Det norske Veritas

TECHNICAL NOTE

Grading:

- ☐ No distribution without permission from section
- ☐ Open distribution within Veritas
- ☐ Open distribution

Note no.: Div./sect.no.-year-no.	Date:
FDIV/23-82-02	19.7.82

Distributed by: T. J. Kvalstad/ Sign.:

Title:

SUBPROJECT CNRD 13-2
TENSION PILE STUDY

Comments to Segment Test Program.

Distribution:

Ron Gratz	Conoco Norway
Jack H.C. Chan	Conoco PES
Jeff Mueller	Conoco PRD
Tom Hamilton	Ertec, Inc.
Fritz Nowacki	NGI
Lars Grande	NTH

Written by:

Tore J. Kvalstad

Summary:

This technical note presents some comments to and proposals for the planned segment test program to be performed at the West Delta, Block 58, CACG Platform in the Gulf of Mexico in the second half of August and the beginning of September 1982.

The comments are based on Veritas' theoretical work, the experience from the first part of the laboratory model pile test program as well as discussions with NTH and NGI on this matter.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The basis for the following comments and proposals for segment pile test program has been based on the description of the segment device and test program given in Ertec's Final Report for the Planning Study (CNRD 13-1). Further we have had discussions with NTH and NGI on this matter where preliminary test results from the first part of the laboratory model test program have been included, together with the analytical and numerical evaluation of the stress distribution along a typical tension pile as well as the estimated load displacement behaviour of the segment device.

The objective of the segment test is mainly to provide data about the load-displacement behaviour under various loading conditions as well as data about the skin friction related to the undrained shear strength and to the effective overburden pressure. Further an improved understanding of the development of pore water pressure and normal stress due to pile insertion and the following reconsolidation (set-up) is aimed at.

The test program should be carried out in a way that allows the best possible predictions for the planned large scale pile test and even though a general understanding is aimed at, the typical load or stress conditions as experienced by a long slender pile subjected to TLP loading should be the main objective for the investigation.

2. DEFINITION OF LOADING CONDITIONS

Based on the yet limited data about the loads transferred to a tension pile serving as an anchor for a TLP, we have carried out the first part of a parameter study on factors influencing the shear stress distribution along a tension pile of the same length, diameter and stiffness as for the planned large scale test.

Analysis method

The DRIVE 15 program developed by ERTEC has been used for this parametric study so far.

T-z curves

The pile has been represented by 20 elements connected to bilinear (close to ideal elasto-plastic) springs. The spring displacement at which failure occurs has been set to 1% and 2% of the pile diameter.

Skin Friction

The skin friction has been assumed equal to the API curve presented in Ertec's Volume I report on Plate 31 which is equal to the interpreted shear strength of the clay, i.e. an alpha-value of 1.0.

Degradation

An evaluation of the effect of degradation of the skin friction was carried out assuming a maximum degradation of 30% and a relatively strong degree of degradation per cycle, using the degradation model of the DRIVE 15 program.

Loading conditions

The pile was assumed to be subjected to a static load of 33% of the capacity. Three different analyses were carried out for the two different t-z curves of 1% and 2% failure displacements respectively as described below:

- Static loading to 33% of capacity followed by 10m cycles of + 33% load variation (i.e. load varying between 0 and 2/3 of the capacity and thus having a total safety factor of 1.5 as prescribed by API under the extreme load). The objective was to evaluate the effect and significance of degradation.

- Static loading to about 95% in compression, unloading to 0, loading to 33% of the capacity in tension and two-cycles of load with + 33% of the capacity to evaluate the significance of residual stresses on the distribution of skin friction down along the pile.

- Static loading to 33% of the capacity and then applying cycles with increasing amplitude +5%, + 10% ..., + 40% of the capacity to evaluate the

Preliminary conclusions drawn from the parametric evaluation

- Degradation takes place only in the upper 10 to 15 meters of the pile under loading conditions as applied. The effect of degradation is rather limited and for the performed calculations less than 5% reduction in axial capacity resulted from 10 cycles of the most extreme design load.

- The residual shear stress distribution after driving does not seem to have a great influence on the final distribution of shear stresses for a pile subjected to a relatively high (1/3) pretension and additional cyclic loading. See Figures 1a and 1b. The difference between the results of analyses with high residual stresses (close to failure in compression) and analyses with zero initial shear stresses damped out nearly completely when pretension and one cycle of high amplitude was applied.

- The stress distributions did not differ very much for the 1% and the 2% failure displacement cases.

- Along the upper third of the pile the soil will be subjected to two-way cyclic load variations which gradually changes to one-way cyclic loading of decreasing intensity towards the pile tip.

To Summarize: Strength degradation does not seem to be very significant for a long flexible pile, designed with a total safety factor of at least 1.5. Two-way cyclic loading dominates only in the top part when the skin friction is low and only a small part of the capacity will thus be influenced.

One-way cyclic loading with relatively high maximum stress levels may develop during storms down to the middle of the pile during moderate storms and to 2/3 of the pile length during extreme loads. "Creep" of the pile and stress redistributions which cannot be simulated with DRIVE 15 is to be expected and should be investigated as a part of the segment test program.

This last comment applies to the lower third of the pile as well, however, the load levels in this part is not thought to give rise to special problems.

