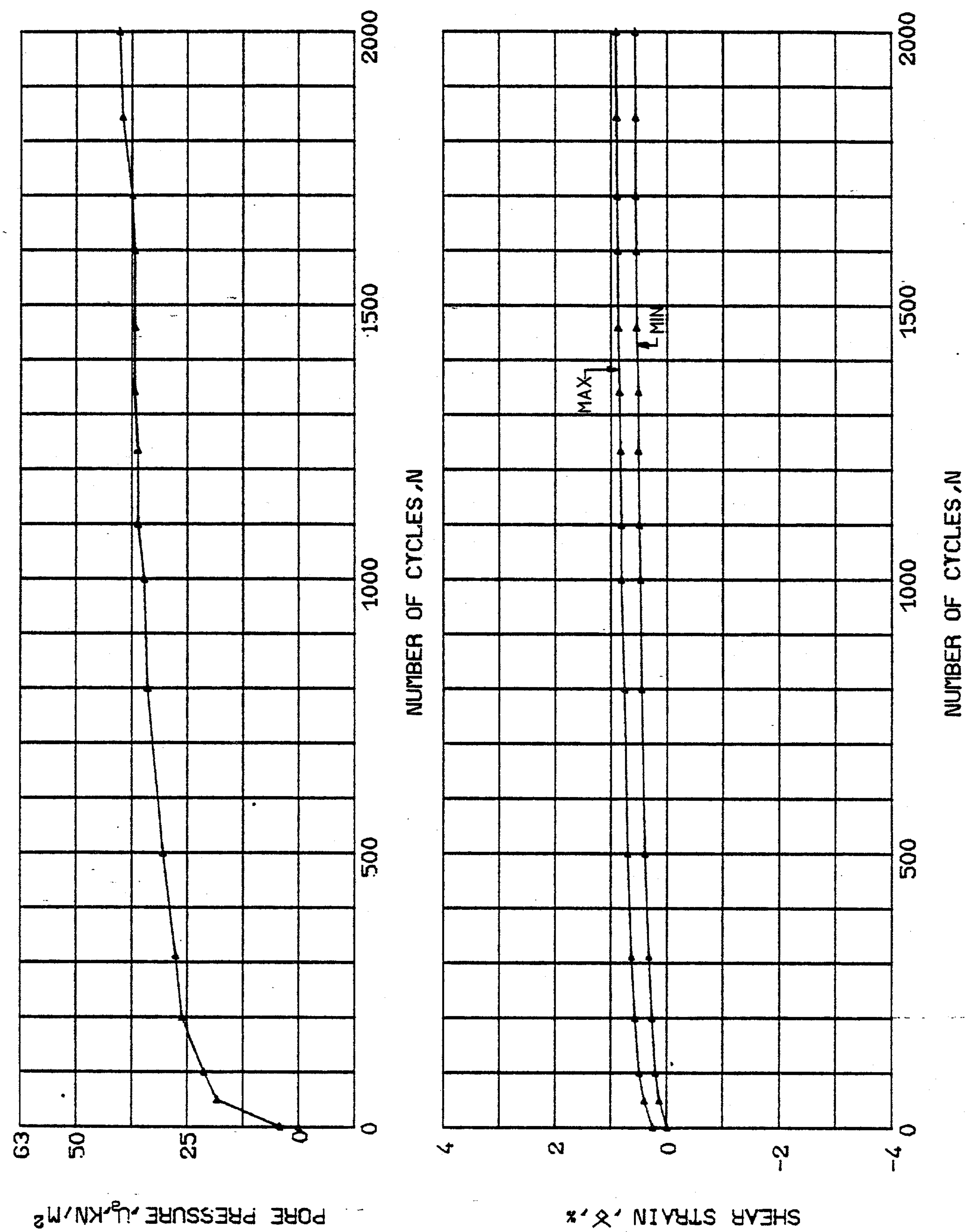
W_I = 55.33 %

APPROVED

PROJ. NO. 81222-2

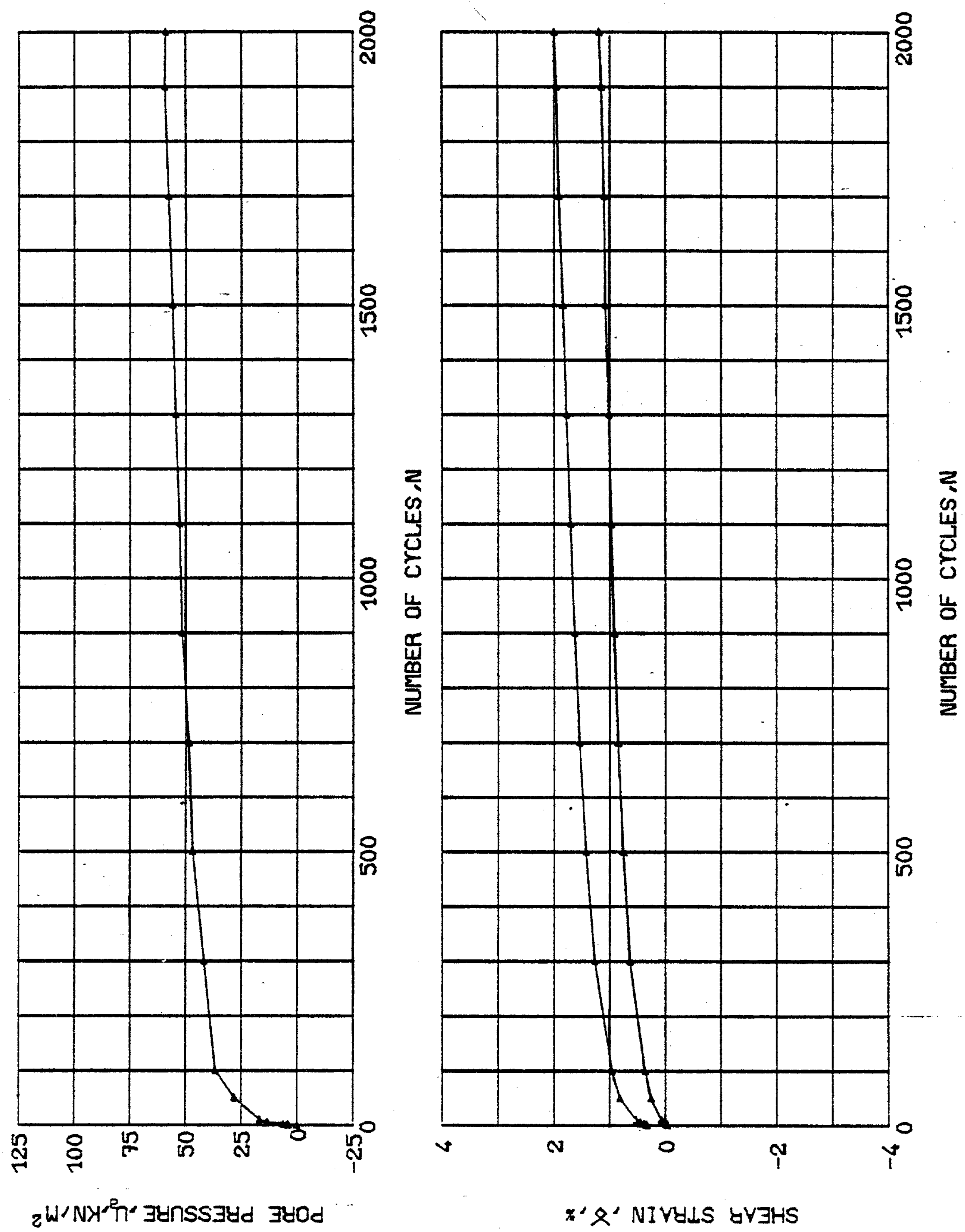
NORWEGIAN GEOTECHNICAL INSTITUTE

DRAW NO. 014



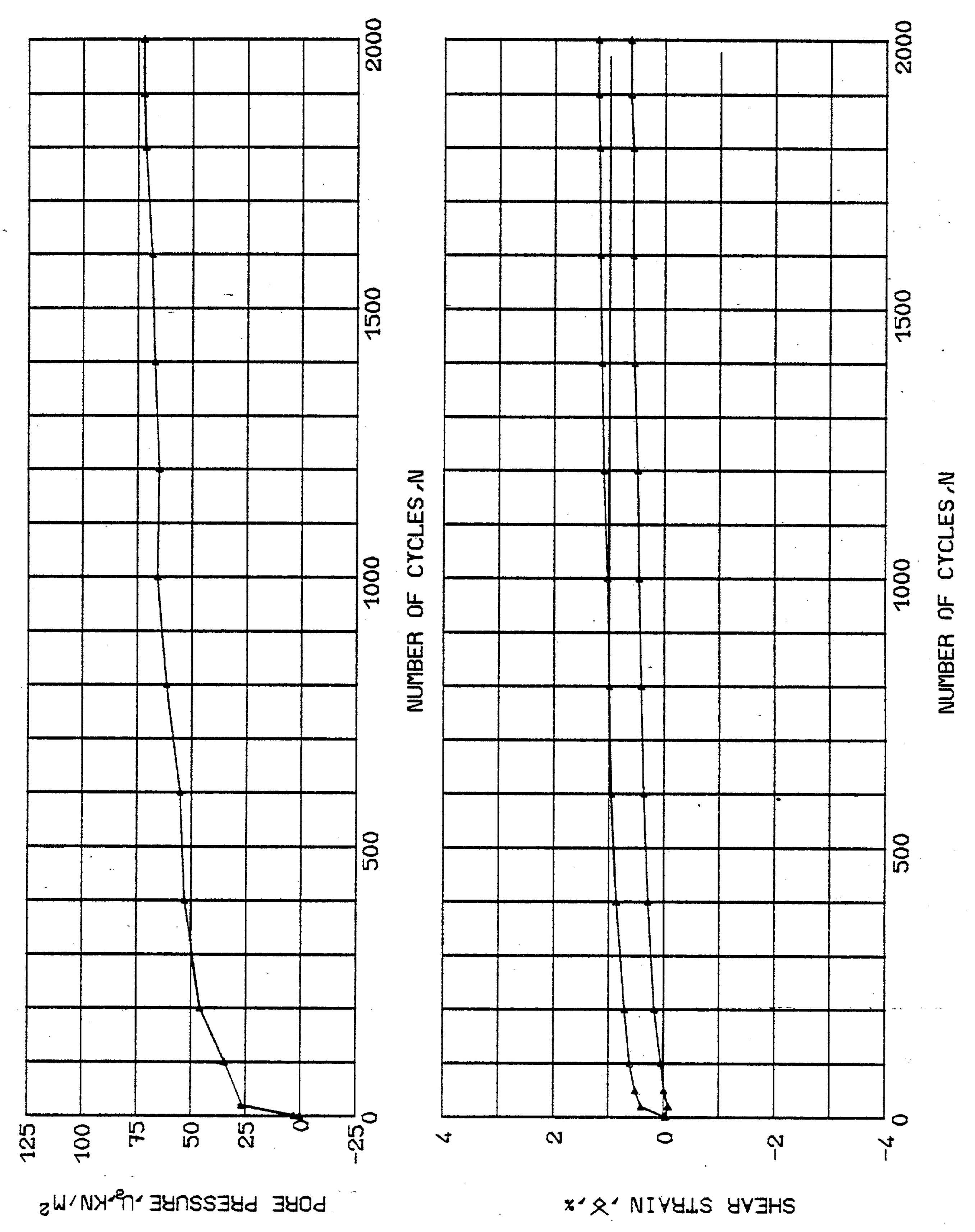
1KN/M²=0.102T/M²

BLOCK 58-W. DELTA AREA GULF OF MEXICO.	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST CYCLIC LOADING BORING: 5 SAMPLE: 65- - D	DEPTH = 33.90 M τ_{AC} =137.7 KN/M² W_I = 38.58 %	APPROVED PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 015



