Det norske Veritas
Research Division

POSTAL ADDRESS: P.O.BOX 300, 1322 HØVIK, NORWAY
TELEPHONE: +47(02) 12 99 55
CABLE ADDRESS: VERITAS, OSLO
TELEX: 16 192 VERIT N

TECHNICAL REPORT

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Title of Report	TENSION PILE STUDY SUBPROJECT CNRD 13-2 Description of Test Procedures and Equipment for Laboratory Model Pile Test
Approved by	Tore J. Kvalstad Senior Research Engineer
Client/Sponsor of project	CONOCO NORWAY, INC.
Client/Sponsor ref.	Ron Gratz
Work carried out by	Kjell Hauge
Reporters sign.	

Summary

This report describes the test equipment and procedures as well as the data acquisition and analysis methods used for a series of laboratory model pile tests. The tests are carried out for Conoco Norway Inc. and is a part of a larger research program including small scale field segment tests and eventually a large scale field pile test.

The model pile tests are carried out to improve the understanding of pile soil interaction under static and cyclic tensile loading as induced by the anchoring forces of Tension Leg Platforms. The pile is instrumented with axial force transducers, total normal stress and pore pressure transducers to allow interpretation on an effective and a total stress basis.

4 Indexing terms

- Tension Leg Platforms
- Tension Piles
- Cyclic Loading
- Strength Degradation

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PREFACE

The Tension Leg Platform (TLP) concept is being considered by Conoco for deep-water locations in the Gulf of Mexico, specifically Green Canyon, Blocks 137 and 184 and Viosca Knoll, Blocks 864 and 908. The soil conditions at these locations will be predominantly soft clay down to a considerable depth and will thus be completely different from the Hutton Field in the North Sea, for which Conoco is presently designing the first prototype TLP. At Hutton alternating layers of very dense sand and heavily overconsolidated clays are found.

The foundations of TLP's will have to resist large tensile forces with combined static and cyclic loading. Pile foundations seems to be the most feasable alternative practically as well as economically.

In order to improve the understanding of the pile-soil interaction resulting from cyclic loading produced by a TLP, taking into account any site specific aspects of the above mentioned Gulf of Mexico Blocks, Conoco authorized Veritas with Ertec Inc. as a designated subcontractor and with the Norwegian Geotechnical Institute (NGI) and the Geotechnical Division at the Norwegian Institute of Technology (NTH) as consultants, to perform a study comprising laboratory model pile tests with a 1" diameter pile segment, field tests with 3" diameter pile segments and eventually a large scale field test with a 67m long, 30" diameter driven steel pipe pile.

This report is the first part of a series of reports describing Veritas activities and results of the project work.

LIST OF TABLES AND FIGURES

1. INTRODUCTION

This report gives a description of the test equipment; test procedures, data acquisition and data analysis used for performing a series of laboratory model pile tests.

The test procedures and the equipment has been modified gradually as a result of the findings and experience gathered during the first tests, and further modifications might be required. The basic set-up seems to work satisfactory although problems with leakage around the total normal stress gauge has turned out to be a problem. The leakes have been created during the pressure testing and calibration of the gauge prior to insertion into the chamber and has thus not influenced the test results, but delays have been unavoidable.

Due to a very low coefficient of consolidation of the remoulded and reconsolidated clay samples the test sequence takes about twice the time estimated during the planning study with the objective of improving the understanding of pile-soil interaction under cyclic tensile loading to improve the design methods and to work out design recommendations.

The test program which consists of laboratory model pile tests, field segment tests and a large-diameter pile test includes also theoretical development and has been worked out as a result of a planning study proceeding this study. The different tasks of this study has been described in detail in the final reports of the planning study:

- Tension Pile Planning Study, Subproject CNRD 13-1, Final Report by Det norske Veritas, Report No. 80-0587, 28. August 1981.

- Final Technical Report, Subproject CNRD 13-1 by Ertec, Inc. Report No. 81-204, 28. August 1981.

Veritas is the principal investigator for the laboratory model pile tests while Ertec is the principal investigator for the field tests

By contract of November 30, 1981 between Conoco Norway Inc. and Veritas authorization was given for the Tension Pile Study. Ertec, as a designated subcontractor for the field tests, entered into contract with Veritas on February 26, 1982, however temporary authorization to start the work was provided for with Conoco's acceptance in the beginning of December 1981.

2. DESCRIPTION OF APPARATUS, TEST SET UP AND TEST PROCEDURES

2.1 Sample Preparation

From the available soil information at the West Delta Block 58 site the soil profile was divided into three different strata (later referred to as Stratum I, II and III) according to the distinct changes in plasticity index and natural water content along the profile. See figure 2.1. From this figure it is seen that Stratum I extends down to about 25 m, Stratum II from 25 m down to about 48 m and Stratum III from 48 m down to 72 m penetration.

Initially the clay samples were extruded from the cylinders supplied by McClelland Engineers, allowing for standard classification including water content, laboratory fall cone tests and preparation of selected undisturbed samples for triaxial tests and standard oedometer tests.

An average of four undisturbed samples from each strata were cut out and preserved for later triaxial and consolidation tests. After performance of initial classification the clay from each strata was stored in a separate water tight tank in order to preserve the natural water content.

The results of the planning study (Ref. 1) indicated three possible alternatives for producing a soil specimen for the pile model·test chamber (see chapter 2.4) with dimensions 350 mm in height and diameter 200 mm, as follows:

(a) Utilize undisturbed samples 200 mm in diameter from special type NGI-sampler.

(b) Utilize a core of intact undisturbed clay in the center with remoulded clay surrounding this.

(c) Use remoulded clay for the whole specimen.

The intent was to test out the three different alternatives with the laboratory model equipment and check any differences in behaviour and characteristics. When the soil investigation started in November 1981, however, the NGI-sampler was not available, and also since this type of sampling is not a standard procedure and in addition has not been used for offshore application, it proved impossible to use undisturbed 200 mm samples for the model tests.

Alternatives (b) and (c) were then investigated using samples of Drammen Clay. A 95 mm undisturbed core was placed in the center of the large consolidometer (see chapter 2.2) and remoulded material was placed around this core to fill up the tank. This new "mixture" was then consolidated to a specified value and subsequently tested. When this consolidated sample was extruded there was an apparent difference in the degree of consolidation over the cross section of the sample. The water content in the center core was considerably higher (~ 20%) than the surrounding, previously remoulded, material. Also, when cutting the sample axially through the center, the center core was clearly visible by cracks and could with ease be separated from the rest.

A test was then made (alternative (c)) using remoulded clay for the whole specimen. Quite consistent values of the water content resulted when using only vertical drainage (top and bottom). In order to speed up the consolidation time, vertical strip filters were placed around the perimeter of the sample. This, however, resulted in a nonuniform consolidation of the sample with higher water content in the middle. This fact should be expected due to the large deformations during consolidation (20%), and material around the perimeter consolidating faster than the center mass due to shorter drainage path and thus developing a higher stress level.

The table below sums up the different consolidation method procedures and the results.

Drainage Conditions	Method (b)	Method (c)
Vertical & radial drainage	non-uniform consolidation, center core distinct from rest	non-uniform consolidation over cross-section
Vertical drain.	not tested	uniform consolidation over cross-section
Vertical drain at top and bottom and at 3 interm. depths	not tested	uniform consolidation over cross-section and height. Faster consolidation

As a result from this investigation it was decided to use remoulded material throughout the consolidation tank with only vertical drainage allowed (horizontal filters). Because of the large dimensions required for the sample (total height of the oedometer is 600 mm) three horizontal intermediate filters covering the whole cross-sectional area were equally spaced in the tank dividing the sample in four equal parts. Drainage from the interior filters was allowed through plastic covered strips along the perimeter connecting the filters from top to bottom. See figure 2.2.

The resulting procedure for preparing one sample for pile model testing thus consists of:

(1) Remould material from the strata to be tested, using a large commercial mixer.

(2) Build in the remoulded clay into the large oedometer. Care has to be made to avoid air pockets and to achieve an optimal uniform packing. Horizontal intermediate filters are saturated and connecting filter strips carefully placed to secure drainage to top and bottom.

The water extruded from the sample during consolidation is saved and used for later remoulding of the same strata to obtain original water content. The amount of water to be remixed is checked by performing fall cone tests of the material during the mixing (remoulding) process.

2.2 Consolidation

The oedometer used for consolidation of the clay sample subsequently used for the pile model test is shown in figure 2.2. It is specially designed for this project to produce a sample with an outer diameter of 200 mm.

Basically the oedometer consists of a bottom plate with a porous stone filter, diameter 160 mm, and a stainless steel cylinder with an inner diameter of 200 mm and supplied with top and bottom flanges. The consolidation pressure is applied on top through a heavy stainless steel piston also equipped with a porous stone filter for top drainage. The piston fits snugly in the cylinder and is equipped with two rubber " O - rings " for sealing and reduction of gliding friction.

The whole set-up is placed in a Wykham Farrance testing frame, and consolidation is started out as a constant rate of strain test until the pressure, measured at the piston base, reaches the consolidation pressure. This pressure depends on the strata to be tested and is 100,300,500 KPa for strata I, II and III respectively.

A pore pressure transducer is mounted on the side of the cylinder connected to a porous stone filter in contact with the clay inside the cylinder. In this way the excess pore pressure can be monitored during consolidation. The intent was to keep the consolidation pressure constant until the excess pore pressure was zero but due to the low coefficient of permeability and large volume of the clay sample, consolidation is terminated when the pore pressure change during 24 hours is considerably small. Time for this has been about 10 days with the described set up for the West Delta clay. An additional 10 days of consolidation at same pressure should have no serious influence on the reduction in excess pore pressure.

In addition to continuous monitoring of the pore pressure and the applied pressure on top, manual measurements of settlements are taken during the consolidation period.