3. EXPERIENCE FROM THE LABORATORY MODEL PILE TESTS

Static capacity

The static skin friction seems to be in the range of 0.5 to 0.6 times the undrained shear strength of the material. Interpretation on an effective stress basis is difficult and relatively large variations have been experienced so far. A beta - value of 0.1 is indicated.

Normal stress and pore pressure development

Large deviations from the cavity expansion theory has been experienced. However, pore pressure measurement device seems to have a too slow response to allow any conclusions to be drawn at present. In general we experience much lower normal stresses than expected.

Load-Displacement behaviour

The load-displacement curves seems to be well predicted by a simple single slice model with a hyperbolic stress-strain relationship for the clay.

Accumulated strains (cyclic creep) seems not to be a continuous process gradually increasing with increasing static and cyclic load level. Instead a very abrupt and sudden failure with "no warnings" have occurred at very high stress levels sometimes exceeding or at least being very close to the static capacity. Before failure takes place the hysterisis of the stress-strain curves is insignificant and even 100 cycles at more than 90% of the failure level seems not to cause "cyclic creep".

The degradation takes place rapidly during the first 10 to 20 cycles. Displacement controlled tests with 100 uniform cycles per parcel and gradually increasing cyclic displacement shows that the skin friction seems to stabilize at a level some 15 to 30 percent below the ultimate skin friction measured under cyclic loading.

Creep/Relaxation

Two spot checks of creep/relaxation have been performed. The creep test was conducted at approximately 75 percent of the measured static skin friction capacity over night. The displacement seemed to stabilize during the first hour and during the following 10 hours the additional creep was insignificant.

Relaxation was checked for some hours for one of the tests after the degradation test had been finished. The pile was loaded to failure in displacement control and then fixed. During the next hours, the load dropped significantly. However, in order to draw any conclusions from such results, more systematic testing is required.

4. RECOMMENDATIONS, COMMENTS TO THE SEGMENT PILE TEST PROGRAM

The test program described in the Final Report of the Planning Study seems to put much weight on the evaluation of degradation. Although we agree that this is an important factor we feel that more weight should be put on testing the pile segment for loading conditions more representative for a typical TLP anchor pile under working loads. This does not exclude the degradation testing which in our opinion seems to be a natural last part of the loading procedure for each segment test.

It is indeed difficult to optimize the testing program. Many factors may influence each other and to some extent partly mask effects which would or would not occur if the load history is changed; i.e. static testing to failure prior to cyclic loading and vice versa.

The two main points are nevertheless to:

a) be able to define the capacity of a tension pile under realistic loads.

b) be able to predict the short term and long term deformations, especially an eventual long-term gradual vertical movement due to a combination of a high static level and cyclic loading.

With the large scale test in mind it might be worthwhile to try to simulate the load/stress conditions expected to be applied during that test and then to vary the load program around a best estimate of these stress conditions. This should not preclude special investigations of a more general nature to be carried out in parallel and/or following this primary testing.

Figures 2 through 4 gives a good indication how a pile head load of 33% of the capacity followed by cyclic loading of varying intensity is transferred down the pile and into the soil.

Our proposal is to use at least, if possible, one of the series segment tests for a load controlled test program. At different depths a static load level is chosen and a series of uniform parcels with increasing shear stress is applied.

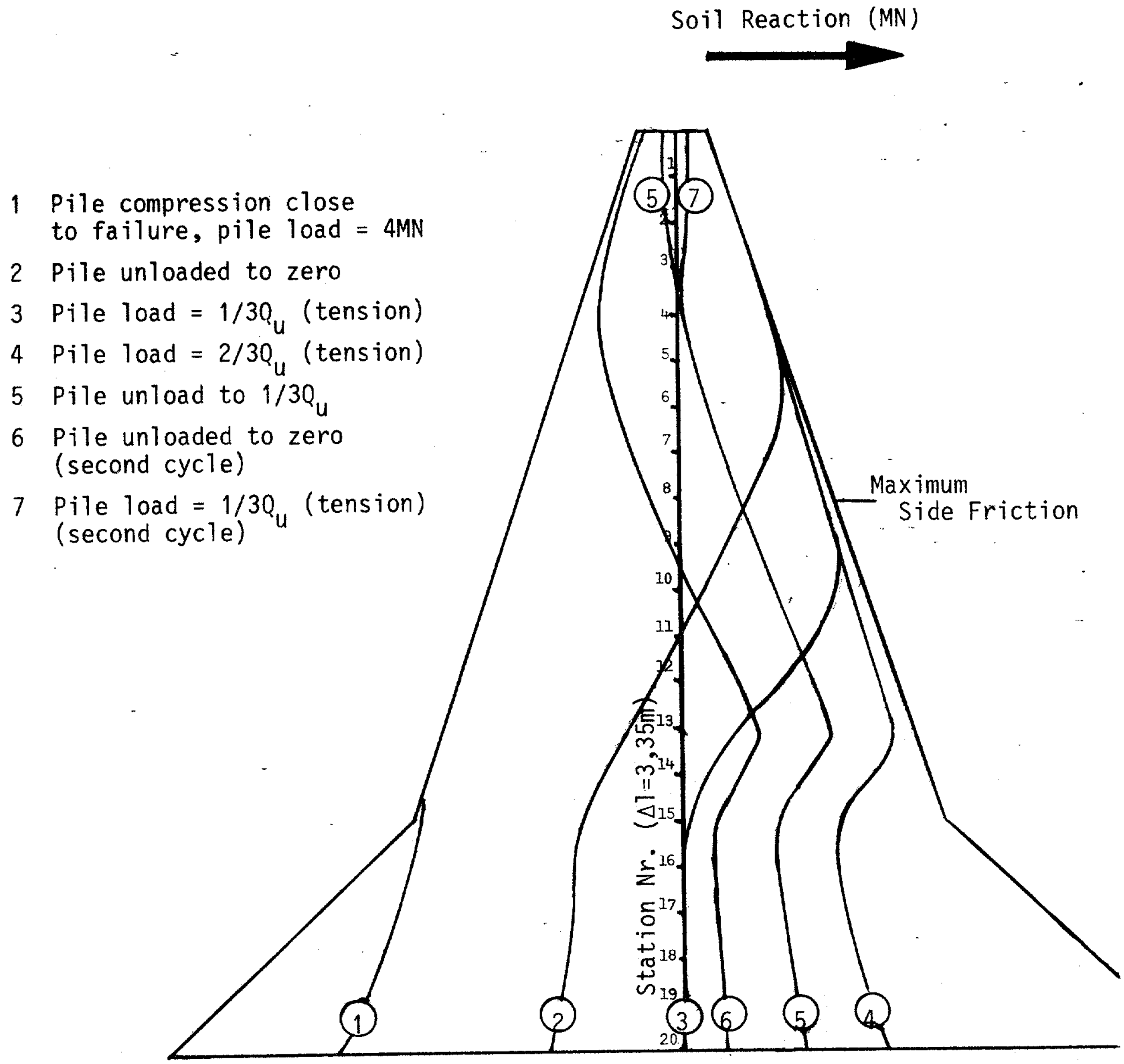
We have had comments from NGI and NTH on the effect of always carrying out a static test prior to the cyclic testing. It might be a good idea to determine the static capacity in one hole and based on this value choose the stress ranges for a cyclic test in the neighbour hole.