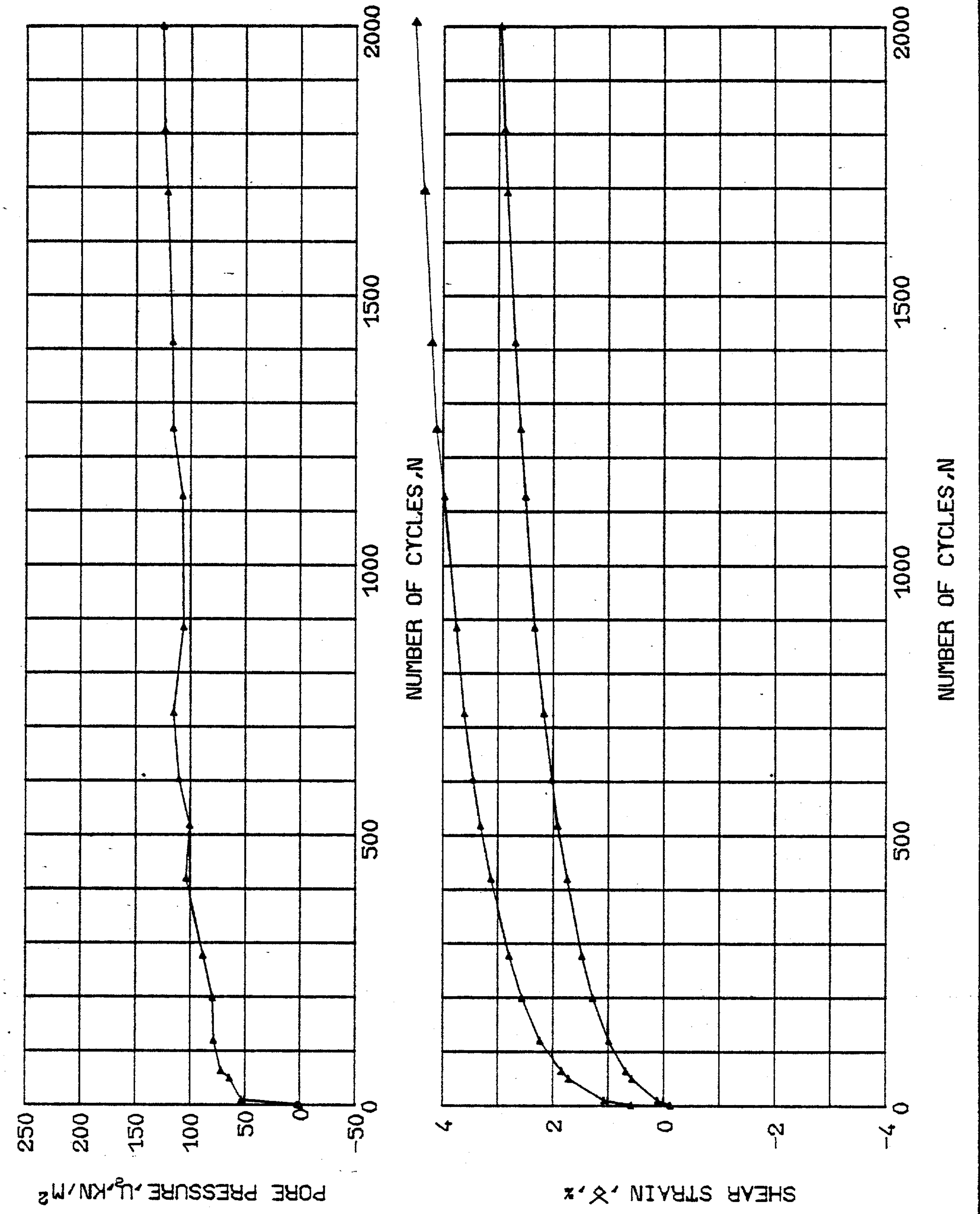
1KN/M²=0.102T/M²

BLOCK 58-W.DELTA AREA.GULF OF MEXICO.	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 33.90 M	APPROVED	
CYCLIC LOADING — τ_{AC} =138.0 KN/M²		
BORING: 5 SAMPLE: 65- - E — W_I = 38.60 %	PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 016	



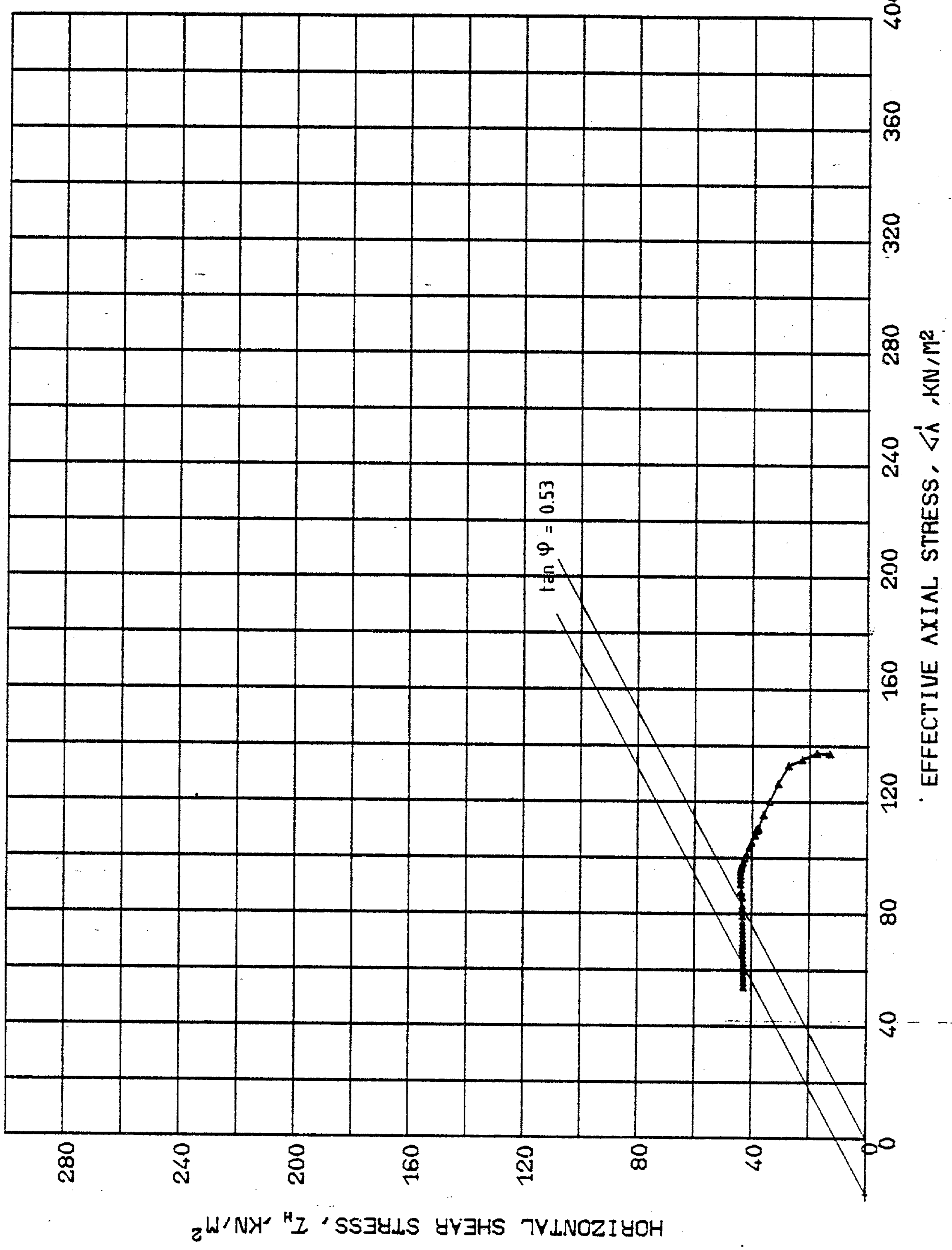
1KN/M² = 0.102T/M²

BLOCK 58-W.DELTA AREA.GULF OF MEXICO.	DATE 11. 5. 82 / DRAWN BY
CCV SIMPLE SHEAR TEST DEPTH = 68.00 M	APPROVED
CYCLIC LOADING τ_{AC} =333.3 KN/M²	
BORING: 5 SAMPLE: 133- - B W_I = 56.86 %	PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 017