2.3 Transfer from Oedometer to Test Chamber

When consolidation of one sample is terminated, the bottom plate of the oedometer is removed and the consolidated sample extruded by means of the piston. The sample is pushed down on the bottom plate of the model pile test chamber (described in chapter 2.4). As the level of an intermediate filter is reached, the cylinder is lifted up, which causes a slip between the clay and the filter, and the filter is then removed.

Subsequently the sample is pushed down again onto the already extruded clay, the weight of the soil causing the two ends to fit snugly together, producing a continuous cylindrical sample.

After the whole consolidated sample has been extruded from the oedometer, it stands by itself on the bottom plate. At this time measurements of undrained shear strength are performed with a pocket penetrometer at about 30 mm intervals along the side of the clay sample, to check the uniformity of the consolidation and the repeatability from sample to sample.

The cylinder of the model pile test chamber is then carefully placed over the sample with a reinforced rubber membrane around its inside perimeter. As the confining cylinder is in place around the consolidated clay sample and in contact with the bottom plate the sample is trimmed on top by carefully cutting off the excess clay. The total inner height of the model test chamber is 350 mm. From this top piece samples can be prepared for triaxial tests and standard consolidation tests to further check similiarity and repeatability between different samples.

The top plate of the model pile tests chamber is then mounted in place and the model pile is inserted in the top access hole to seal off the sample. The confining pressures to duplicate the previous consolidation pressure is then applied. In an attempt to fully saturate the sample and get a good pore pressure response a back pressure (usually 300 KPa) is applied to the clay at this time. The now ready built in sample with confining pressures is left to reconsolidate for a period of about four days.

The oedometer can now be cleaned and made ready for a new consolidation sequence of a new sample, while a pile model test can be performed on the sample now built in. It was the intention that the whole sequence starting with building in a sample in the oedometer, consolidation and subsequent transfer to the pile model test chamber should take about one week. But due to the low coefficient of permeability of the West Delta clay and its slow pore pressure response, additional time for consolidation and set up effects had to be included. With the described equipment, and obtained experience with the West Delta clay a sequence now takes about two weeks.

2.4 Model Pile Test Chamber

The model pile test chamber is shown in figure 2.3 together with the model pile. Basically the chamber consists of three main parts, namely the confining cylinder (1) (referring to figure 2.3) and the top and bottom plate (2). These two end plates are identical in configuration and has in the center a hole for the center bearing (7). The bearings can move relative to the end plates by the rubber sealing rings.

As mentioned in the previous section the clay sample is extruded from the oedometer onto the bottom plate of the test chamber. The bottom center bearing is then in place and the pressure chamber (12) for bottom (vertical) pressure is filled with water. A circular dough-nut shaped rubber membrane (9) is used to separate the clay sample from this water and is tightly connected to the center bearing. Its outer diameter is larger than that of the confining cylinder so that it is kept tight to the perimeter of the bottom plate from the contact pressure of the confining cylinder. In order to produce a flat surface on the bottom of the sample a perforated disk (10) is placed in the pressure chamber.

After the sample stands by itself on the bottom plate, the confining cylinder (1) is placed over the sample, aided by the lock bolts (14) and the guide cylinders (15) fastened to the outside of the confining cylinder. The confining cylinder has inside flanges on top and bottom, which with a rubber membrane around its inside perimeter produces a pressure chamber (11) for lateral confining stress on the clay sample. During the placement of the confining cylinder a vacum is applied to this chamber so that the rubber membrane is kept close to the inner wall preventing the sample from being accidentally disturbed.

When the sample has been trimmed on top the top plate, with the center bearing (7) and membrane (9) in place, is locked in place by four nuts on the lock bolts (14). The pressure chambers (11), (12) and (13) are now securely enclosed by the fastening operation on the top plate which actually forces the two end plates tight onto the two ends of the confining cylinder.

The model pile is placed in the top access hole with the tip barely penetrating the clay, and a plug with same diameter as the model pile is placed in the bottom access hole. In this way the clay sample is completely sealed off and the prescribed confining pressures applied.

A back-pressure can be applied to the sample through the center bearings. (see figure 2.3, U_b). The hole made through the bearings leads into a back pressure chamber (16) which is penetrated by the pile. A hard rubber seal around the pile separates this chamber from the clay and flow of water is facilitated by filter strips from the back-pressure chamber, by-passing the rubber seal into the tank. A circular filter paper, in contact with the filterstrips, is placed between the clay and the top and bottom membranes. Around the perimeter of the clay sample filter strips are equally spaced to connect the top and bottom filters. Back-pressure can now be applied at top and bottom through a closed pressure system so that a measure of water going into or out of the model tank clay sample is available.

The clay sample when built into the model pile test chamber is left to reconsolidate at the prescribed confining pressure, and subsequently the model pile is jacked into place by a hydraulic pressure system mounted on top of the model tank. A period of about four days is now allowed for excess pore pressure at the pile surface to dissipate before the loading program is started.

During actual load testing the model tank is placed in a testing frame standing on three legs screwed on to this frame. The load on the pile is applied by a hydraulic actuator (see chapter 2.6) on top of the testing frame. The load on the pile is transferred to the soil by shaft friction and out to the confining rubber membrane. This membrane is reinforced in axial direction with inelastic threads which makes the membrane inelastic in axial (upward or downward) direction but elastic in tangential direction (thus allowing for radial movement). The confining membrane is fastened to the endplates and the tank itself is screwed on to the test frame. Experience has showed that good bondage between the clay and the rubber membrane results.

The center bearings can move relative to the end plates, which allows the center mass of the clay sample to deform in axial direction as the pile deforms.

2.5 Model Pile

A sketch of the model pile is also shown in figure 2.3. The outside diameter is 25mm and the total length is 600 mm. It consists of three separate parts with measurements taken in the middle part which is centered in the model tank after the installation of the pile.

The three parts are connected by two force transducers (3) which allows for measurements of axial load in the pile at two distinct levels. When the pile is loaded, the difference in load between the two transducers is the friction excerted from the clay to the pile between the two points. The center piece is 250 mm long, leaving 50 mm on each side to the ends when the pile is in centre (neutral) position.

In the middle of this center piece a 15 mm wide and 100 mm tall "lid" (4) is cut out form the pile wall. This "lid" fits snugly in the pile perimeter and rests on two stiff commercially made miniature force transducers (6). The edge of the lid is sealed off with silicon rubber adhesive to prevent water from "penetrating" into the pile. In this way the total pressure on the pile wall can be measured by summing the forces from the two load transucers and dividing by the area of the lid.
To prevent the lid from moving in axial direction it is hooked up to two slender axially oriented bolts.

In the center of the total pressure cell ("lid") a 10 mm diameter porous stone filter (5) is placed, connecting on the inside of the pile to a sarane tube and up to an external pressure transducer. The outside perimeter of the model pile is smooth and shows only minor signs of the relatively heavy instrumentation contained inside.

The model pile is hollow, with the cables from the transducers coming out near the top of the pile. The tip is closed ended with a 60 cone. During insertion of the pile a "cone resistance value" is measured by the lower axial cell when this level enters the clay.

In the tip a drain hole is made. This hole is plugged with a screw during insertion. After insertion of the pile, when the tip is located below the bottom plate this plug is unscrewed and a sarane tube connected to room temperature pressured air is hooked up to the drain hole. In this way an attempt is made to prevent moisture to build up inside the pile and thus helps maintain the stability of the strain gauges and transducers inside.

2.6 Instrumentation

A sketch of the test set up with indication of the instrumentation and data acquisition system is shown in figure 2.4. The model pile test chamber is shown in the test frame with the pile in centre (neutral) position connected to the hydraulic acutator.

The axial load transducers in the pile are in-house made strain gauge based sensors and are calibrated to show converted shear stress along the pile directly. A differentior to show the difference between the two levels is built and is led into the control unit allowing for load controlled testing.

The transducers to measure total pressure are commercially made miniature load cells. They have a capacity of 2.5 KN and are very stiff with a maximum deflection of about 0.01 mm. The lid that rests on these load cells onto which the total pressure acts is sealed with a silicone rubber adhesive. This acts like a pad and is primarily to prevent water from entering the interior of the the pile and also helps keep the lid in place. Calibration of the total pressure cell is done in a pressure chamber filled with water which also gives a check of the water tightness of the rubber sealant. Pressure tests of this kind have shown the total pressure transducer to be linear within the range 300 kPa to about 800 kPa with minimal hysteresis. For lower pressures than those indicated the transducer shows nonlinear effects, although zero drift is minimal. When pressure exceeds 800 kPa nonlinerity results probably due to hardening of the rubber sealant leading to a transfer of load out to the rubber which affects the reading on the load cells.

Schematically the total pressure transducer has the configuration of a simply supported beam with the load transducers acting as supports. Since the total pressure over the measured area is constant the readings from the two sensors should be equal. This fact is true as long as the pile is held steady, but as the pile is loaded, and thereby moving, the friction along the pile shaft (shear force) seems to excert a moment on the lid, resulting in a small change in the two load cell readings.

Measurements when the pile is loaded upwards, have shown the reading of the lower sensor to increase and the upper to decrease which should confirm this assumption. The total pressure is thus taken as the average between the two readings.

Pore pressure at the pile shaft is measured through a porous stone filter on the total pressure cell lid. A sarane tube leads into this filter and up through the pile to a pore pressure transducer fastened to the top of the pile. When the filter is fully saturated the pore pressure measurement system shows prompt response in the afore mentioned pressure chamber, used for calibration.

A calibration and check of the transducers contained in the model pile is performed before each test and these values are checked against zero readings and calibration when a test is completed and the pile is extruded from the model test chamber.

The load on the pile is exerted on top by a load or stroke controlled hydraulic acturator. An MTS control unit with a function generator and hydraulic pressure control is used to perform the tests in a controlled fashion. This facilitates a wide variety of tests to be performed including static tests, creep tests and cyclic tests. The displacement of the pile is measured by a LVDT hooked up to the top of the actuator.