Reconsolidation under static loading (i.e. simulating pretension) is thought to have a positive effect on the capacity. This is at least the experience we have had on norwegian marine clays.

We are at the moment of writing not fully aware of the loading system to be applied. If a closed loop control is available displacement as well as load controlled testing could be carried out with a high degree of accuracy. This would probably be required for creep and relaxation testing.

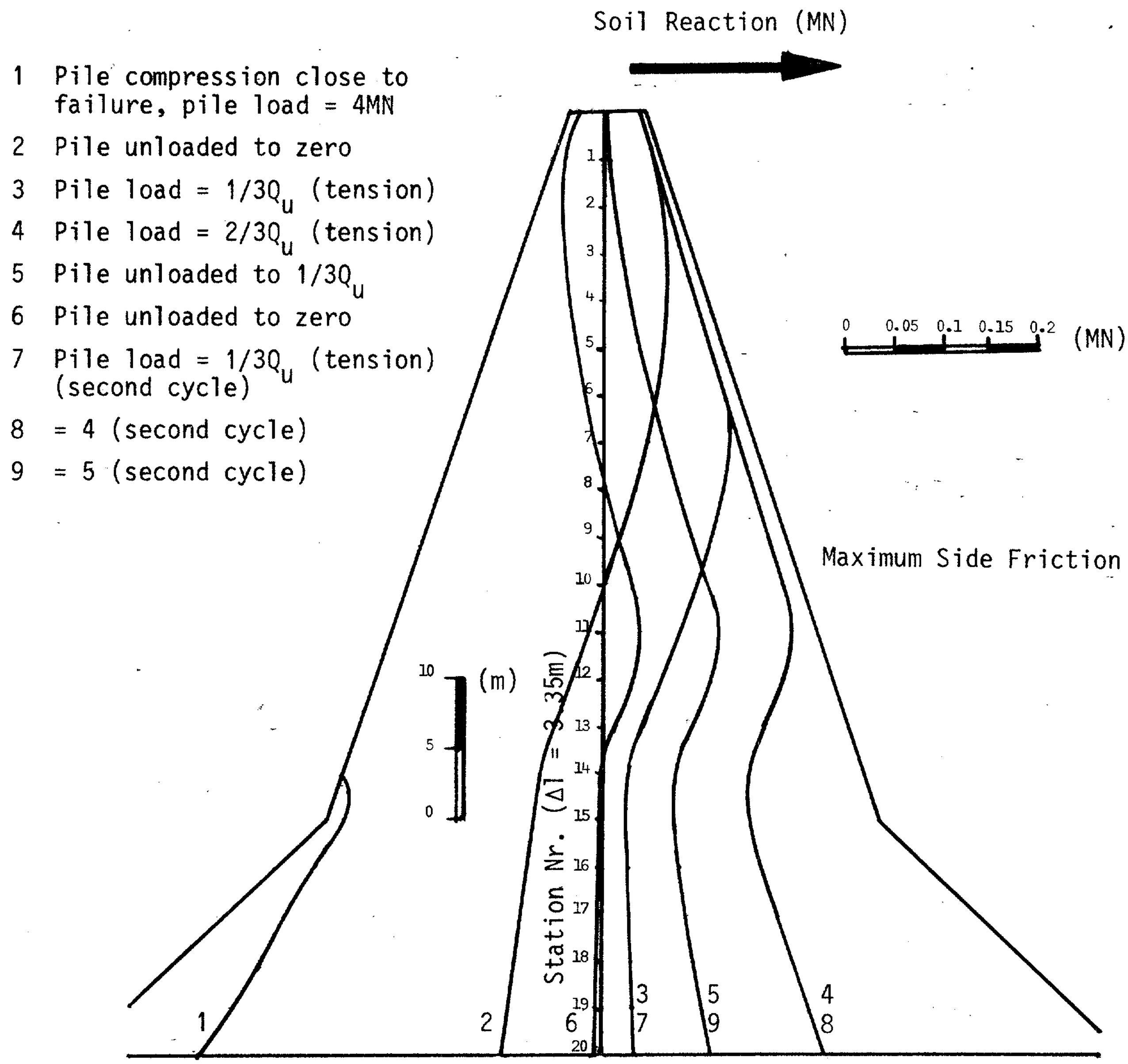
The total test plan will necessarily have to be rather flexible as there are uncertainties connected to some vital points like set-up time and level of ambient pore pressure. The above comments are meant as a clarification of Veritas', NGI's and NTH's points of view on where priority should be put during the test program.