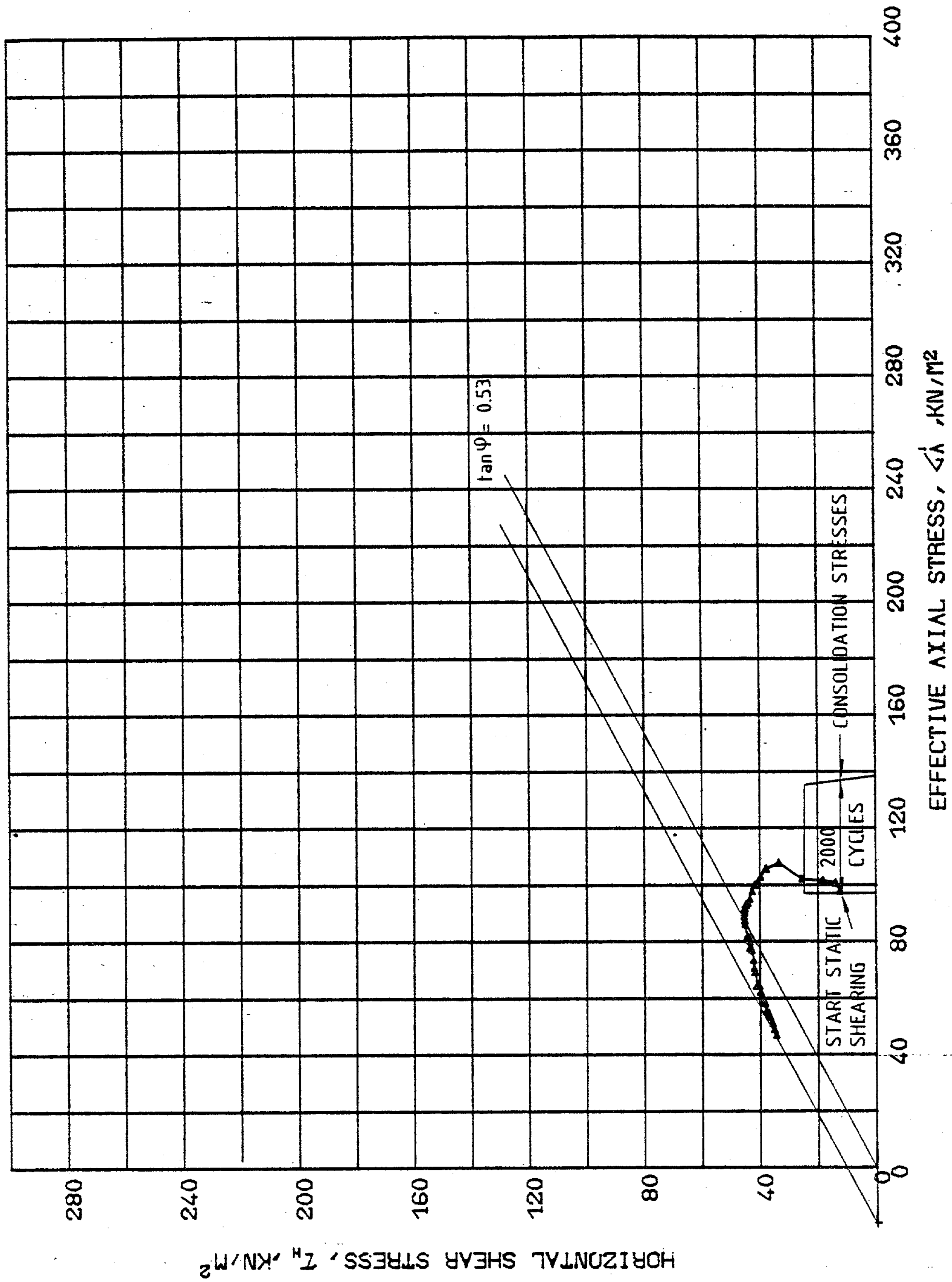
1KN/M² = 0.102T/M²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	DATE 11. 5. 82	DRAWN BY
CCU SIMPLE SHEAR TEST CYCLIC LOADING BORING: 5 SAMPLE: 133- - D	DEPTH = 68.00 M σ'_{AC} = 332.5 KN/M² W_I = 55.33 %	APPROVED PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 018



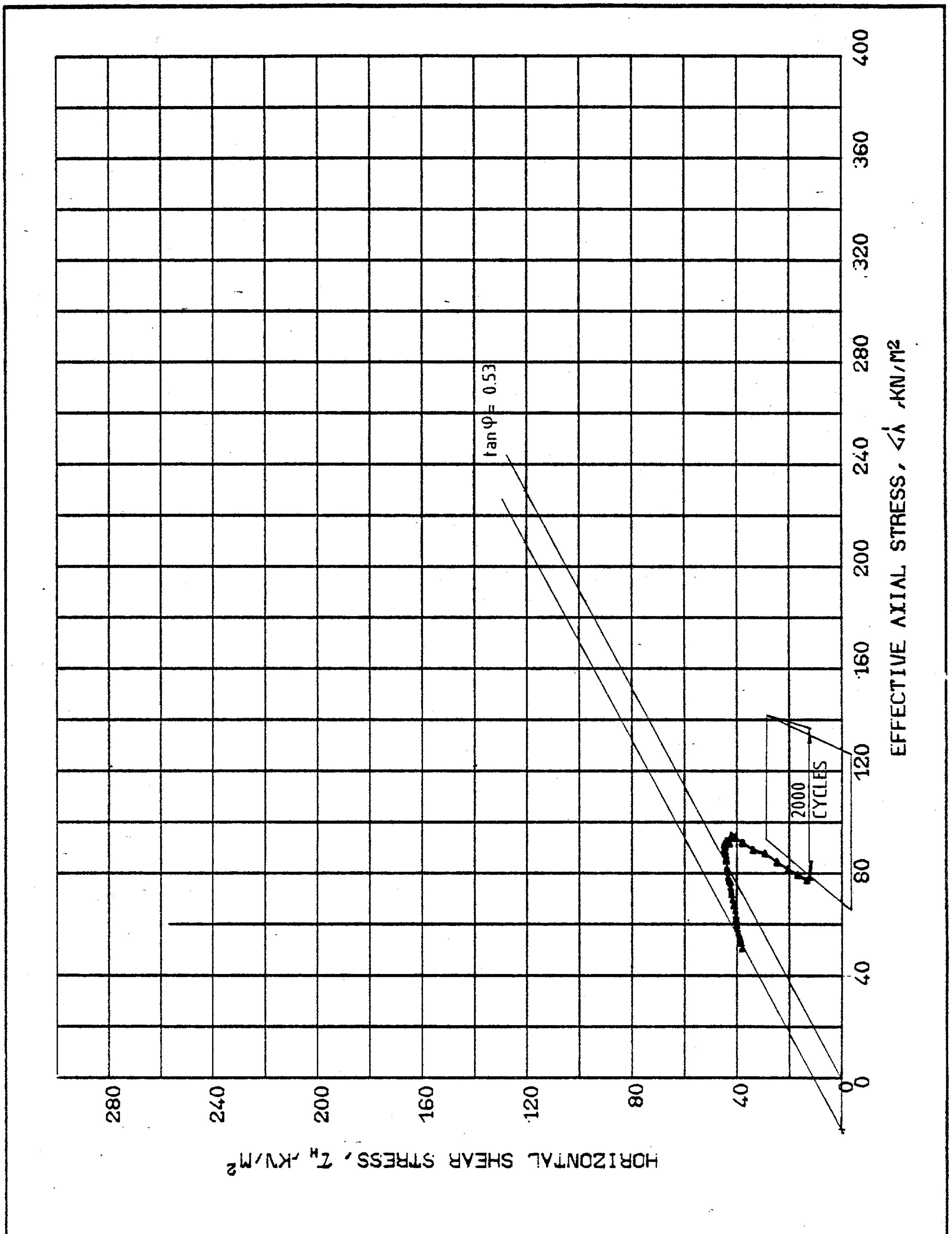
1KN/M² = 0.102T/M²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST EFFECTIVE STRESS PATH BORING: 5 SAMPLE: 65 - B	DEPTH = 33.90 M σ_{AC} = 138.2 KN/M² W_I = 37.61 %	APPROVED PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 019



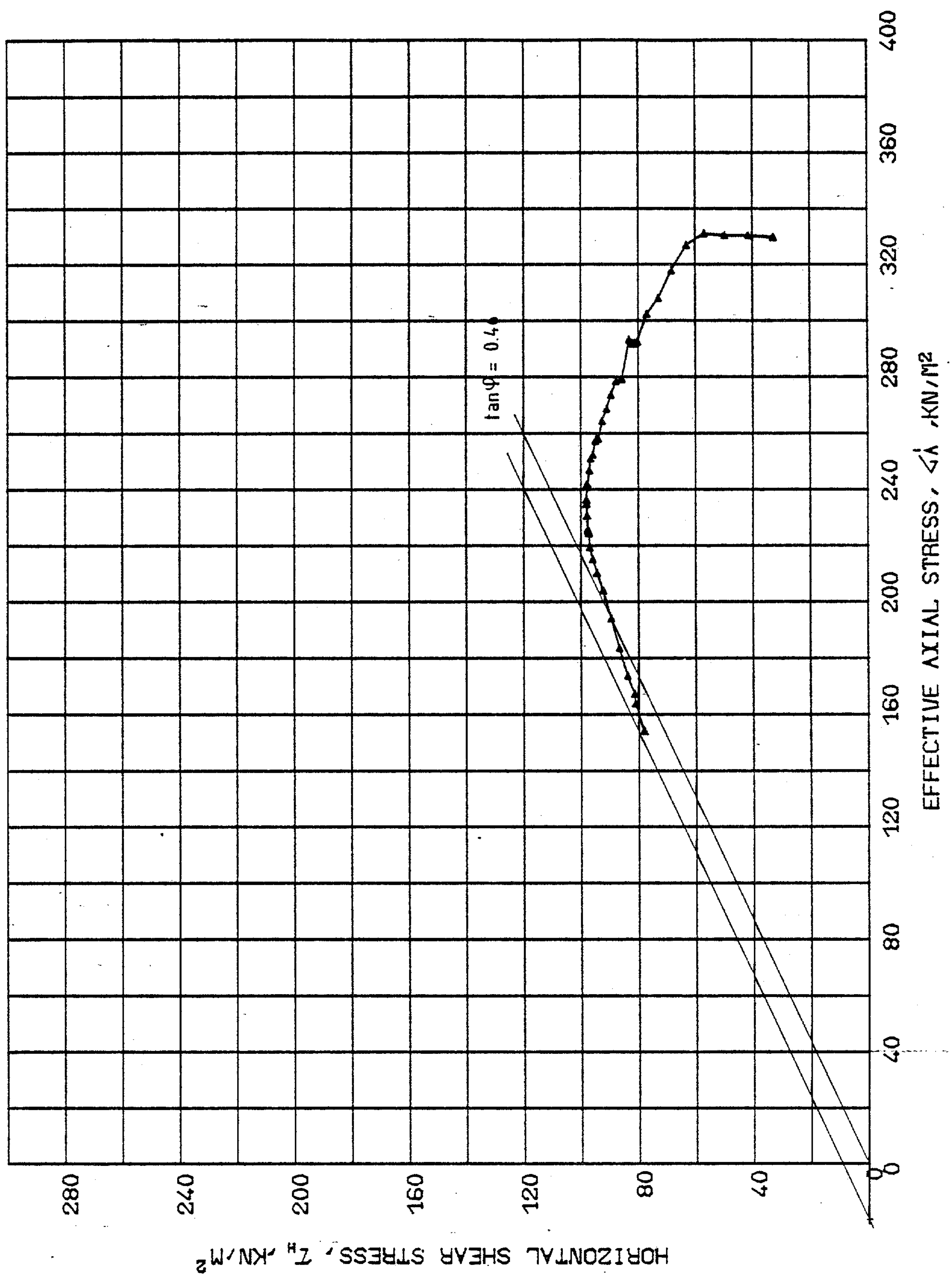
1KN/M² = 0.102T²

BLOCK 58-W. DELTA AREA GULF OF MEXICO.	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 33.90 M EFFECTIVE STRESS PATH — σ'_{AC} = 137.7 KN/M² BORING: 5 SAMPLE: 65- - D — W_I = 38.58 %	APPROVED PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 020	