Since the center of the soil mass is free to deform with the pile by the center bearing, a LVDT is also mounted on top of the model pile test chamber connecting to center bearing. In this way a measure of the relative movement between soil and pile is available, since the LVDT on the acutuator measures the total displacement of the pile and soil.

A pneumatic compressor with connecting differential valves and manometers facilitates and maintains the confining pressures and the back pressure at the prescribed level. The back pressure system is also hooked up to a volume change transducer so that water going into or out of the clay specimen can be monitored.

2.7 Data Recording

During pile load tests periodic readings are recorded from eight separate sensors using an eight channel pulse code modulator (PCM) onto a PCM compatible tape recorder.

These eight channels consists of:

- Lower axial load transducer in pile
- Upper axial load transducer in pile

- Lower load sensor in total pressure cell
- Upper load sensor in total pressure cell
- Pore pressure at pile soil interface
- Displacement of model pile
- Time
- ID number (for reference)

The confining pressures and back pressure on the sample are held constant during a test and are therefore not monitored. Manual readings of water going into or out of the clay sample are made.

In addition to the periodic recordings on tape continuous readings of normal pressure (from one of the load sensors of the total pressure transducer), pore pressure, pile displacement and transferred shear stress along pile shaft (difference between the two axial load sensors) are recorded on a four track strip chart recorder giving continuous readings of the respective quantities versus time.

Also a x-y plotter is used to plot two of these variables against each other which usually are shear stress versus pile displacement. This gives a direct visual description of the test progress and provides a good aid in the decision making for further or prolonged testing.

2.8 Data Analysis System

In order to transform the results recorded on the tape into a comprehensible and consistent format a data analysis program has been made. The data aquisition system used for monitoring of the tests is basically the same as the existing system used for cyclic triaxial testing and the program devloped for the pile model tests is therefore a modification of this program.

Data from one pile model test is recorded on tape in the laboratory. These are replayed through a PCM demodulator, digitized and subsequently stored on magnetic tape. The different channels are then separated and calibration factors are applied to the measured voltages to resume the actual physical quantities measured using a sorting routine, and stored on intermediate files. A processing program then treats the data so it can be presented in a tabular or graphical form.

Different alternatives for presenting the results in graphical form consists of the following:

- skin friction versus pile deflection for up to 5 different cycle numbers on one plot

- skin friction versus total or effective normal pressure for up to 5 given cycle numbers

- variation of skin friction, pore pressure and total normal pressure during a cycle.

- Maximum, minimum and mean skin friction, pile deflection, pore pressure or normal pressure versus cycle numbers

Only cyclic tests are analysed using the data analysis program. Static tests and creep tests are also recorded on tape, but for back up purposes. These tests are monitored continuously on the x-y plotter and the strip chart recorder together with manual readings from the digital readout of the transducer conditioner.

Examples of processed results from initial tests of the pile model equipment using Drammen Clay are shown in the following section.

2.9 Initial Tests with Drammen Clay

Trial tests of the model pile equipment and test procedures were performed using clay samples from Drammen, Norway. This type of clay is well documented in the geotechnical literature and a typical soil profile is shown in figure 2.5. The test described below was mainly used to check the equipment and test procedures and the results and duration for various parts of the test might differ from the tests performed with the West Delta clay.

The clay was remoulded using the large commercial mixer to a uniform consistency for about 10 minutes and measurements of remoulded strength showed 2 KPa using a laboratory fall cone penetrometer. The remoulded clay was built into the oedometer and left to consolidate at a pressure of 300 KPa for three weeks. After 12 days the settlement was about 20% and the excess pore pressure 15 KPa, reducing down to about 10 KPa over the next ten days. Original height of remoulded clay in the oedometer was 580 mm and final height after three weeks of consolidation was 445 mm resulting in 23% deformation.

The water content of the remoulded clay before consolidation was 49% and after consolidation 29.5%. Shear strength measurements from pocket penetrometer and unconfined compression tests gave fairly consistent values over the cross section of the consolidated specimen at about 80 KPa.

The consolidated sample was then transferred to the model test chamber and confining pressures were applied resembling previous consolidation pressure. Vertical pressure was set to 300 KPa and radial pressure to 180 KPa assuming a K_o value of 0.6. The sample was then left to reconsolidate for three days before the pile was installed. A period of ten days was allowed for set up with monitoring of total pressure and pore pressure on the pile wall as shown in figure 2.6. The back pressure was left at zero and the total and pore pressure is seen to show steady state at about 200 KPa and 80 KPa respectively after about one day.

A static test was first performed on the pile by pulling the pile with speed 0.2 mm/min. Figure 2.7 shows a plot of transferred shear stress along pile shaft versus pile deformation. A peak in transferred shear stress of 80 KPa is seen at a pile deformation of about 0.7 mm reducing to a residual value of 70 KPa for larger deformations. Upon reversal of pile movement a similar peak is seen on the "compression" side with the same residual value. The plot shown in figure 2.7 is a direct trace from the x-y plot produced during the test.

Subsequently, after a four hour rest period, a stress controlled cyclic test was performed, cycling about 1/3 of the tensile static capacity found earlier in "packages" of 100 cycles with a period of 10 seconds per cycle. Each cyclic package consisted of 100 cycles starting with an amplitude of 1/3 of the permanent stress and increasing successively with an additional third after one hundred cycles until failure occured. Figure 2.8 show the results of the applied shear stress versus pile displacement plotted on the x-y recorder. As can be seen from this no serious deformation results from the low amplitude cycling for the number of cycles tested. As the shear stress reaches the static capacity (cycles 601 etc.) the maximum capacity is reached and excessive deformation of the pile results.

Processing of the data recorded on tape from this test can give additional information as can be seen in figures 2.9 through 2.13. The skin friction (transferred shear stress) and deflection is plotted versus cycle numbers in figure 2.9 and 2.10 respectively. In figure 2.11 a plot of total normal pressure against the pile wall versus cycle number is shown. This plot is from one of the transducers in the total pressure cell which describes the relatively large variation in total pressure during one cycle, as described in chapter 2.6. The mean total pressure, however, gives a good indication of the variation in total pressure versus number of cycles. As can be seen from figure 2.11 this pressure tends to decrease with increasing cycle numbers and increasing shear stress level along the pile. Due to problems with the recording of this test the data showing failure was not obtainable, so that only 400 cycles was available.

A similar plot of pore pressure versus cycle numbers is also available.

In case the development of pore pressure, total pressure and skin frictin during one cycle is of interest, a plot like the one shown in figure 2.12 is available. Here, also the total pressure shown is from one transducer in the total pressure cell which describes the large cyclic behaviour.

As a final example of plots from the data analysis program a plot of total skin friction versus total pile deflection for one cycle is shown in figure 2.13. Total values here refers to the actual values during the test refering to the neutral position of the pile before the cyclic test started, keeping in mind that this is a shear stress (skin friction) controlled test cycling about a permanent stress of about 25 KPa.

A two way cyclic deformation controlled test was then performed with a period of 10 seconds. The results from this is shown in figure 2.14 where transferred shear stress is plotted against pile deflection. The pile was cycled 50 times about neutral position with amplitude 0.3 mm. As was expected the shear stress was largest for the first cycle and then dropping about 20% after four cycles to a relatively constant level over the remaining cycles. The pile was then brought to neutral position and allowed 30 minutes rest before a new 50 cycle test was run with a double amplitude. The resulting shear stress was now somewhat higher for the first cycle which is believed to be due to the increased strain rate since the cycling period is kept the same (10 sec.) as for the former best. But also here the resulting shear stress dropped about 20% after 3 to 4 cycles with no further loss during the remaining 46 cycles.

2.10 Conclusions

The pile model test equipment has been described in the previous chapters together with testing procedures and preparation of clay samples. Preparation of one sample and transfer to the pile model tank takes about two weeks. Additional time for consolidation and pore pressure response (saturation of sample) is allowed after pile is installed in the clay. Duration for actual pile testing with data monitoring is dependent on type of test but is usually performed in one or two days.

Example of results from initial tests of the equipment using Drammen clay indicates successful performance of the equipment and analysis and processing tools. It must be noted, however, that the pore pressure response at the pile wall is much slower than could be expected. The reason for this is not readily understood but is thought to be due to the large volume of the clay sample in the model tank. This large volume allows for accumulation of fine air pockets in the soil structure introduced during the remolding process. During consolidation the main part of air should be expelled and the set up time allowed after installation of the pile in the model tank together with application of back pressure in the sample should help optimize the degree of saturation. Even so, the accumulation and dissipation of excess pore pressure shows a slow response after pile installation.

The transducer measuring transferred shear stress along the pile shows steady values with minimal drift over time and proves to be reliable for load (shear stress) controlled testing. Total pressure measurements indicate good correspondence with anticipated pressures and show good response upon pressure variations. Some problems with sealing of the "lid" have occurred, however, this is closely checked after each test, and sealing is replaced whenever signs of leakage occurs.

It is therefore believed that the equipment described herein will successfully help to give improved insight into the shear transfer mechanism for cyclically loaded piles by measurements of shear transfer, total pressure and pore pressure at the pile shaft, thereby allowing for an effective stress conceptual evaluation of the shear transfer process.