However, it is quite clear that boundary conditions exists regarding to available time and cost. A too complex and comprehensive program might have a negative effect in the end. Nevertheless we hope the above comments are in line with what Ertec is planning for at the moment.



This figure shows a case when the pile is first loaded with a compression load close to failure. This load makes the maximum soil reaction for subsequent tensile loads to occur deeper than in the previous case.

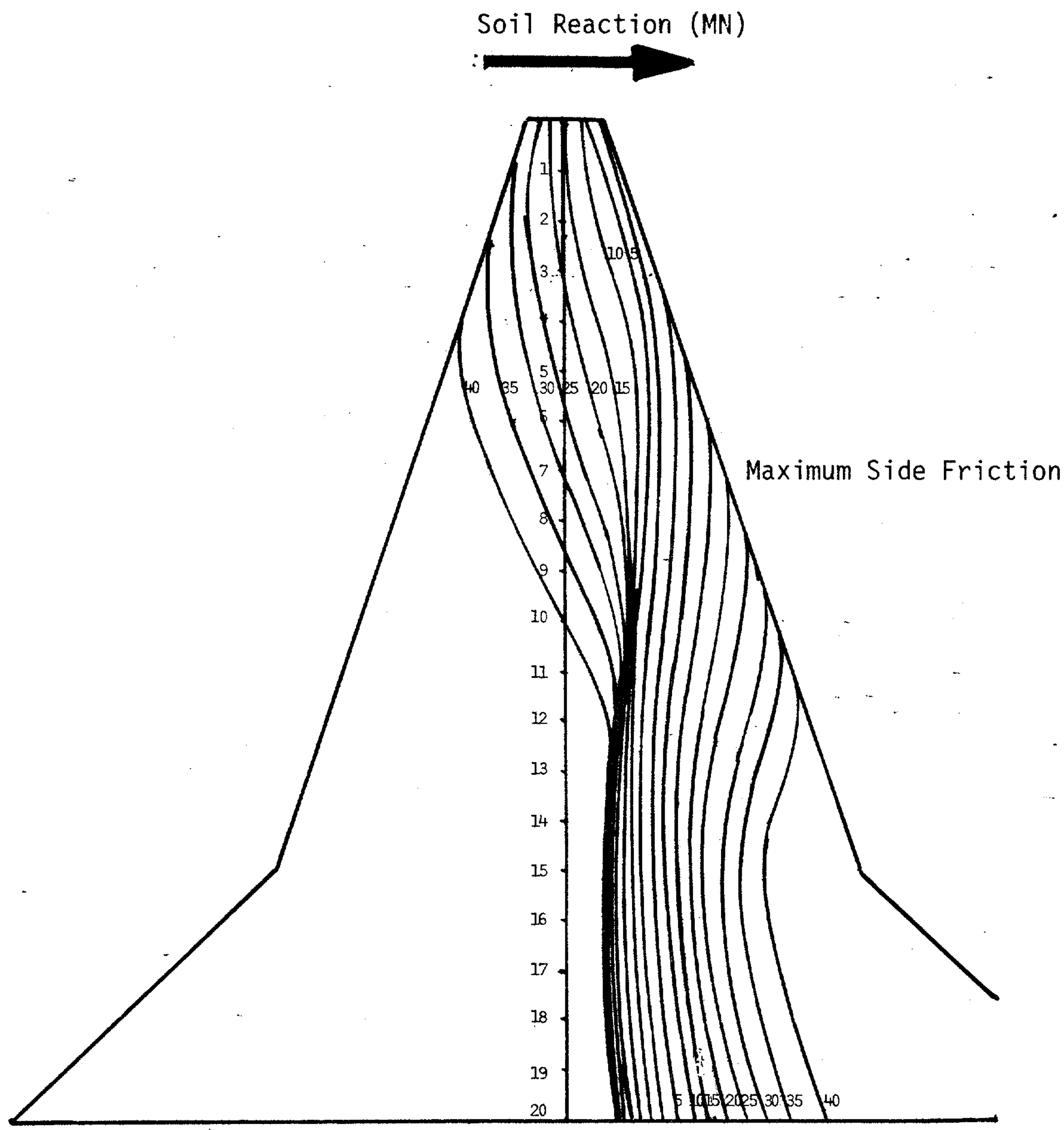
CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS		231004
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature] Approved [signature]	Date 82.07.23 Fig. No. 1a



This figure shows a case when the pile is first loaded with a compression load close to failure.