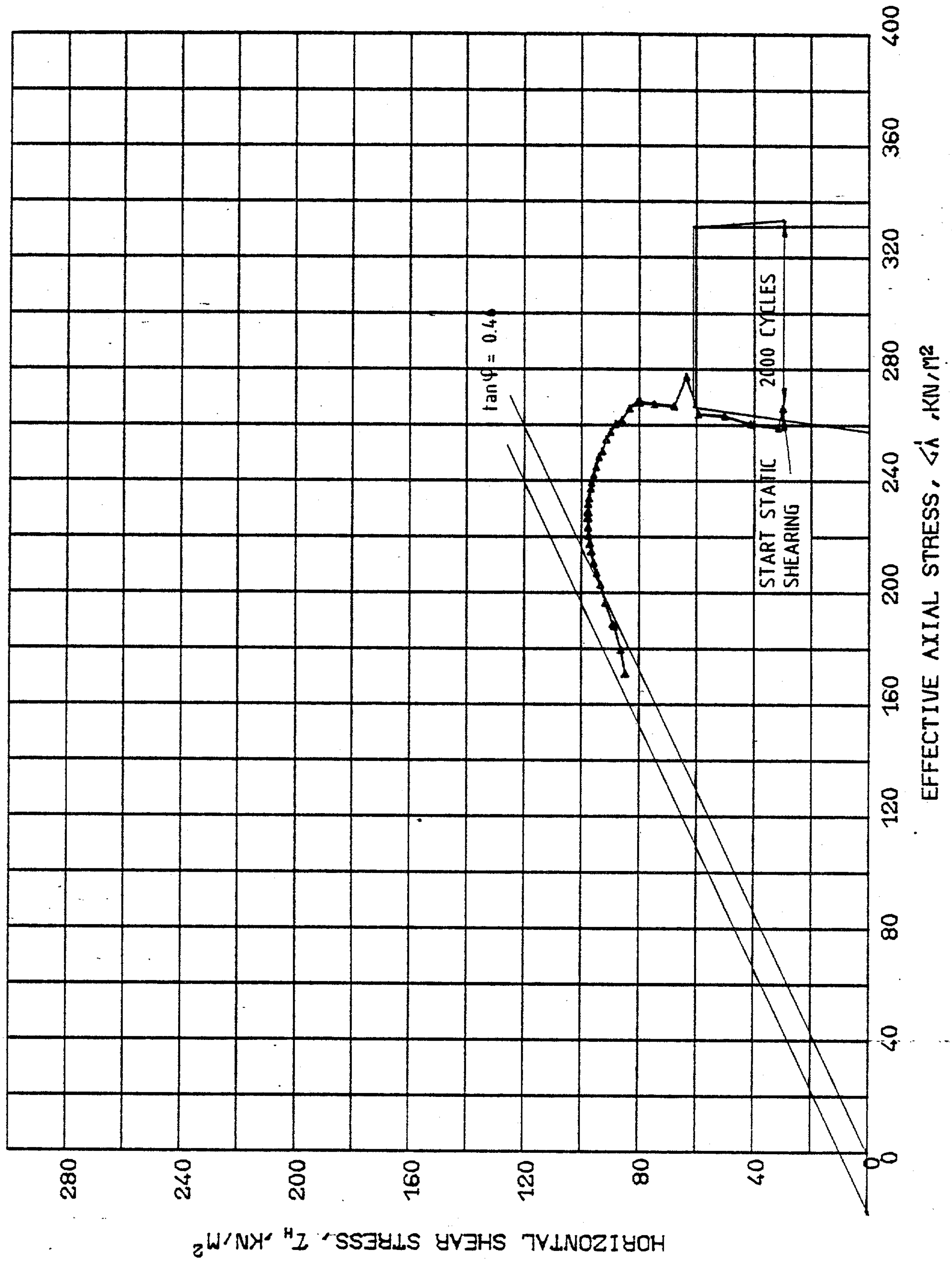
1KN/M²=0.102T/M²

BLOCK 58-W.DELTA AREA.GULF OF MEXICO.	DATE 10. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 33.90 M EFFECTIVE STRESS PATH — σ_{AC} = 138.0 KN/M² BORING: 5 SAMPLE: 65- - E — W_I = 38.60 %	APPROVED PROJ. NO. 81222 -2	
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 021	



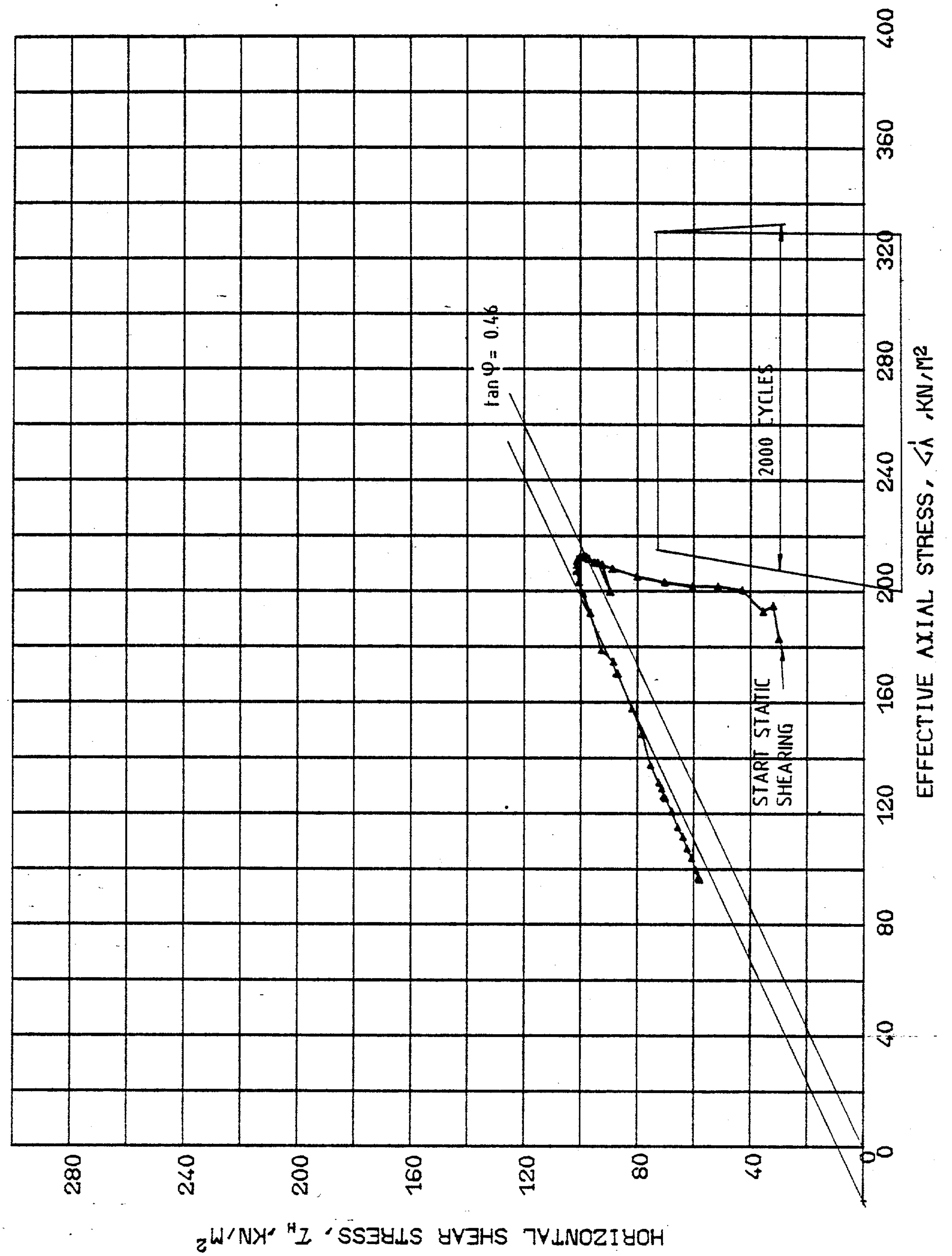
1KN/M² = 0.102T/M²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	DATE 11. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST EFFECTIVE STRESS PATH BORING: 5 SAMPLE: 133- - C	DEPTH = 68.00 M σ'_{ac} = 333.4 KN/M² W_I = 52.61 %	APPROVED PROJ. NO. 81222-2
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 022	