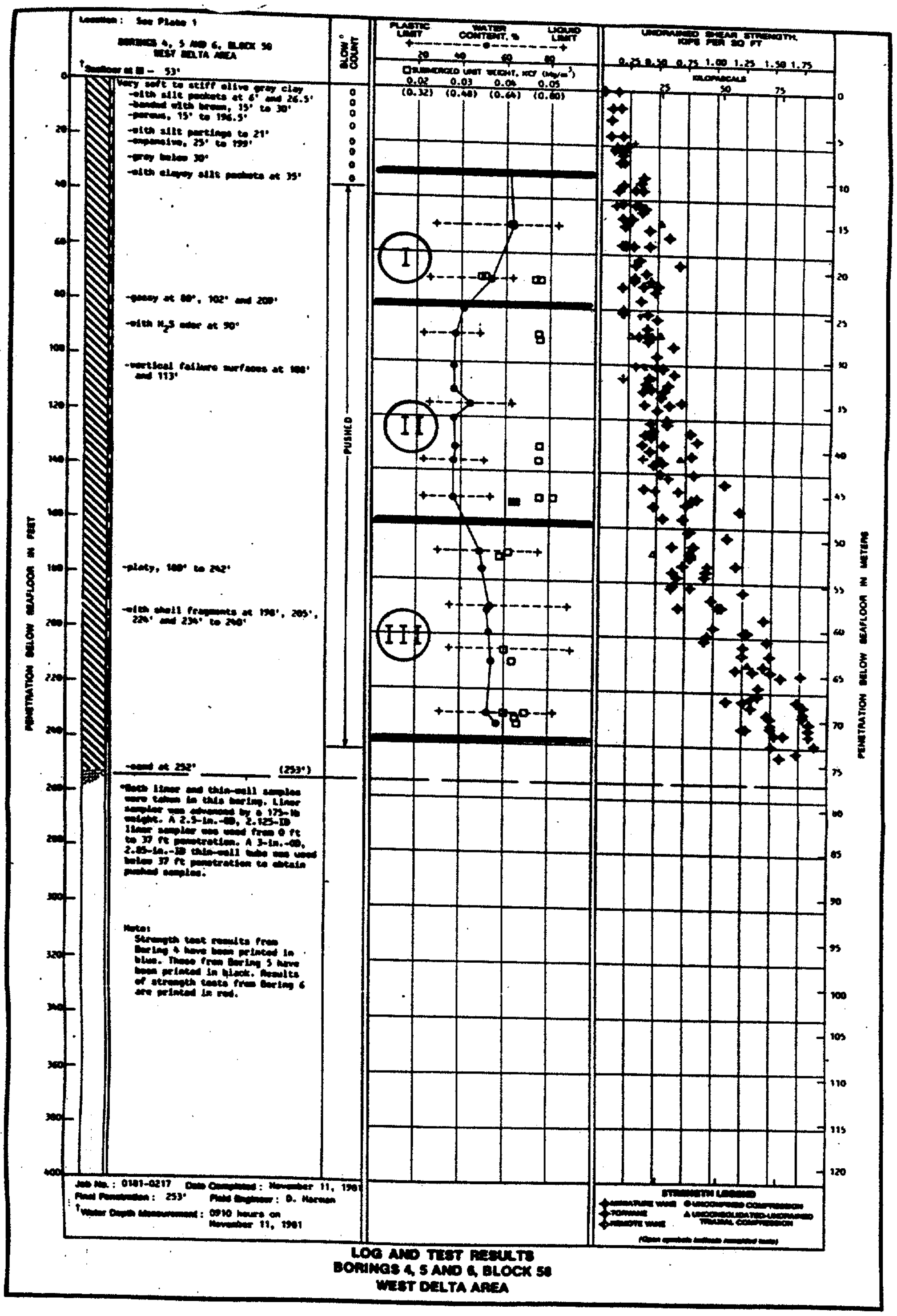
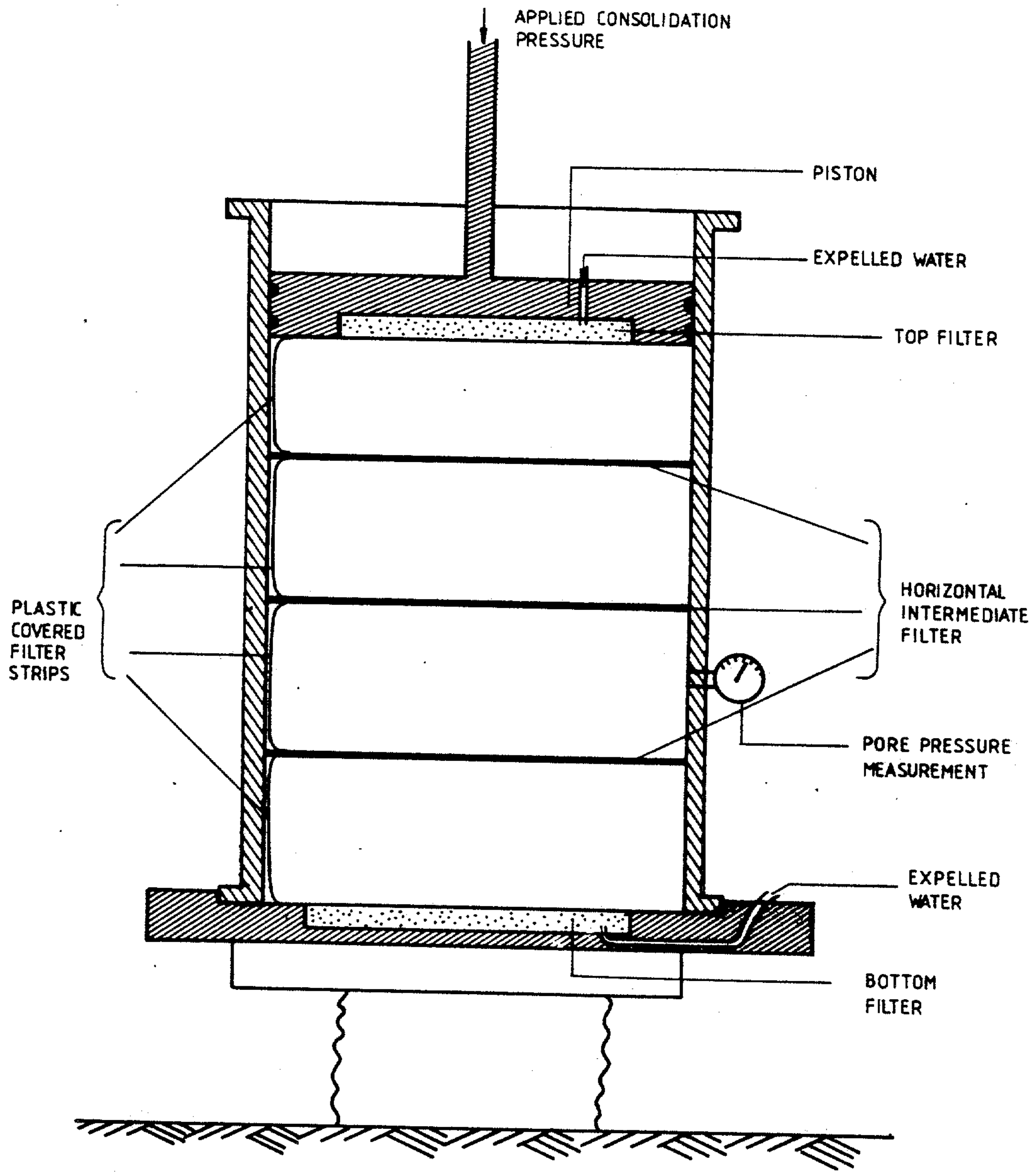
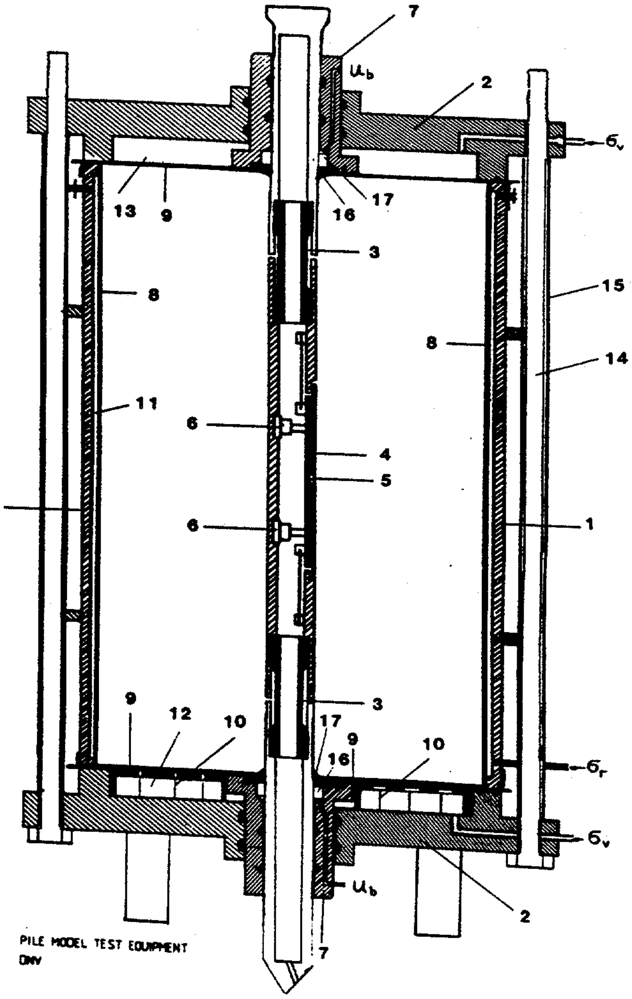


Figure 2.1 - Soil Profile for West Delta Block 58 with indication of the three distict strata

