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TECHNICAL NOTE

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Title:	Distribution:
SUBPROJECT CNRD 13-2 TENSION PILE STUDY Prediction of Small Scale (3") Segment Pile Test Results	R.Gratz, Conoco NOR J.H.C. Chan, Con.PES J.Mueller, Con.PRD Tom Hamilton, Ertec Fritz Nowacki, NGI Lars Grande, NTH

Written by:

Tore J. Kvalstad

Summary:

This technical note presents Veritas attempt of predicting the results of a series of tests with 3" diameter pile segments developed by Ertec which are to be installed and loaded at different depths in a clay sediment at West Delta, Block 58 in the Gulf of Mexico.

Based on theoretical analysis and the experience from the first part of a test series with 1" diameter laboratory model piles performed at Veritas on clay from the same location the following predictions of different test results have been described:

- skin friction during insertion
- development of pore water pressure (installation and set-up)
- development of total and effective normal stress
- static capacity in tension and compression
- load displacement behaviour under static and cyclic loading
- degradation of skin friction under two-way cyclic loading

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1. GENERAL

The following pages describes in short Veritas' predictions of the results of the planned segment tests. These predictions are based on the data presented in Ertec's "Site Characterization Report", our own experience from the first part of the laboratory model pile test program, data from NGI and NTH about the behaviour of the West Delta clay under cyclic loading as well as theoretical analysis and parametric studies of the influence of different soil parameters on the interaction between pile and soil under static and cyclic loading.

As we have at the time of writing received no detailed test program describing the planned depths for testing, planned set-up time, the loading pattern etc. for the different series of tests, our predictions may have to be modified somewhat to better represent the the actual testing conditions. This should preferrably be done prior to the execution of the segment test program.

2. SKIN FRICTION DURING INSERTION

The skin friction expected to develop during insertion of the pile segment will according to our experience from the laboratory model pile tests be in the range of 30 to 35 percent of the undrained shear strength of the soil at the relevant penetration depth. A plot of expected skin friction on the segments during insertion is shown in Figure 1. The shear strength curve used as a basis for this prediction is the interpreted shear strength curve presented on Plate 29 of Ertec's "Site Characterization Report".

Further data for prediction of these values would be the sleeve friction measurements performed during the Cone Penetration Testing (CPT).These values have been plotted in Figure 1 as well for comparison.

The different shapes of the tip of the laboratory model pile and the CPT cone compared with the segment pile may have a certain influence on the development of pore water pressure and the degree of remoulding during insertion of the different devices. We do at present not consider these differences to be very significant regarding their influence on the skin friction during insertion.

3. DEVELOPMENT OF TOTAL NORMAL STRESS AND PORE WATER PRESSURE DUE TO THE INSERTION OF A PILE SEGMENT

3.1 Total normal stress

Based on the first part of the laboratory-model pile test program our experience is that the total normal stress developing during pile insertion is not exceeding the vertical consolidation stress. Tests on material from Stratum II as well as from Stratum III performed with consolidation stresses of 300 kPa vertically and 210 kPa radially for Stratum II and 500 kPa vertically, 350 kPa radially for Stratum III indicates that the normal total stress will be in the order of 80 t0 120 percent of the effective vertical consolidation pressure.

On a total stress basis our findings are that the ratio between total normal stress (backpressure subtracted) and undrained shear strength of the clay lies in the order of 6 to 7, which corresponds well with predictions based on cavity expansion theory by Randolph, Carter and Wroth (1979). A prediction of the total normal stress versus penetration is shown in Figure 2.

3.2 Excess pore water pressure

The pore water pressure measurement system adopted for the first version of Veritas' pile equipment does not seem to have a sufficient fast response to allow conclusions or predictions at this stage. We hope to improve this system by changing to a miniature pore water pressure transducer which will be placed directly at the pile wall.

Prediction of excess pore water pressure immediately after pile segment insertion could be based on cavity expansion theories and on data from various types of pile tests and piezometer probe installations.