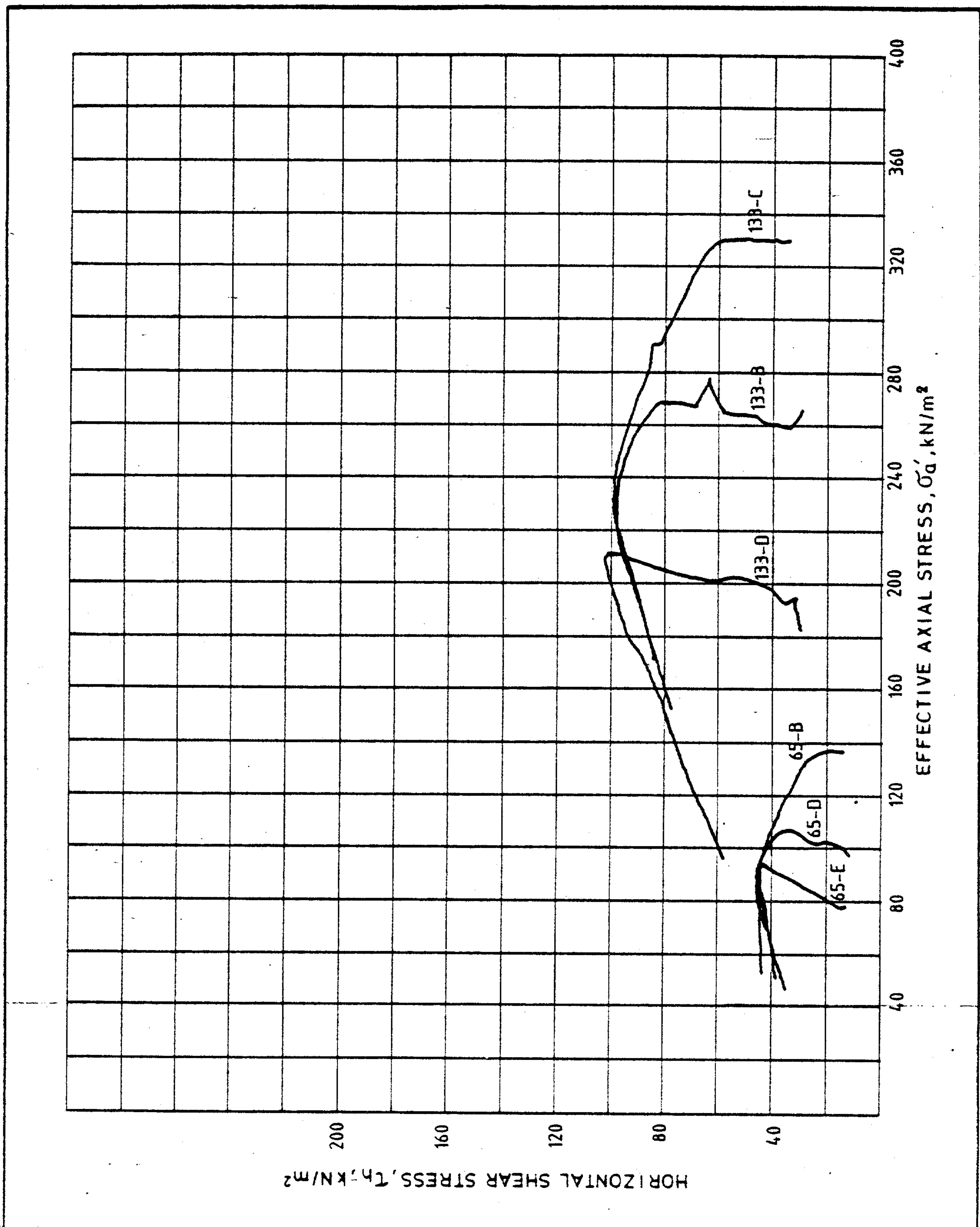
1KN/M² = 0.102T²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	DATE 11. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST — DEPTH = 68.00 M	APPROVED	
EFFECTIVE STRESS PATH — σ'_{AC} = 333.3 KN/M²	PROJ. NO. 81222-2	
BORING: 5 SAMPLE: 133- - B — W_I = 56.86 %		
NORWEGIAN GEOTECHNICAL INSTITUTE	DRAW NO. 023	



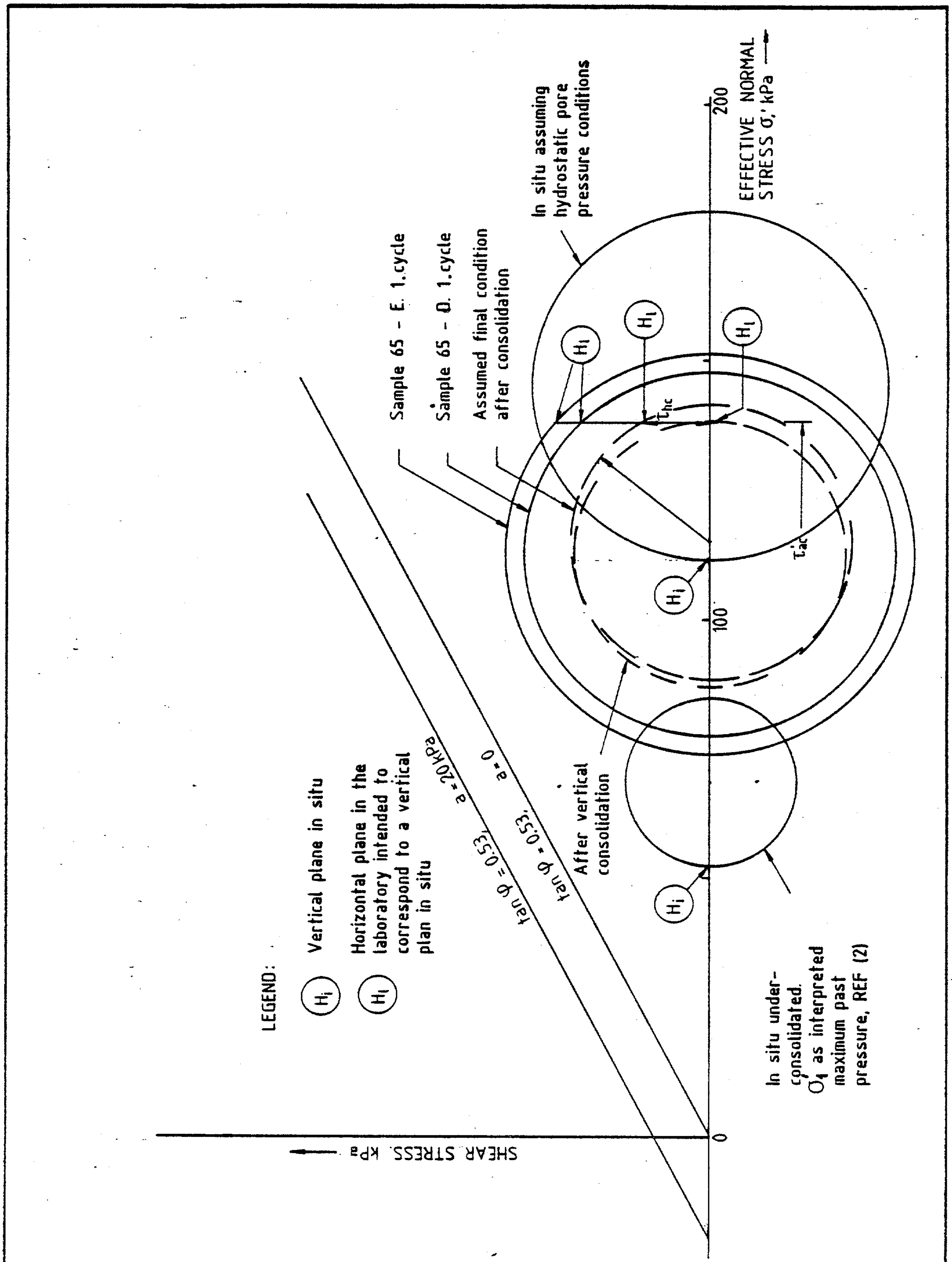
1KN/M²=0.102T²

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.		DATE 11. 5. 82	DRAWN BY
CCV SIMPLE SHEAR TEST EFFECTIVE STRESS PATH BORING: 5 SAMPLE: 133- - D	DEPTH = 68.00 M σ_{AC} = 332.5 KN/M² W_I = 55.33 %	APPROVED	
		PROJ. NO. 81222-2	
NORWEGIAN GEOTECHNICAL INSTITUTE		DRAW NO. 024	