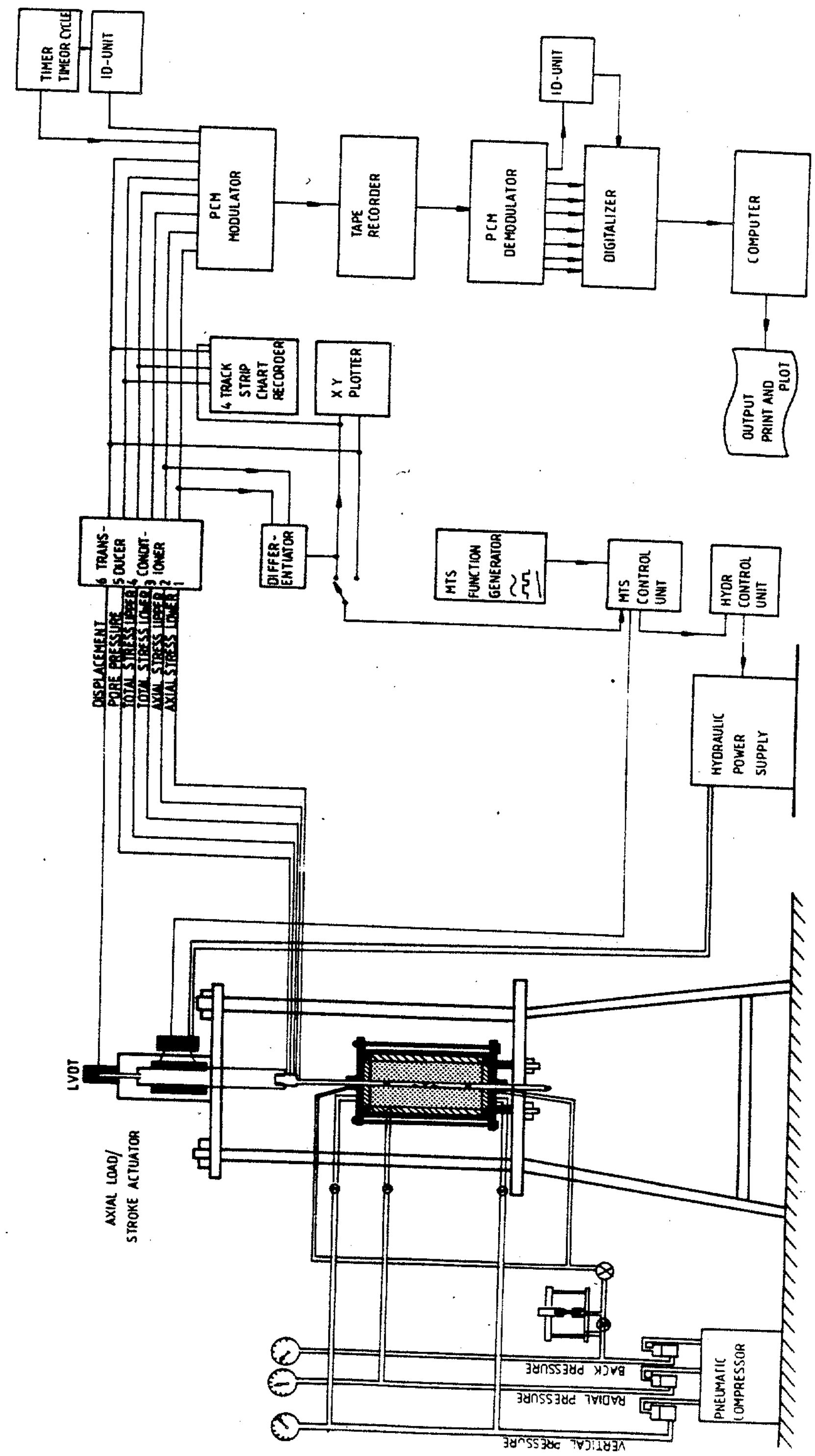


CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Oedometer to produce 200 mm dia. clay samples	Scale
DET NORSKE VERITAS Geotechnical Laboratory — Drawn by ETlh — Approved [signature]	Date
	Fig.No. 2.2

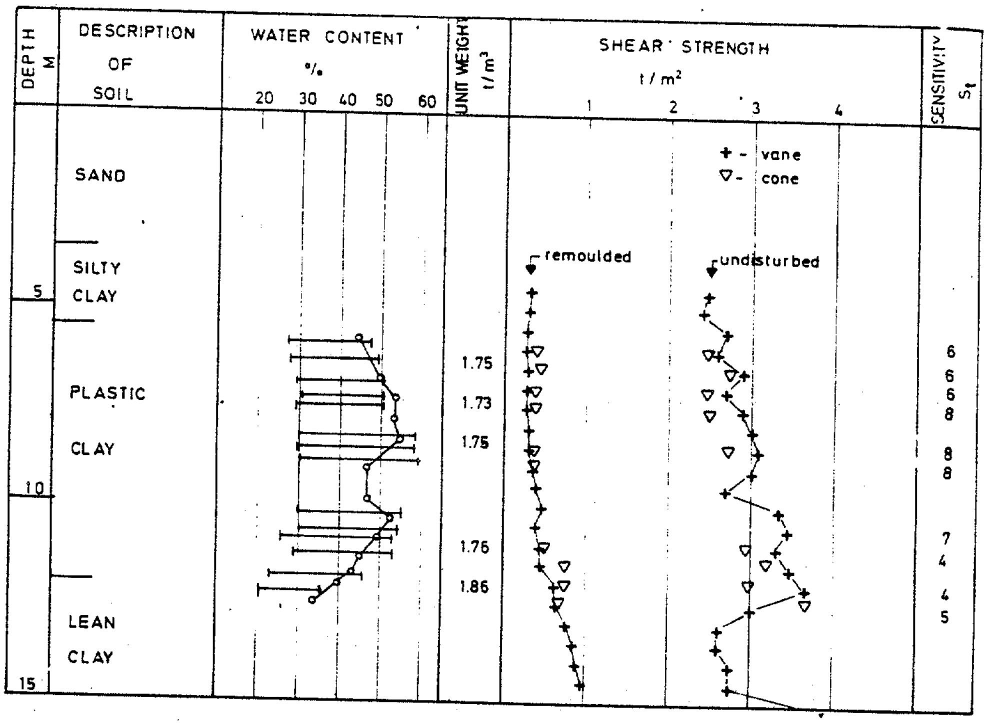


1 - Confining Cylinder
2 - Top and Bottom Plate (Identical)
3 - Axial Load Transdusers for skin friction measurement
4 - Total Pressure Cell
5 - Porous Stone Filter
6 - Load Cells for total pressure measurement
7 - Top and Bottom Center Bearing sealed with rubber "o-rings"
8 - Axially Reinforced Rubber Membrane for application of radial confining pressure
9 - Circular Rubber Membranes for application of vertical confining pressure
10 - Perforated Base Plate
11 - Radial Pressure Chamber
12 - Bottom Pressure Chamber
13 - Top Pressure Chamber
14 - Lock Bolt
15 - Guide Cylinder
16 - Back Pressure Chamber
17 - Hard Rubber Seal

CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Pile Model Test Chamber with Model Pile	Scale 1:4
DET NORSKE VERITAS Geotechnical Laboratory — Drawn by ETIh — Approved KHau	Date
	Fig.No. 2.3



CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Test Set-up with indication if Instrumentation and data aquisition system	
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by ETlh Approved KHau Fig.No. 2.4