Based on the predictions by Randolph & al. (1979) one could expect excess pore pressures in the range of 3 to 4 times the undrained shear strength of the material. A plot of this estimate of excess pore pressure as well as a best estimate of the total pore pressure (including ambient excess pressure as well as the hydrostatic water pressure) is shown in Figure 3.

4. DISSIPATION OF EXCESS PORE WATER PRESSURE, SET-UP TIME

Oedometer tests performed by McClelland, NTH and NGI all indicate cv - values in the range of 0.8 to 1.5 m**2/year for stress levels comparable to the existing in situ stresses in Stratum II and III. Ertec's tests show higher values.

Oedometer tests performed by Veritas on remoulded and reconsolidated samples from the large consolidometer indicate that the cv - values of the laboratory model pile soil samples in general will be considerably lower and in the order of 0.1 to 0.2 m**2/year for the tested stress conditions.

Theoretical predictions of the dissipation of pore water pressure at the pile surface vs time have been performed with the program OCEAN2, a 3-dimensional, axisymmetric finite element program. These predictions have been summarized in Figure 4.

The experience from the laboratory model pile tests is so far that set up is taking place at an extremely low rate. However, this may be due to our difficulties in measuring the expected high pore pressure values directly after pile insertion.

Data from an investigation of excess pore water pressures in the Mississippi Delta, Bennet and Richards (1979), indicates set-up curves for a 4" diameter piezometer probe as shown in Figure 5. When scaled down to a 3" diameter pile segment by a factor of 3"**2/4"**2 = 0.56, the shaded curve results. One should note the limited depth of the piezometer probe used in this investigation compared with the 220 ft total depth below mudline for the planned large scale field test.

Effects of existing methane gas in the sediment may influence the pore pressure measurements considerably. The tidal and wave induced changes in the water pressure acting on the sea bed may further lead to cyclic changes in the measured pore water pressures.

Having all these uncertainties and complicating factors in mind our best estimate is presented in Figure 6 as expected pore water pressure vs log time for various depths below mudline.

5. SKIN FRICTION UNDER STATIC LOADING

5.1 Total Stress Basis

Based on our experience from the laboratory model pile tests we predict an alpha value in the range 0.5 to 0.6 for the segment tests. The corresponding skin friction vs depth below mudline is shown in Figure 7 which represents maximum skin friction values. The residual values are expected to be about 10 percent lower and are indicated in Figure 7 as well.

These values contradicts the API-regulations which allowe maximum alpha values of 1.0 for the soft Gulf of Mexico clays. A summary of the preliminary laboratory model pile test data about skin friction and undrained shear strength is presented in Table 1.

TABLE 1. Summary of Static Model Pile Results on a Total Stress Basis

Test No.	Undrained Shear Strength su kPa	Maximum Skin Friction tult kPa	Residual Skin Friction tres kPa	Ratio tult / su	Ratio tres / su
1	50	28 to 30	22	.56 to .60	.44
2					
3	40 to 45	22	17	.49 to .55	.38 to .43
4	65	34	29	.52	.45
5	50 to 55	33	30	.60 to .66	.54 to .60
6	75 to 80	39	36	.48 to .52	.45 to .48
7	40 to 45	19	17	.40 to .47	.38 to .42

5.2 Effective Stress Basis

An interpretation of measured skin friction as a function of the measured effective normal stress has been performed with the preliminary data from the model pile tests. In Table 2 a summary of the static test results on an effective stress basis has been given. The Table shows interpreted values for the interface friction angle as well as for Burland's beta-values.