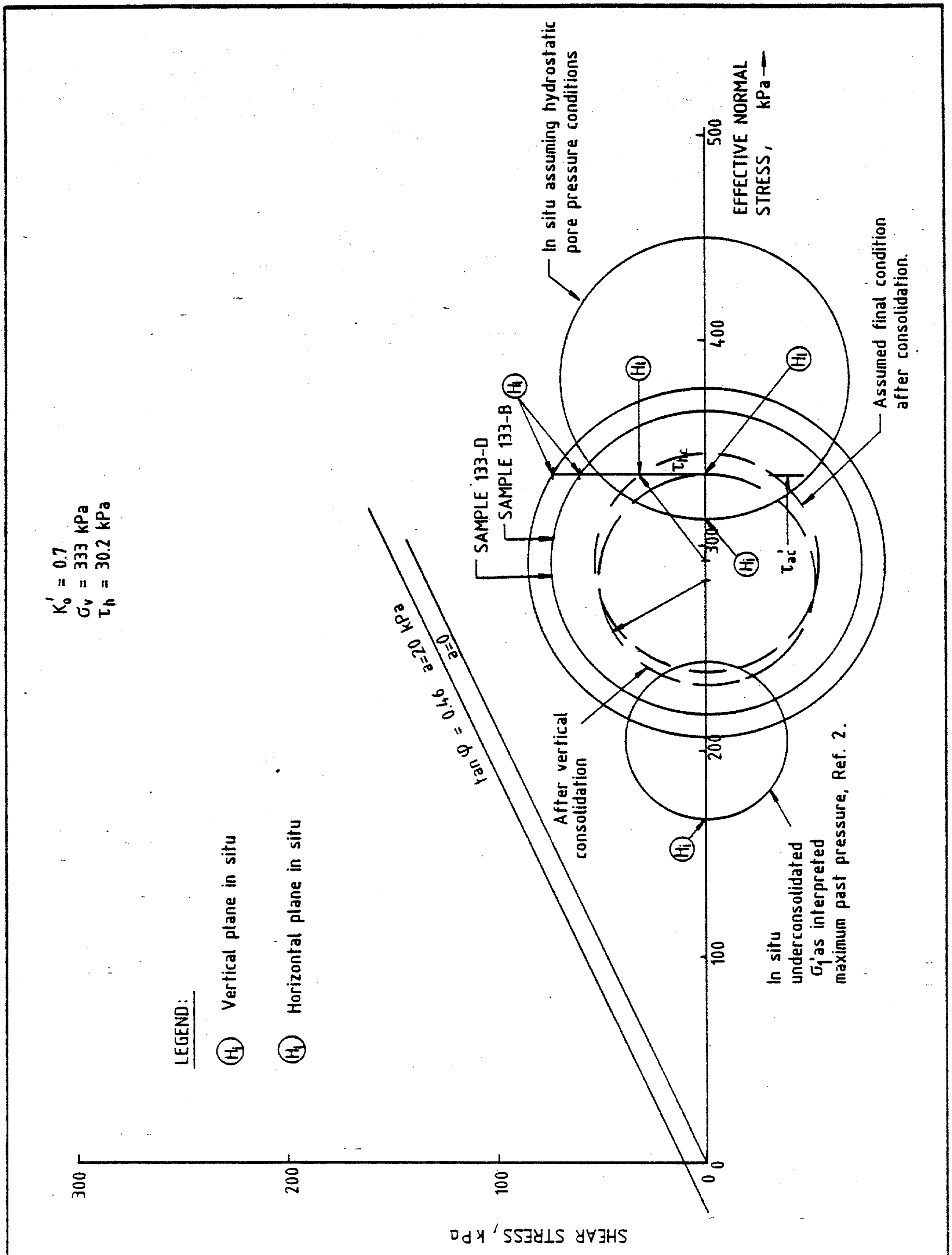


1 kN/m² ≈ 0.1 t/m²

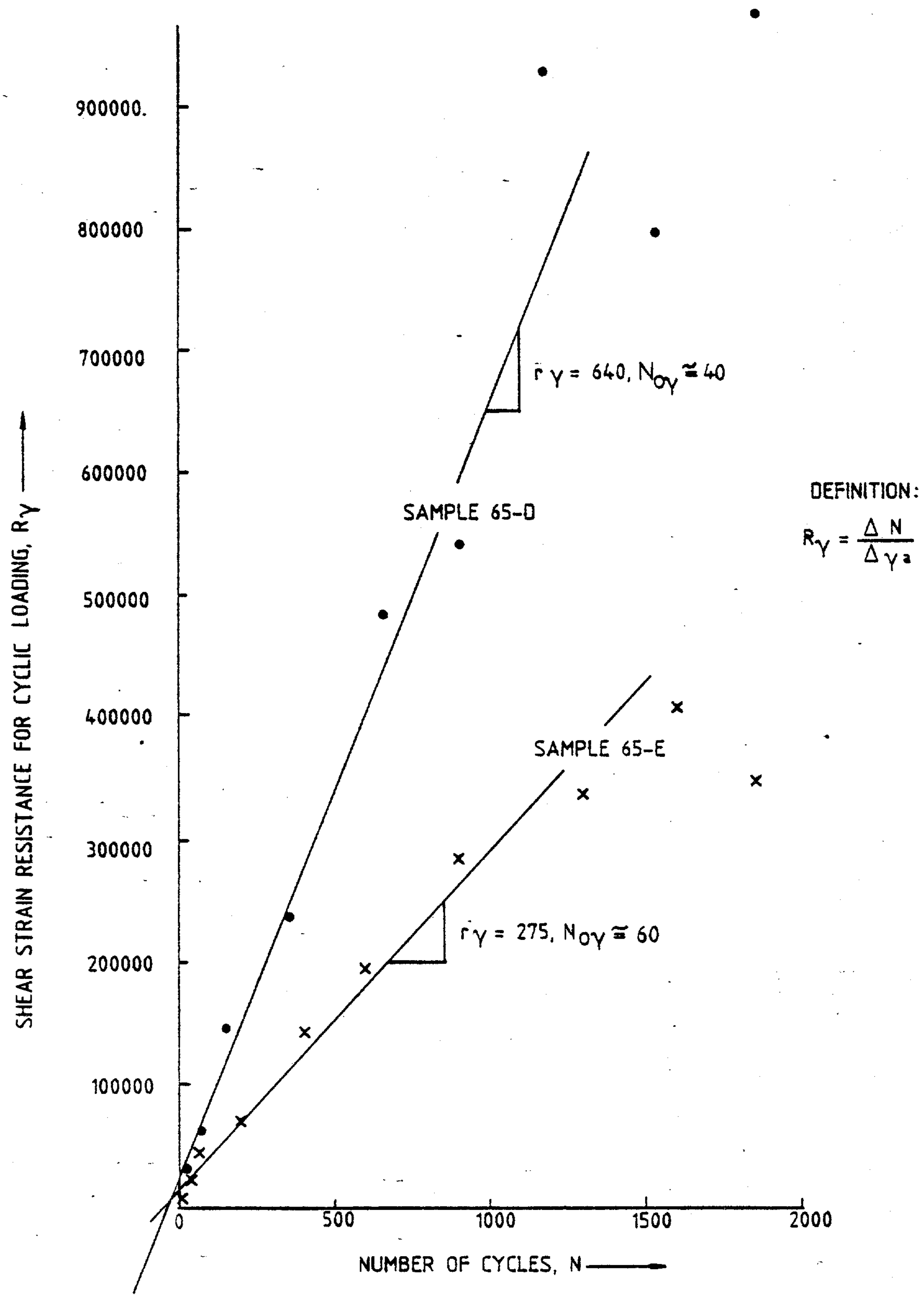
BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by aak
CCV Simple shear test Summary of effective stress paths STATIC LOADING.	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 025	



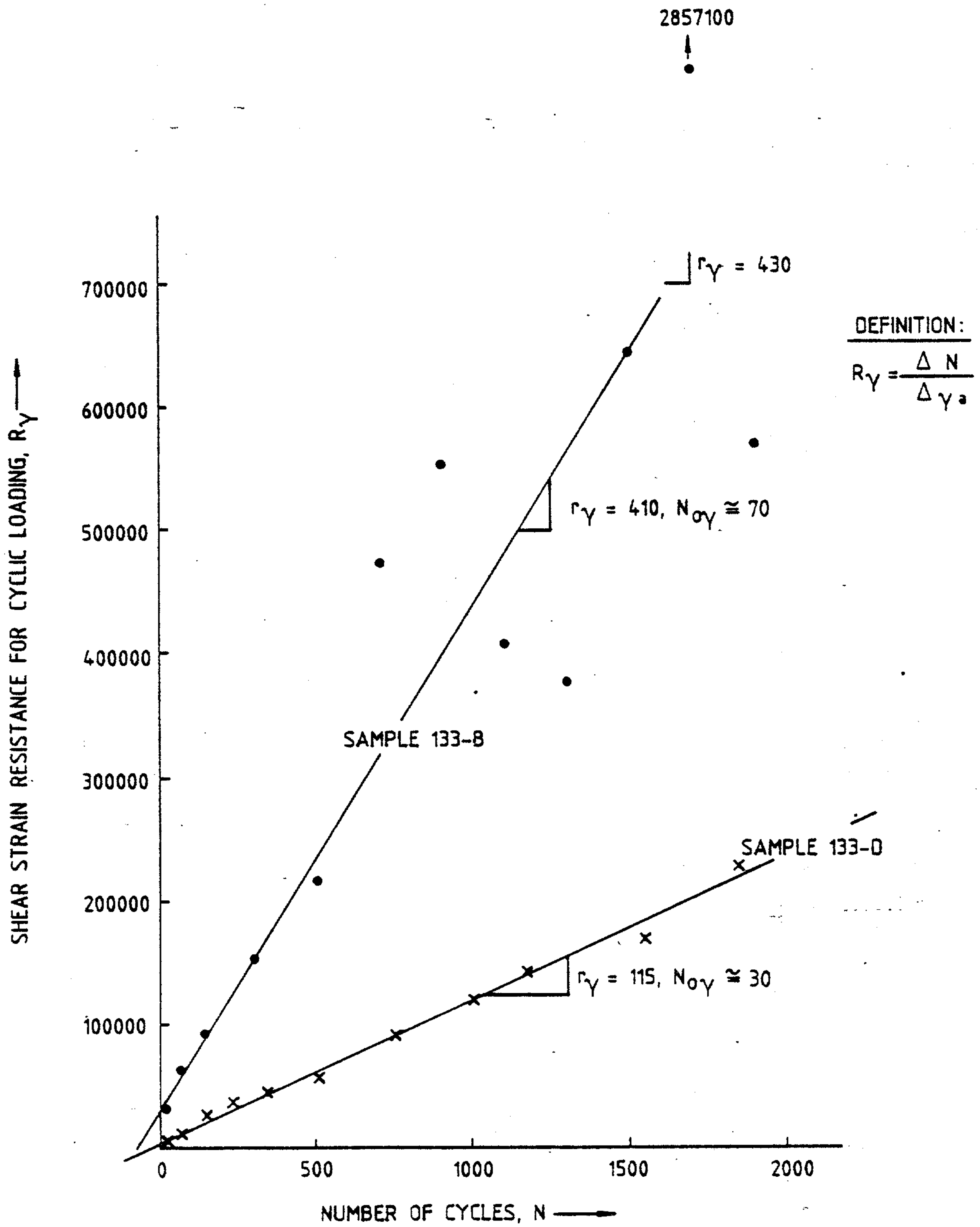
BLOCK 58-W. DELTA AREA. GULF OF MEXICO	Date 21.06.82	Drawn by T.J.
Sample 65. Assumed consolidation stress and effictive stress conditions at first load cycle . Mohr diagram.	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 026	



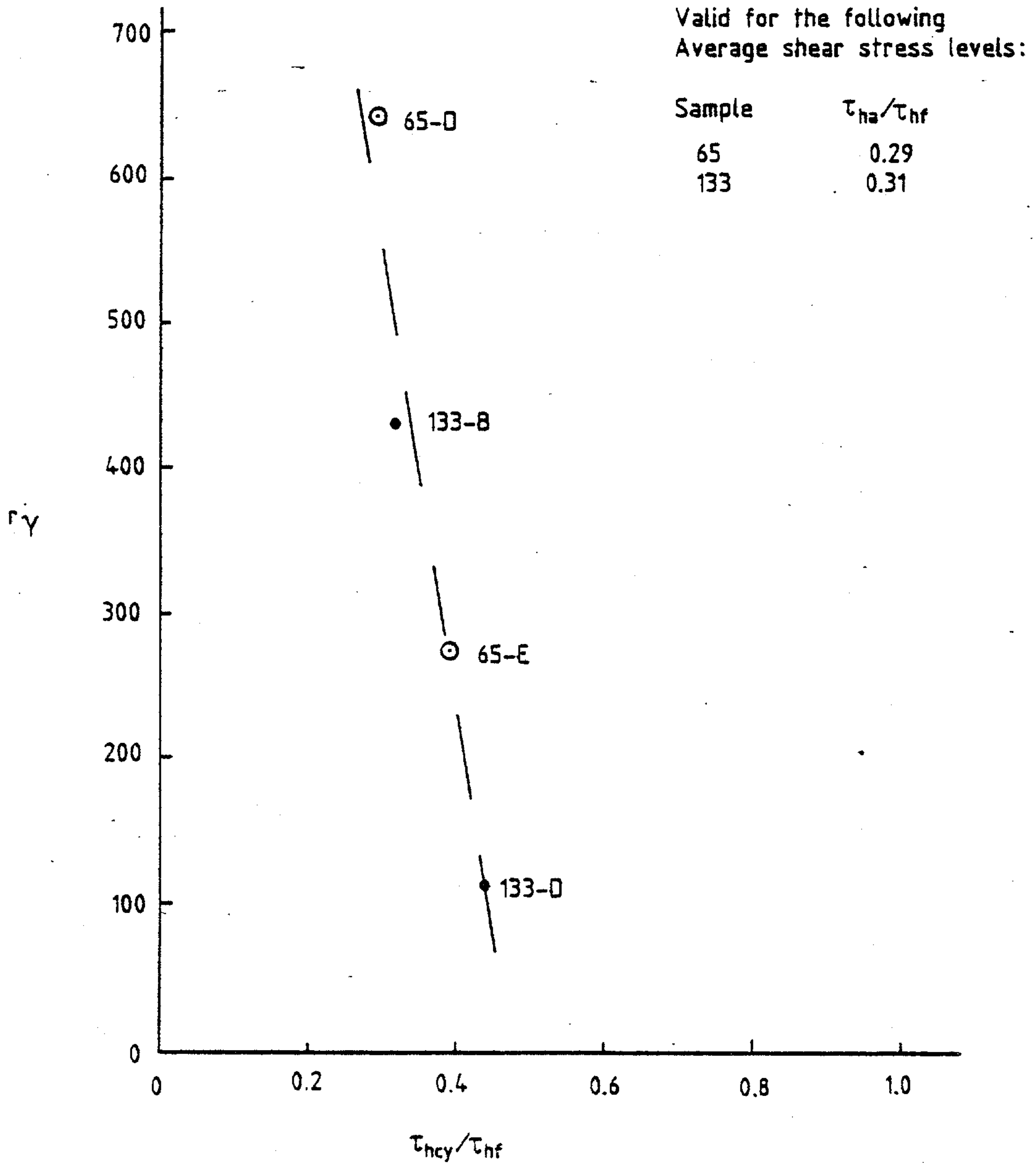
BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by aak.
Assumed consolidation stress and effective stress conditions at first load cycle. Sample 133. Mohr diagram.	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 027	