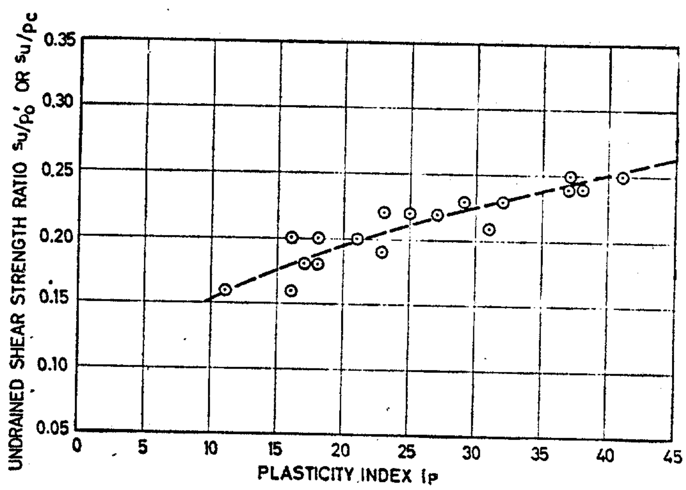
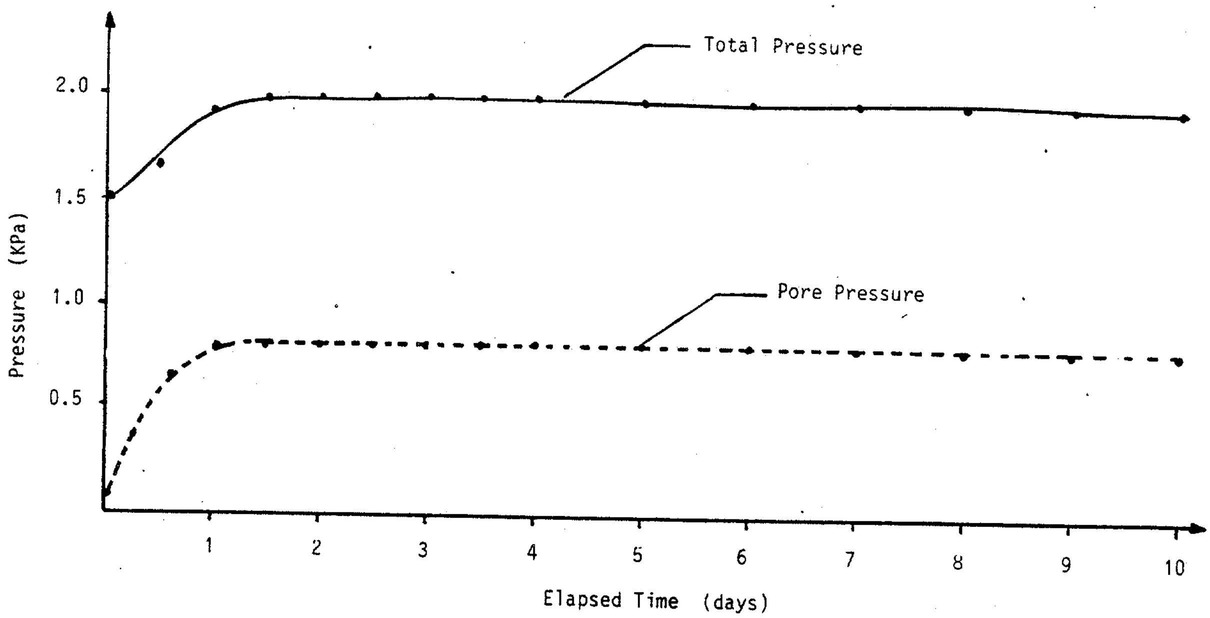
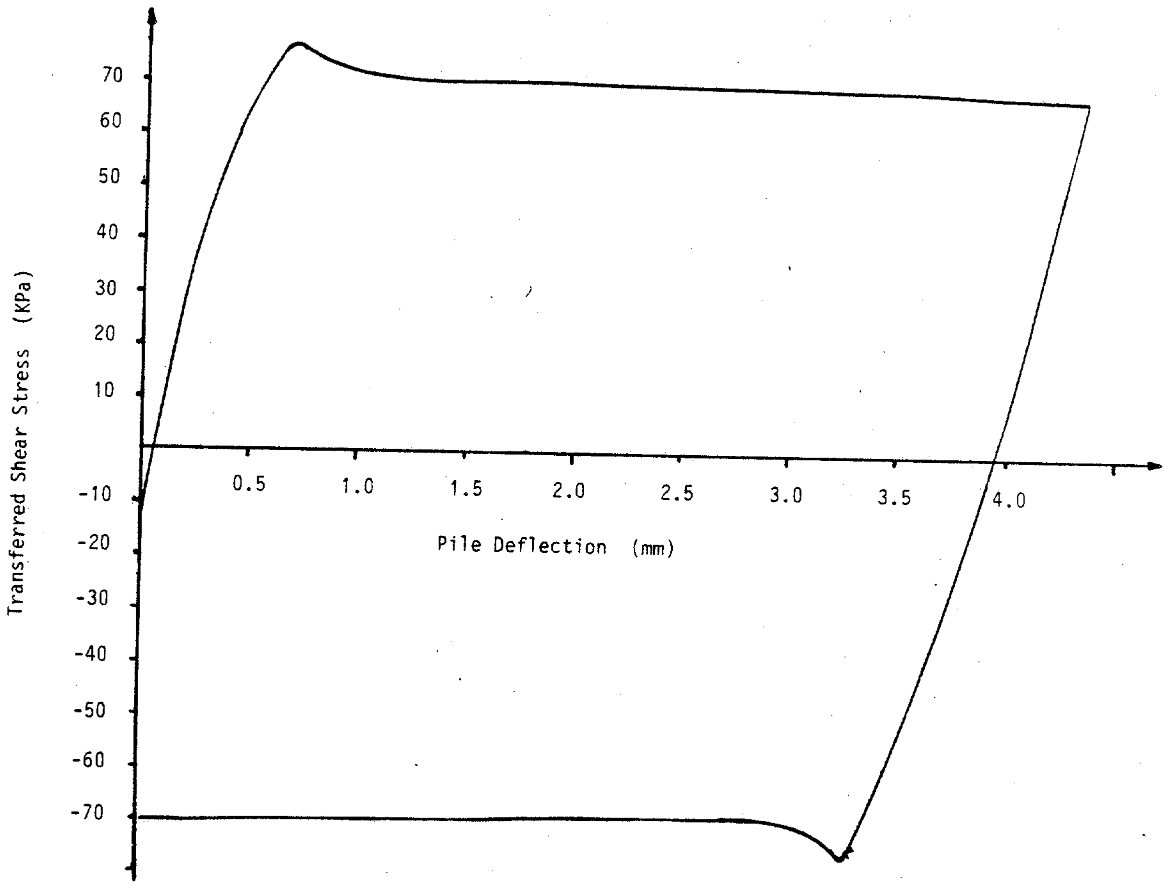


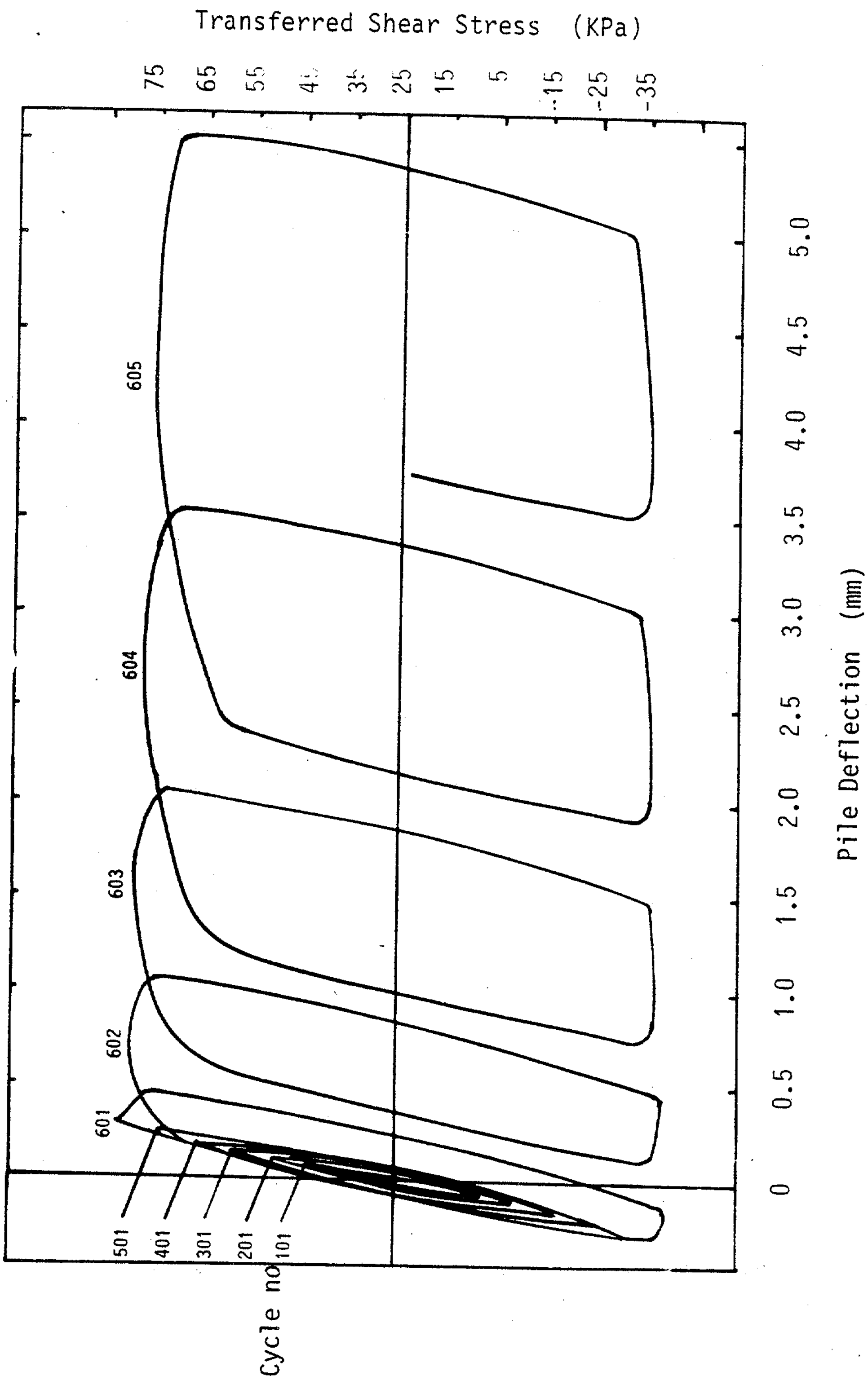
Figure 2.5 - Geotechnical profile through a normally consolidated clay in Drammen. (From Ref. 2)



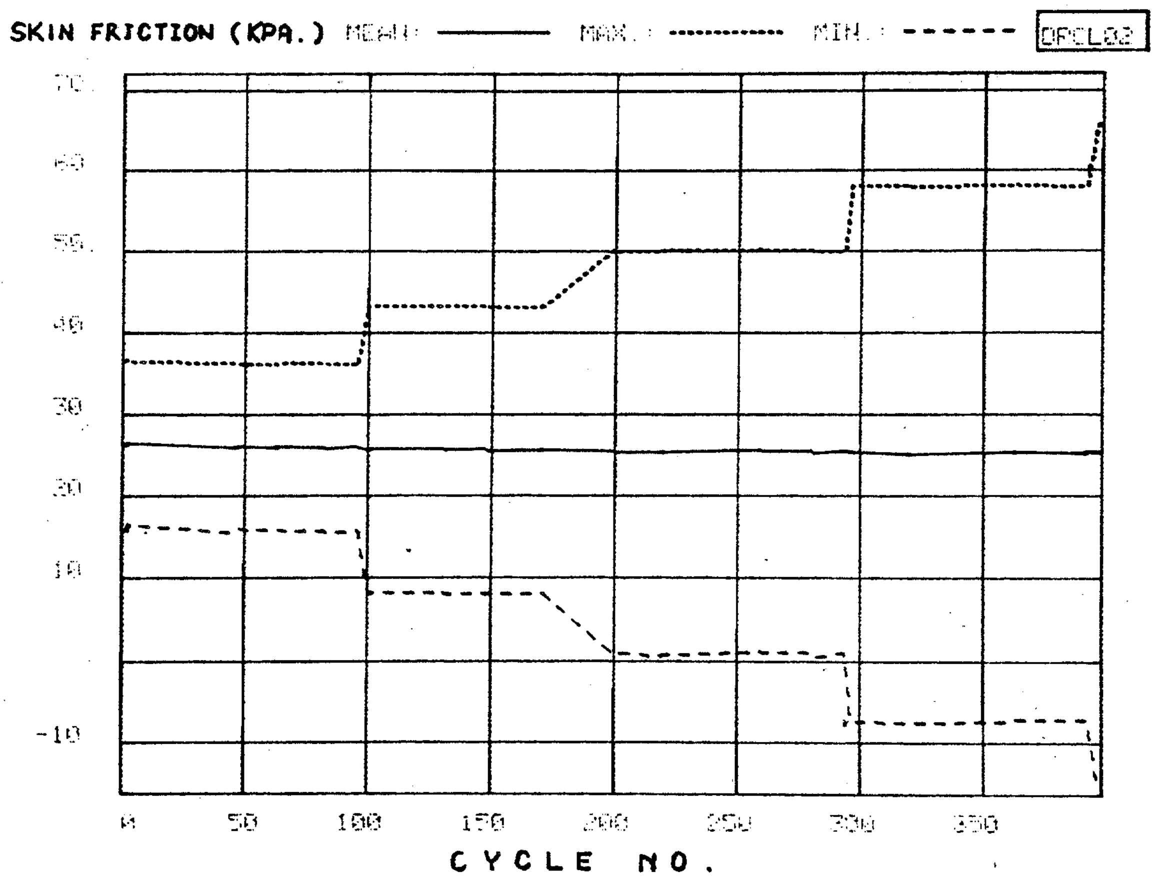
CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Pressures at pile wall after pile installation	Scale
DET NORSKE VERITAS Geotechnical Laboratory — Drawn by / Approved KHau	Date / Fig.No. 2.6