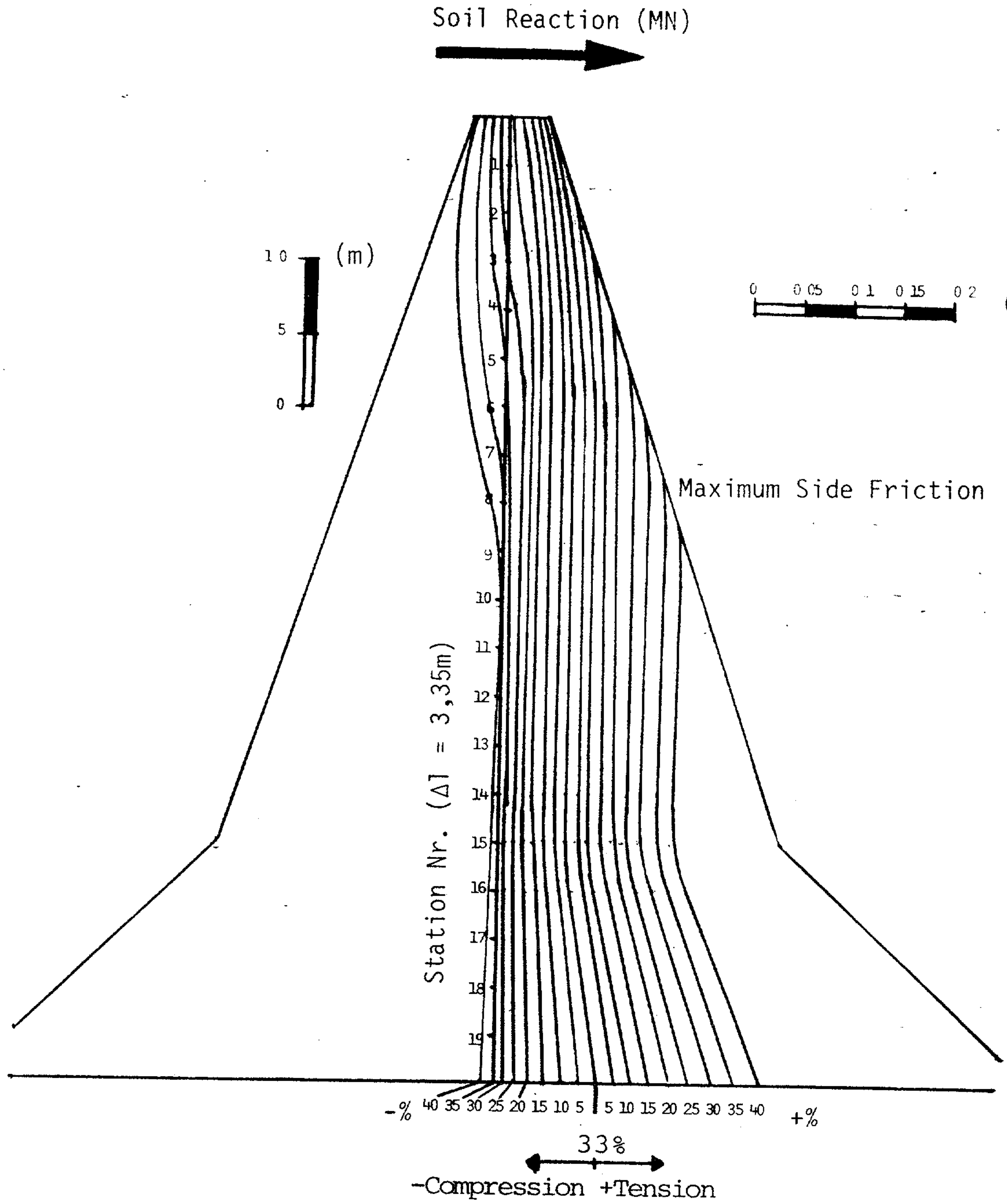
This plot also shows the effect of a change in the yelding deformation (u = 2% D).

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004		
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature]	Date 82.07.23
	Approved [signature]	Fig. No. 1b



This plot shows the mobilization of shear stress along a tension pile with pretension of 33% of the ultimate capacity and varying cyclic loads between ± 5% to ± 40% of the ultimate capacity.