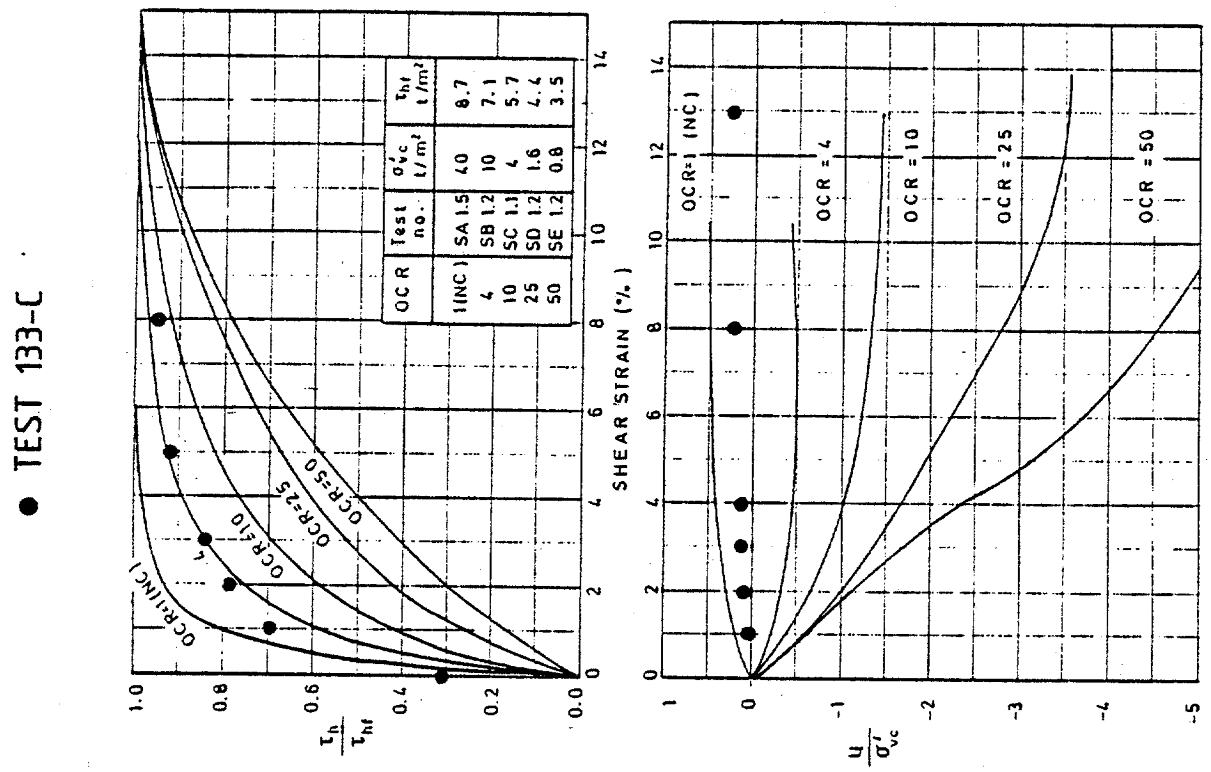
BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by [signature]
Sample 65. Shear strain resistance during cyclic loading.	Approved [signature] Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 028	

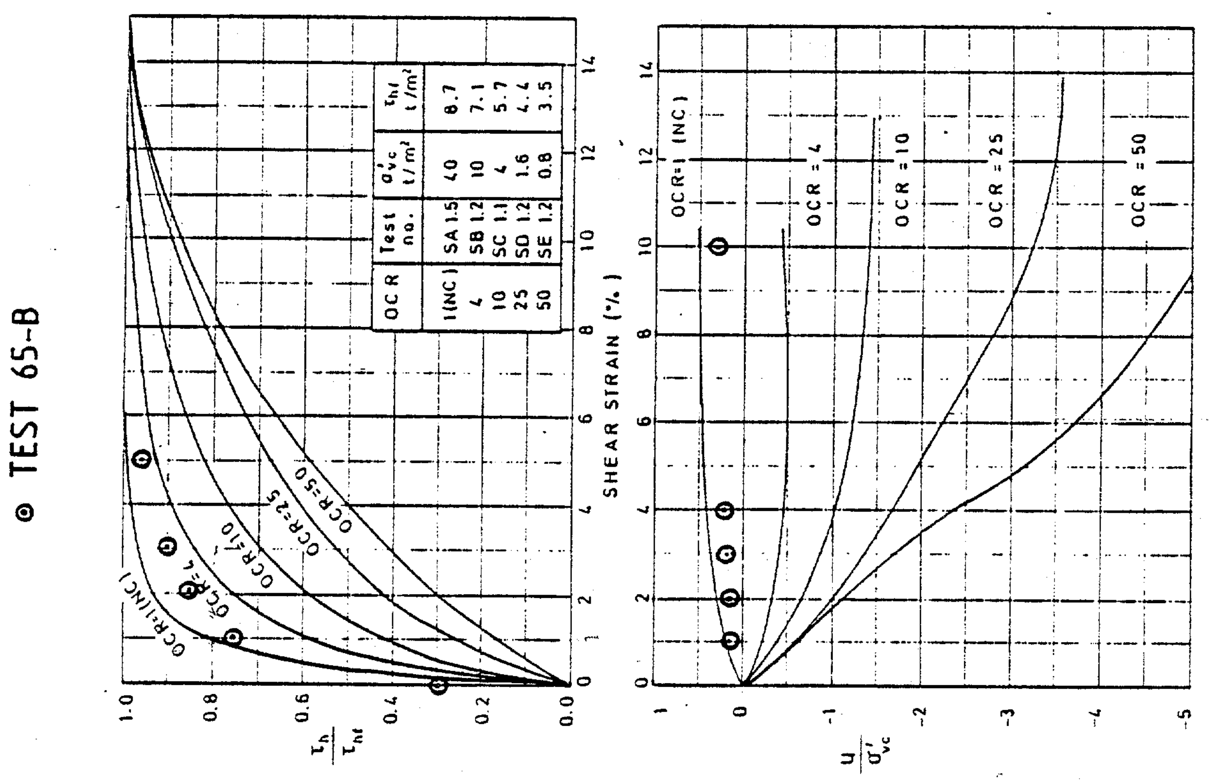


BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by ααk
Sample 133. Shear strain resistance during cyclic loading.	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 029	



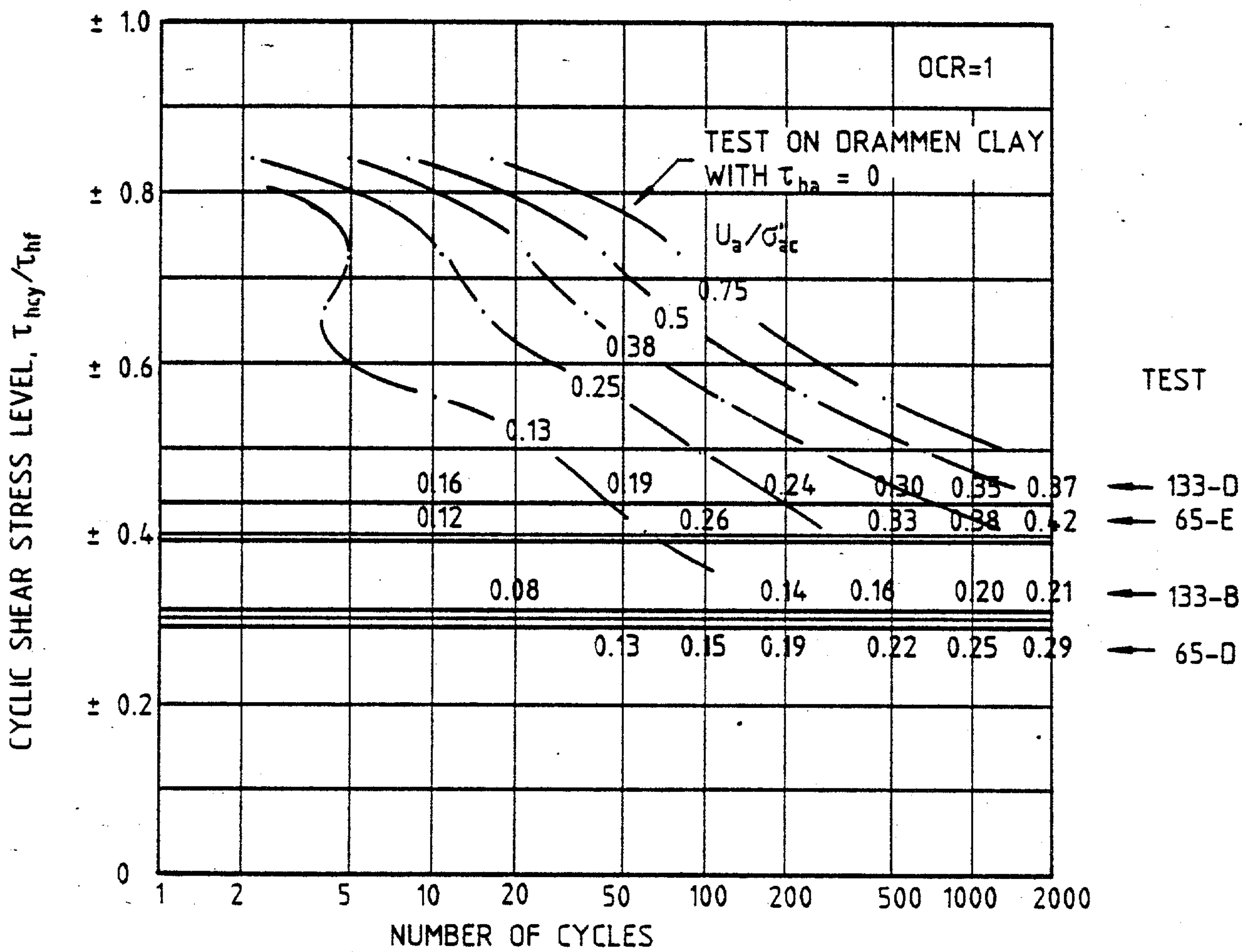
BLOCK 58-W. DELTA AREA. GULF OF MEXICO	Date 21.06.82	Drawn by
Resistance number r_γ versus cyclic shear stress level.	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 030	