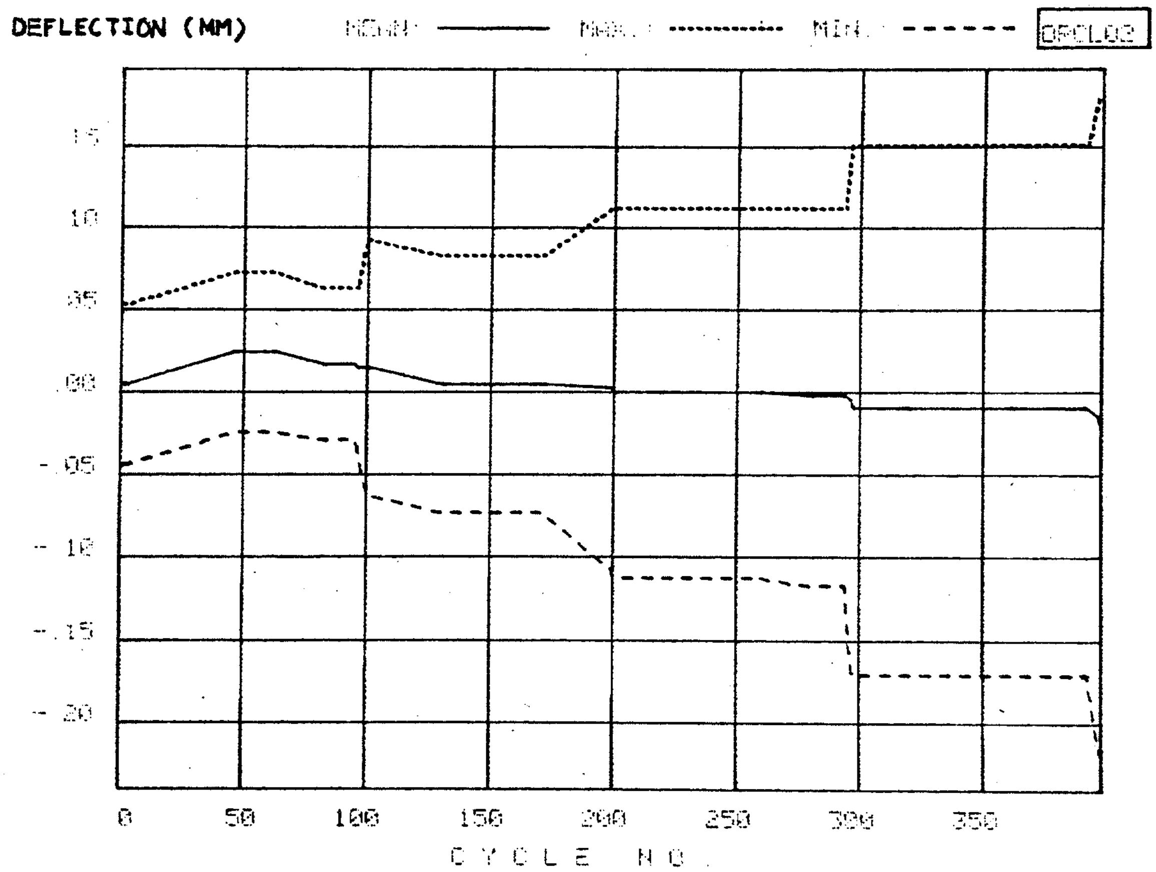
CNRD 13-2 TENSION PILE STUDY		Proj.No. 231004
Static Pile Test		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved KHau	Fig.No. 2.7



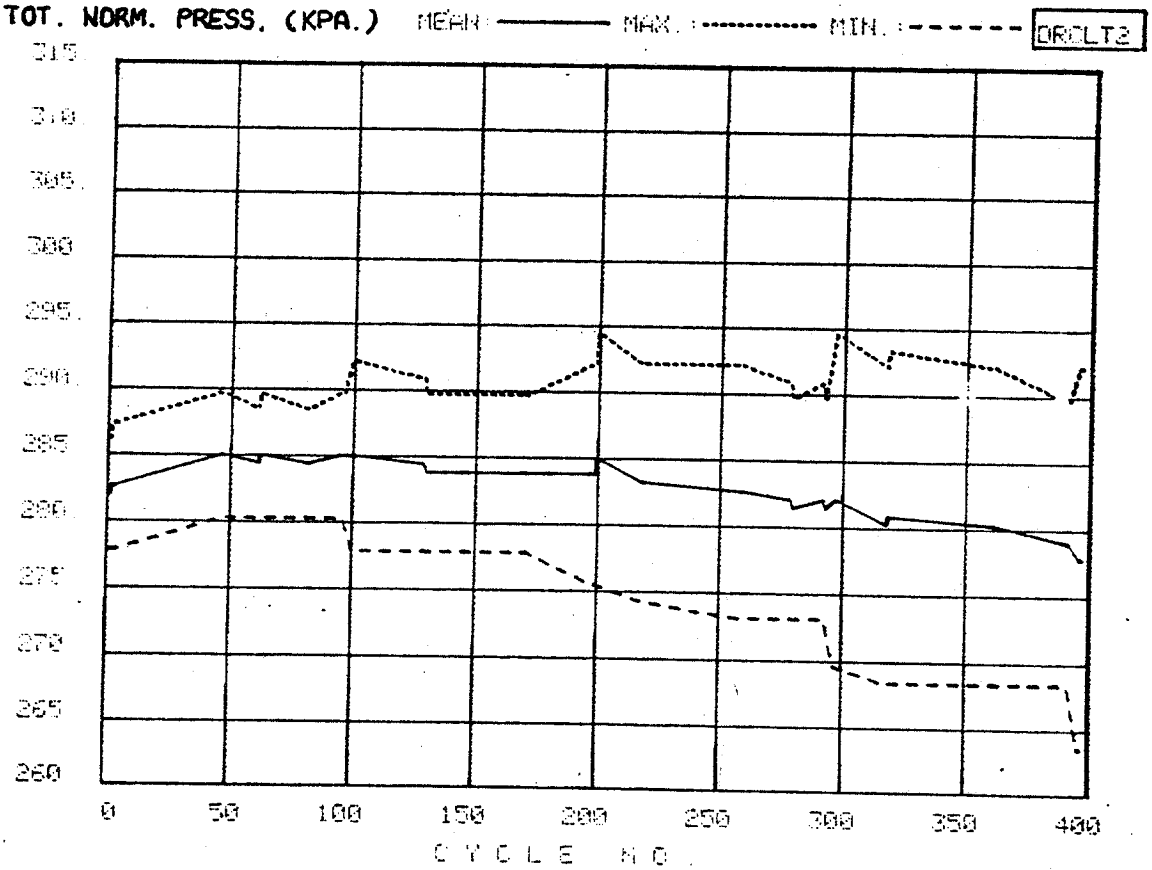
CNRD 13-2 TENSION PILE STUDY		Proj.No. 231004
Cyclic Pile Test; Stress Controlled		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 2.8



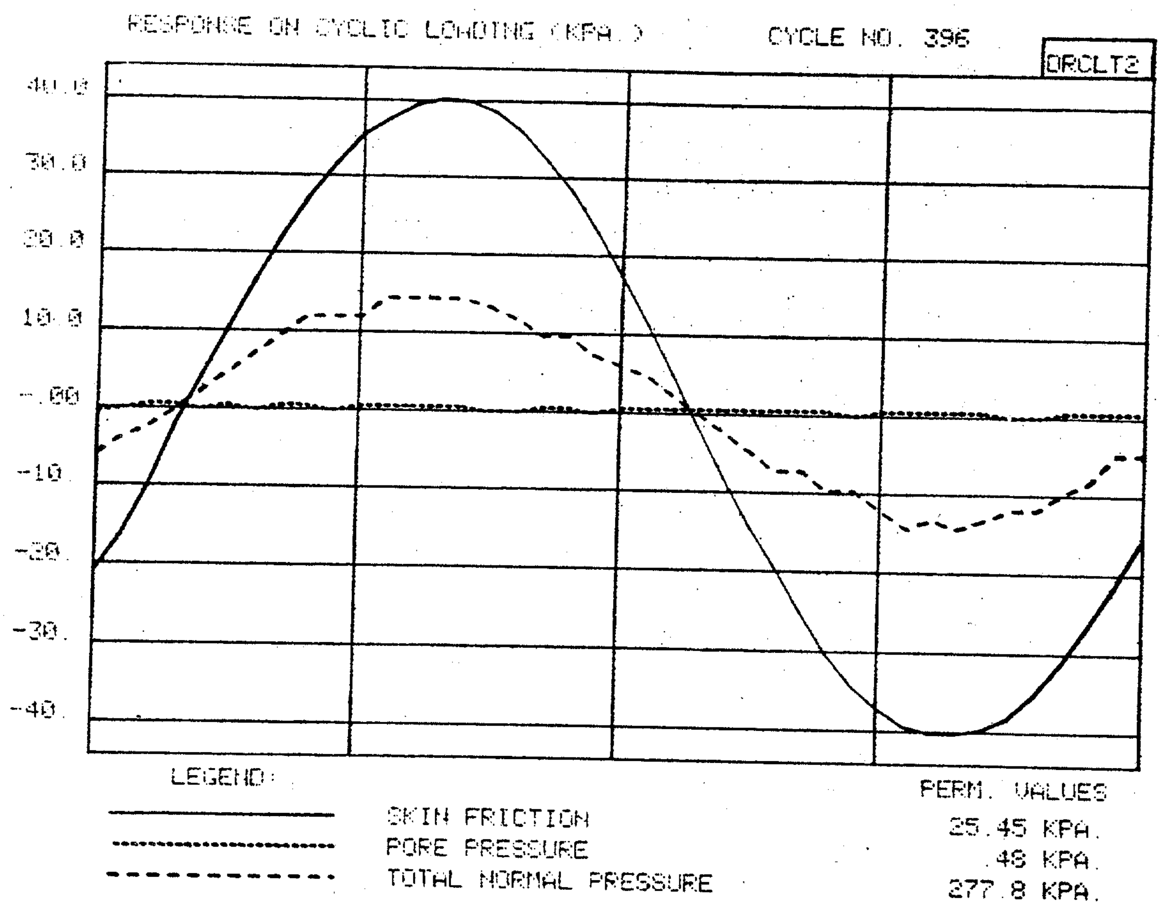
CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Cyclic Pile Test; Stress Controlled	Scale
DET NORSKE VERITAS Geotechnical Laboratory — Drawn by / Approved	Date
	Fig.No. 2.9