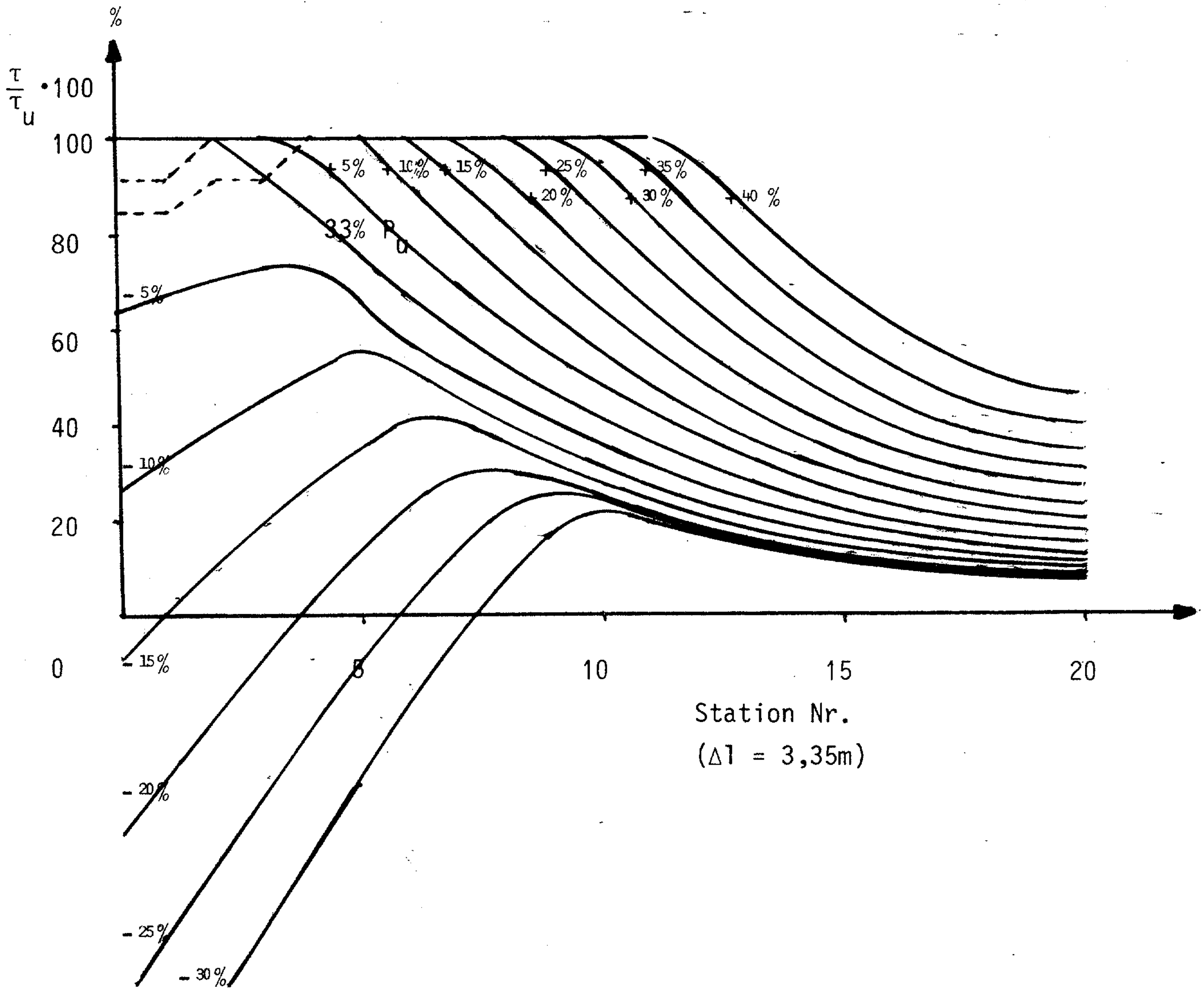
CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004		
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature]	Date 82.07.23
	Approved [signature]	Fig.No. 2a



This plot shows the mobilization of shear stress along a tension pile with pretension of 33% of the ultimate capacity and varying cycling loads between ± 5% to ±40% of the ultimate capacity

This plot shows the effect of a change in the yielding deformation (u = 2% D).

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004		
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by Approved	Date 82.07.23 Fig.No. 2b