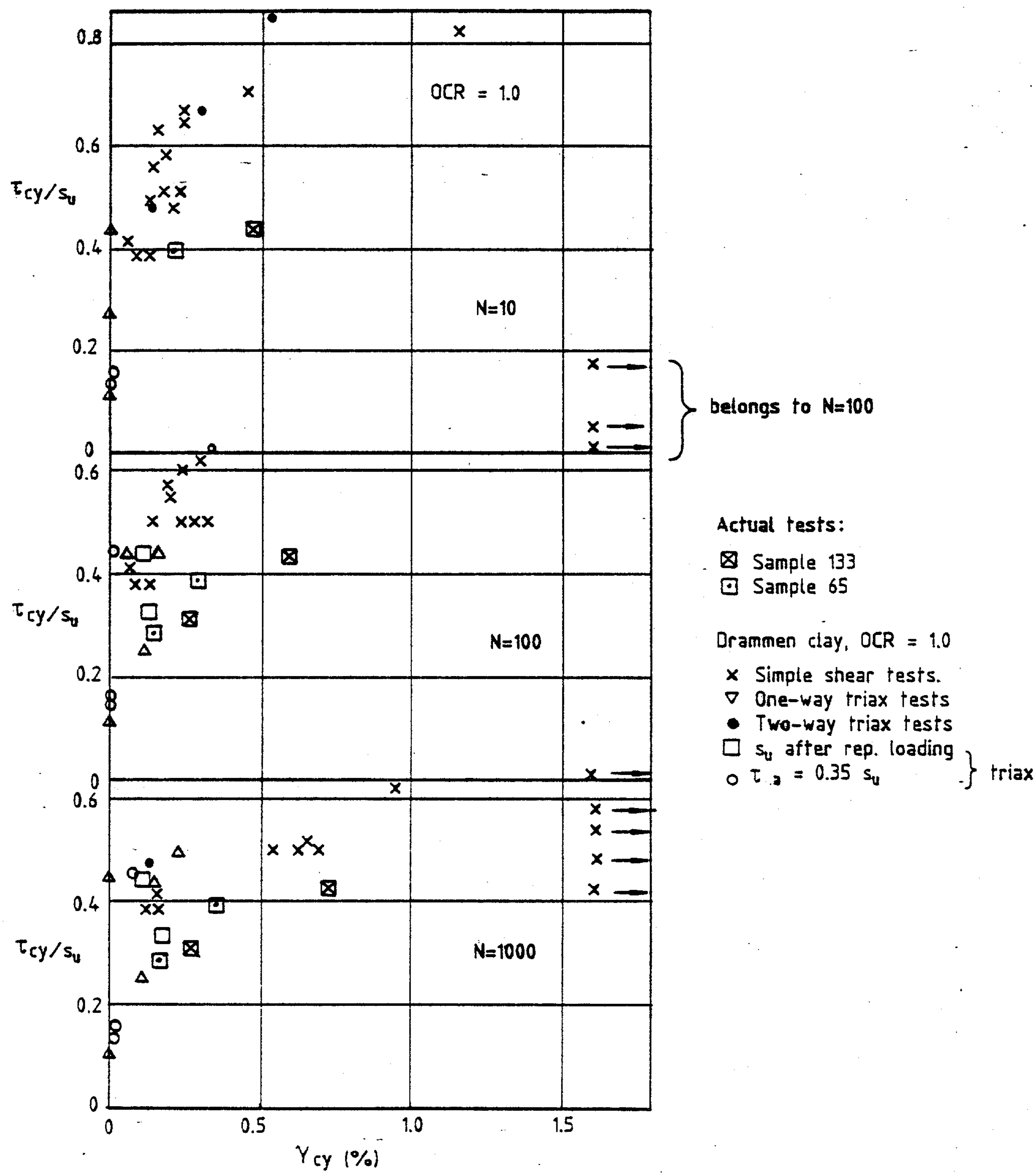
DIAGRAMS ARE TAKEN FROM REF. 1.

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date: 21.06.82	Drawn by: [signature]
Results from the static simple shear tests compared with normalized results from Drammen clay.	Approved: [signature]	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 031	



TESTS ON DRAMMEN CLAY TAKEN FROM REF. 1

BLOCK 58-W. DELTA AREA. GULF OF MEXICO.	Date 21.06.82	Drawn by [signature]
Development of average pore pressure as a function of total cyclic shear stress level and number of cycles. Comparison with SST on Drammen clay.	Approved Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 032	



BLOCK 58-W. DELTA AREA. GULF OF MEXICO

Date	Drawn by
21.06.82	T.J.

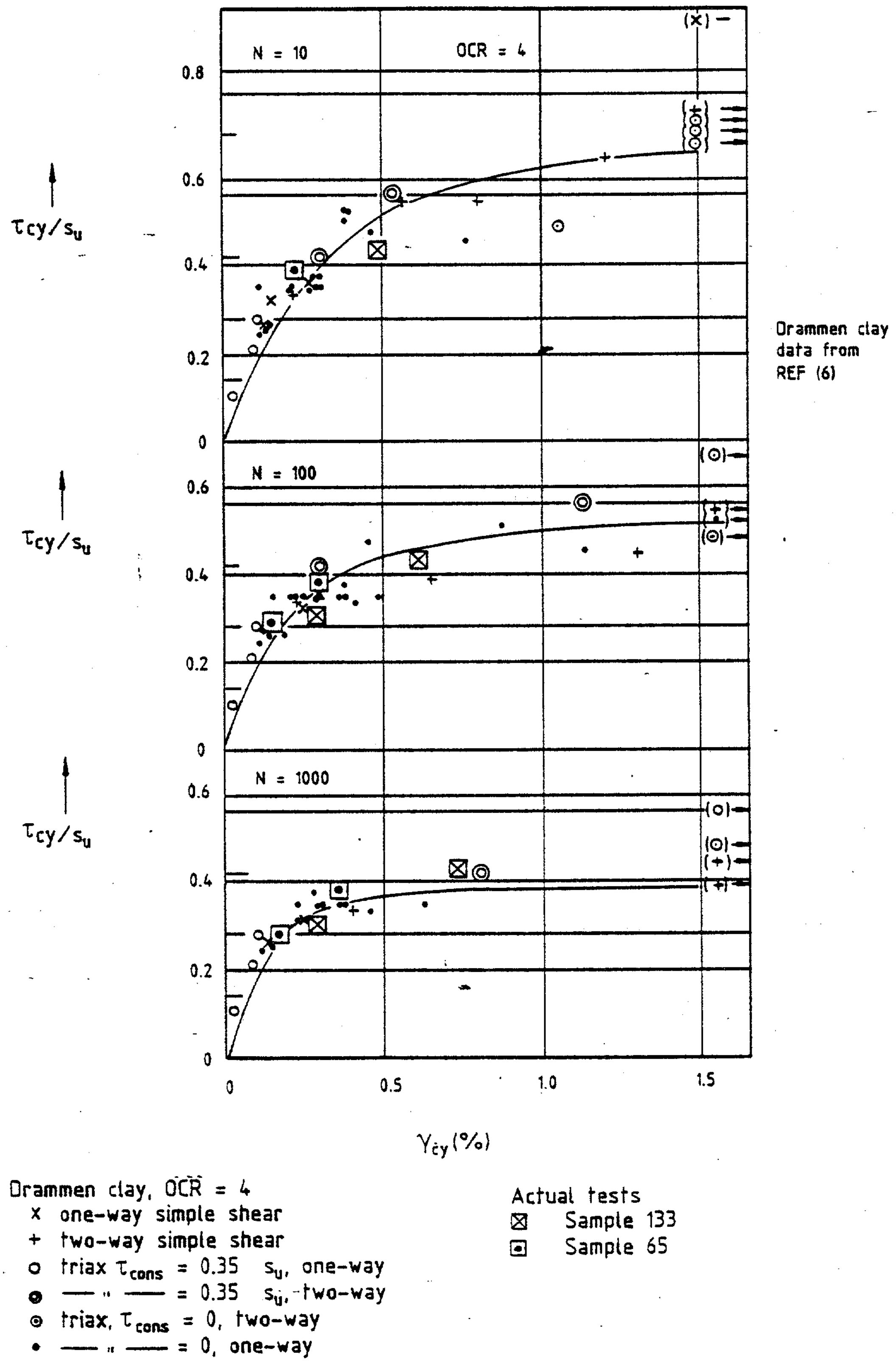
Relationship between cyclic shear stress level and cyclic shear stress after 10, 100, and 1000 cycles.
Result from Drammen clay with OCR = 1.0 compared with actual tests.

Approved

Project no. 81222-2

Norwegian Geotechnical Institute

Drawing no. 033



BLOCK 58-W. DELTA AREA. GULF OF MEXICO	Date 21.06.82	Drawn by T.J.
Relation between cyclic shear stress level and cyclic shear stress after 10, 100, and 1000 cycles Results from Drammen clay whith OCR = 4 compared with actual tests	Approved	
	Project no. 81222-2	
Norwegian Geotechnical Institute	Drawing no. 034	