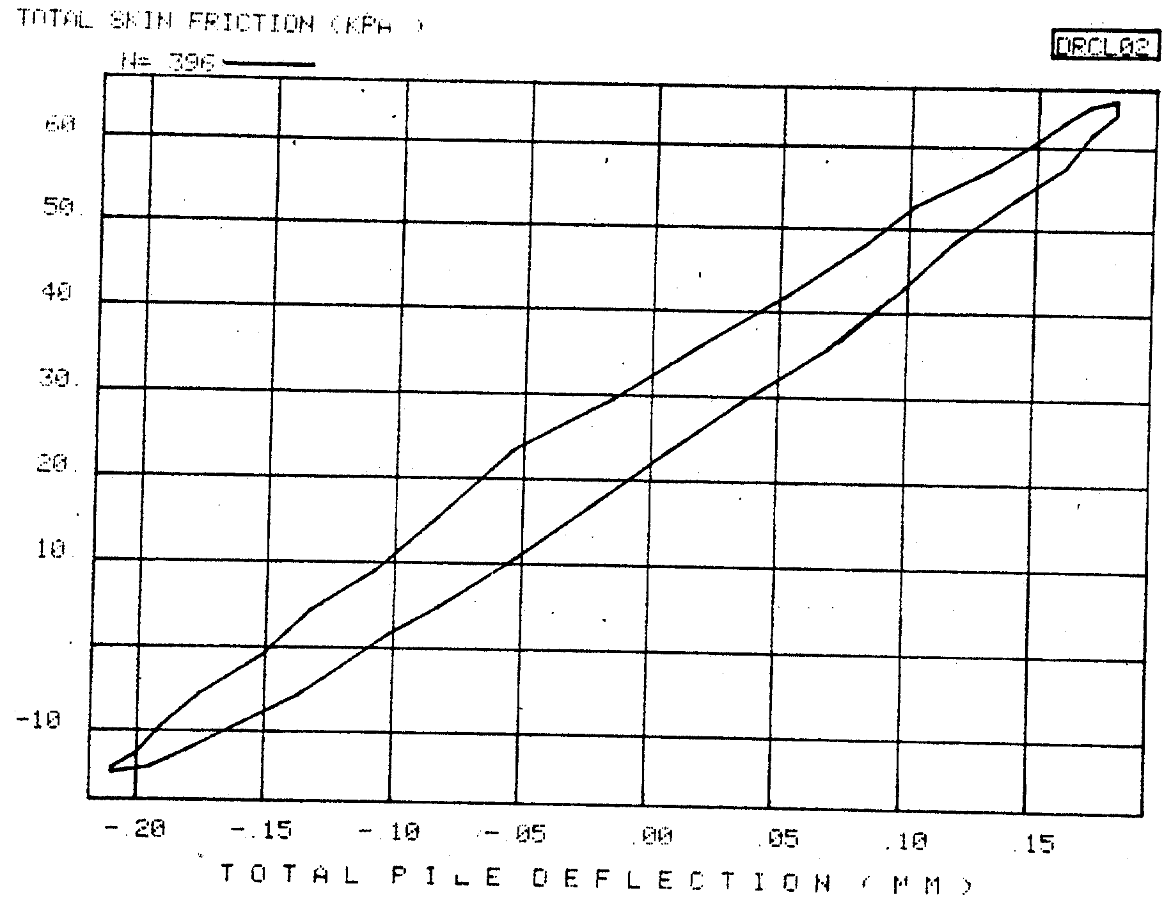
CNRD 13-2 TENSION PILE STUDY		Proj.No. 231004
Cyclic Pile Test; Stress Controlled		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved *(signature)*	Fig.No. 2.10



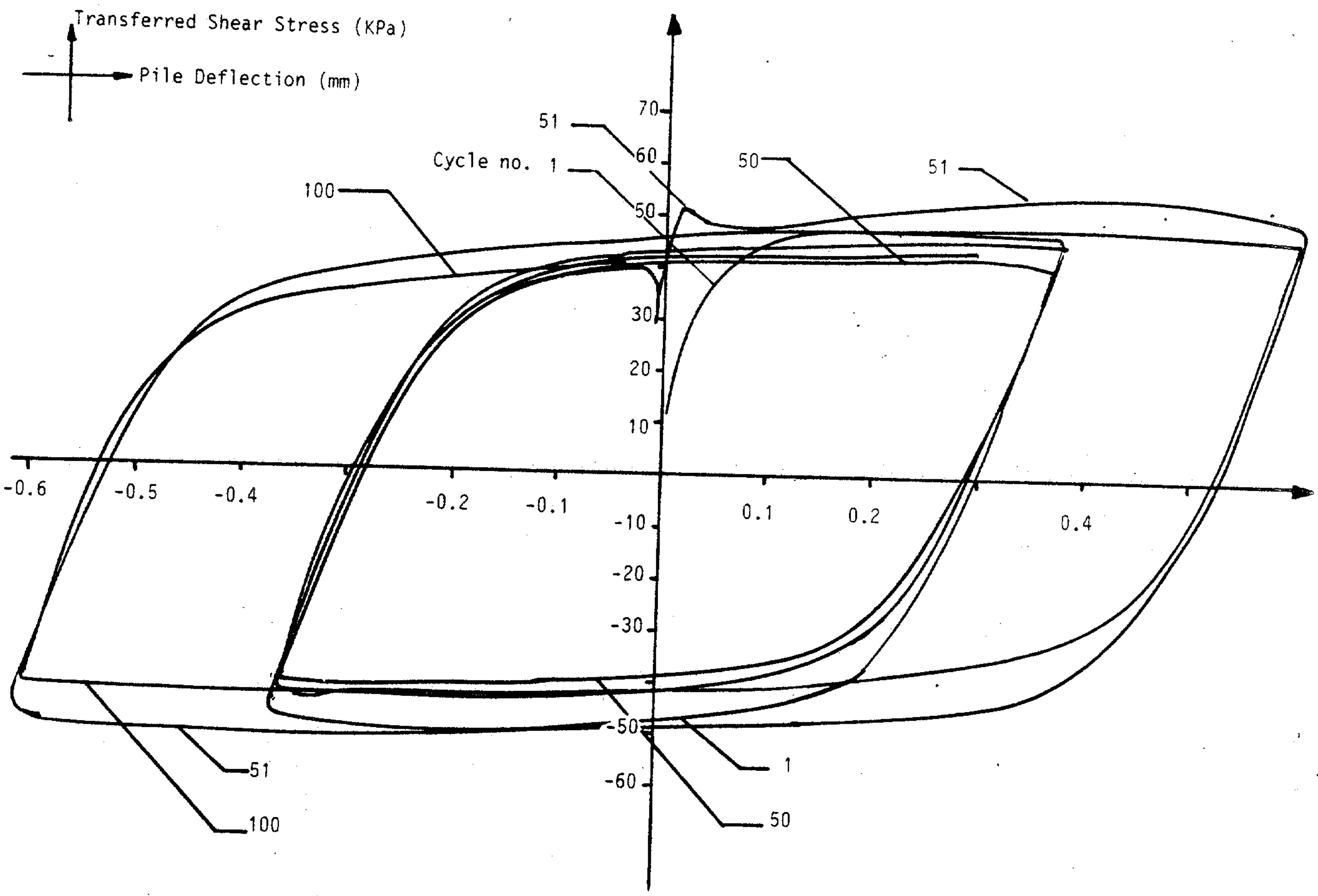
CNRD 13-2 TENSION PILE STUDY		Proj.No. 231004
Cyclic Pile Test; Stress Controlled		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved KHau	Fig.No. 2.11



CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Cyclic Pile Test; Stress Controlled	Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by
	Date
	Approved KHau
	Fig.No. 2.12



CNRD 13-2 TENSION PILE STUDY	Proj.No. 231004
Cyclic Pile Test; Stress Controlled	Scale
DET NORSKE VERITAS Geotechnical Laboratory | Drawn by	Date
Approved KHau	Fig.No. 2.13



CNRD 13-2 TENSION PILE STUDY		Proj.No. 231004
Cyclic Pile Test; Displacement Controlled		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved KHan	Fig.No. 2.14