TABLE 2. Summary of Static Model Pile Results on an Effective Stress Basis

Test No. -	Normal Stress at Failure kPa	Pore Pressure at Failure kPa	Maximum Skin Friction kPa	Interface Friction Angle Degr.	Vertical Consol. Stress kPa	Beta Factor -
1	657	438	28 to 30	7 to 8	150	0.19
2						
3	539	486	22	22	120	0.18
4	612	480	34	14	380	0.09
5	610	444	33	11	170	0.19
6	650	395	39	9	380	0.10
7	572	475	18	11	155	0.12

The vertical effective consolidation stresses used for these calculations are corrected for estimated loss in pressure due to wall friction in oedometer and for pore pressure in sample at time of extrusion from oedometer.

Based on these preliminary results we expect beta-values in the range of 0.15 to 0.19 for stratum 2 (25 to 50 m) and about 0.1 for stratum 3 (50 to 72 m).

6. DEGRADATION OF SKIN FRICTION DUE TO TWO-WAY CYCLIC LOADING

Two-way cyclic load tests under displacement control showed that no significant degradation will take place until failure is reached. This conclusion has been based on the first tests where a limited number of cycles has been applied to the model pile.

Degradation started as soon as the cyclic displacement exceeded the failure displacement of say 2 percent of the pile diameter. The following cycles resulted in a rather fast degradation towards a rather stable level some 20 to 30 percent below the failure load.

Increasing the relative displacement to 8 percent of the pile diameter did lead to a further degradation. A summary of some of these data is given in Table 3 below.

TABLE 3. Summary of Degradation Tests With Two-Way Cyclic Loading

Test No.	Maximum Static Skin Friction tult,stat. kPa	Maximum Value Skin Friction at Start of Degradation tmax,start kPa	Peak Values at End of Degradation Test kPa	Degradation in Percent of tult,stat. %	Degradation in Percent of tmax,start %
1	28 to 30	33	25	14	24
2					
3	22	18	14	36	22
4	34?	50	41	?	18
5	33	33	27	18	18
6	39	41	35	10	15
7	18	22	15	17	35

7. LOAD - DISPLACEMENT BEHAVIOUR UNDER STATIC AND CYCLIC LOADING

A theoretical prediction of the model pile behaviour as well as the segment pile behaviour under static loading has been carried out. A single slice model with a hyperbolic stress-strain material model for the soil was adapted. See Figure 8.

The shear stress decreases from the value t(ro) at the pile wall to a value of t(r) at a distance r from the centerline of the pile according to the following expression:

$$t(r)=t(ro)*ro/r$$

where ro is the pile radius.

The hyperbolic model gives the following relationship between the shear stress, t, and the shear strain, y:

$$t=\frac{y}{1/Gi + y/tult}$$

where Gi = initial shear modulus
tult = shear strength

The following relationship can be shown to exist between the secant shear modulus and the degree of shear stress mobilization (i.e. t/tult)

$$Gsec=Gi*(1-\frac{t}{tult})$$

The vertical (or axial) movement,dv, of a section of the single slice with thickness dr subjected to a shear stress t will be:

$$dv = (t/Gsec)*dr$$

By inserting the above expressions for t(r) and Gsec(t) into the latter expression and integrating from r=ro to a certain distance R from the pile centerline, the following expression is derived:

$$v = \frac{t(ro)*ro}{Gi} (\ln(R/ro - t(ro)/tult) - \ln(1 - t(ro)/tult))$$

Based on Gi - moduli extrapolated from triaxial and simple shear test results from the laboratory reports by Ertec, McClelland and NGI, which tended to lie in the range 80 to 180 times the undrained shear strength, and by assuming an outer boundary R equal 8*ro for the model pile and 20*ro for the segment pile the shear-stress vs axial displacement curves shown in Figure 9 and 10 for the two devices respectively could be derived. By further assuming alpha values of 0.5 to 0.6 at the pile soil interface the shaded ranges can be taken as our best estimate of normalized load displacement behaviour under static loading.