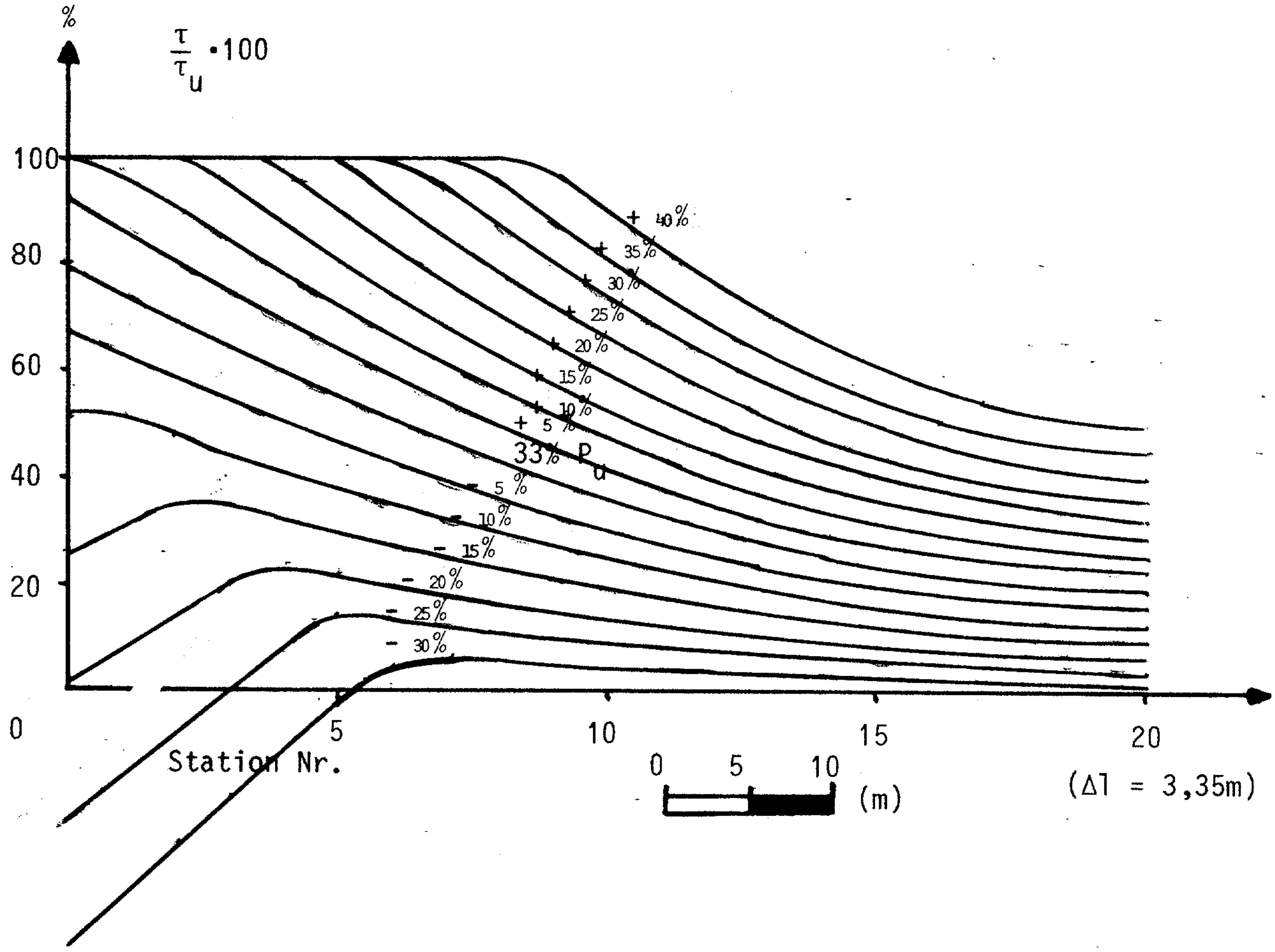


Mobilization of the shear stress along the pile under tensile cyclic loads.

$\delta_f/D = 1\%$

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004

		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature] Approved [signature]	Date 82.07.23 Fig. No. 3a

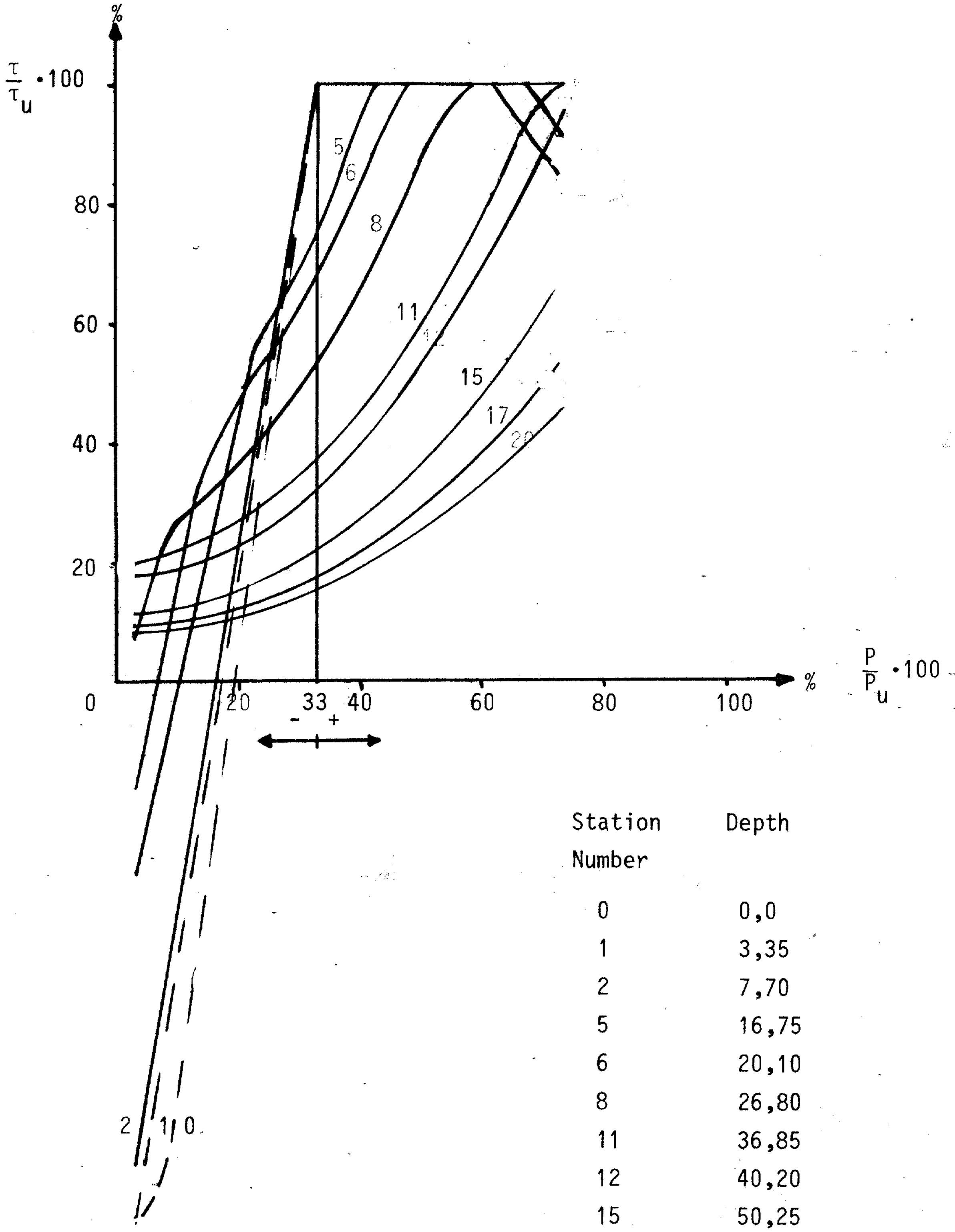


Mobilization of the shear stress along the pile under tensile cyclic loads.

$\delta_f/D = 2\%$

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004

		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by: [signature] Approved: [signature]	Date: 82.07.23 Fig.No. 3b

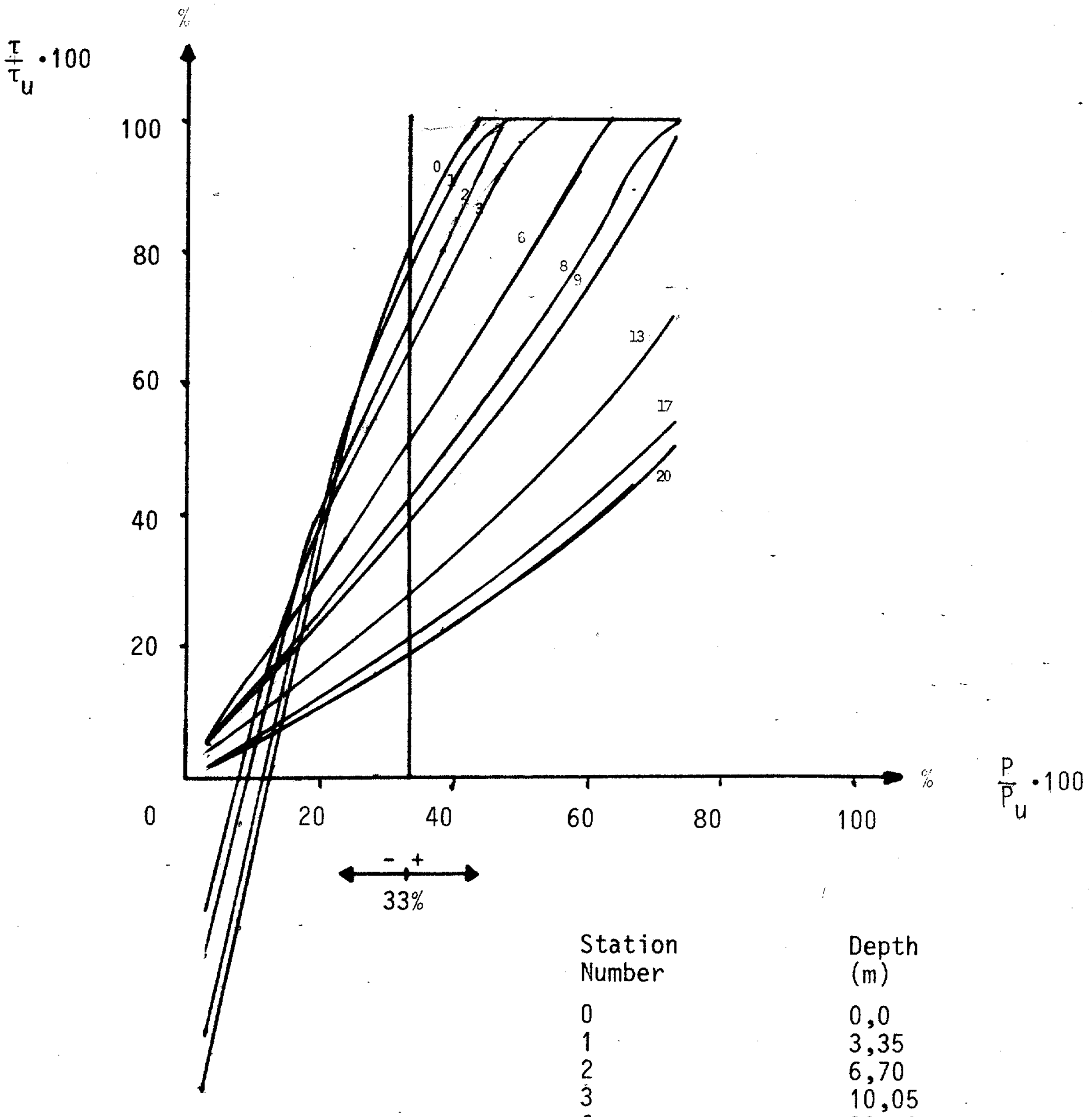


Station Number	Depth
0	0,0
1	3,35
2	7,70
5	16,75
6	20,10
8	26,80
11	36,85
12	40,20
15	50,25
17	56,95
20	67,00

Variation of the shear stress with respect to the applied load for different depths along the pile.
$\delta_f/D = 1\%$

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004

		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature] Approved [signature]	Date 82.07.23 Fig.No. 4a



Station Number	Depth (m)
0	0,0
1	3,35
2	6,70
3	10,05
6	20,10
8	26,80
9	30,15
13	43,55
17	56,95
20	67,00

Variation of the shear stress with respect to the applied load for different depths along the pile.

$\delta_f/D = 2\%$

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004

		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by [signature]	Date 82.07.23
	Approved [signature]	Fig. No. 4b