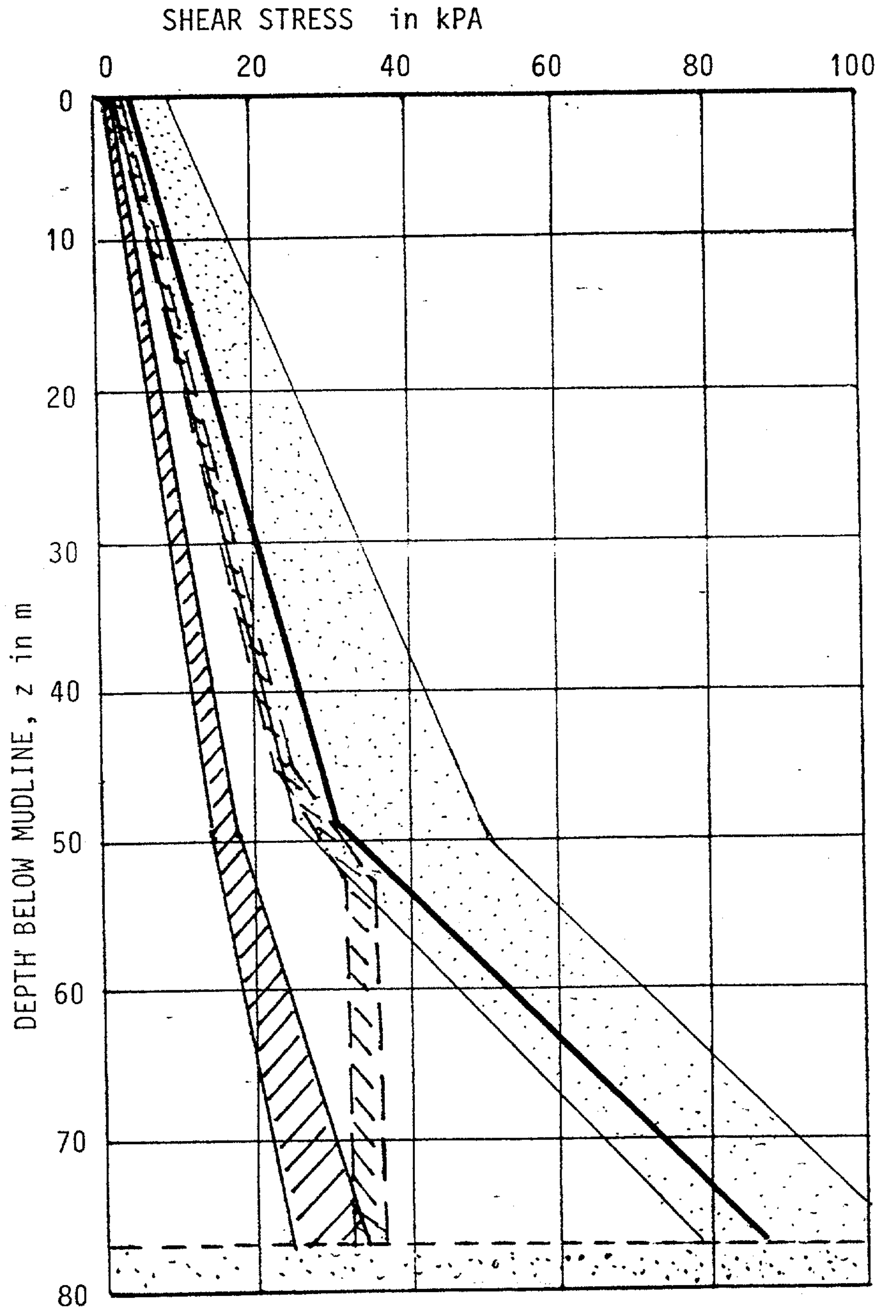
The results of the prediction of the laboratory model pile test compares fairly well with the measured load - displacement behaviour during the first part of the test program.

The choice of a finite boundary, R, at a distance 30*ro from the pile center does not have a very strong influence on the results. At low load levels, say about .2, a variation of R from 10*ro to 50*ro makes the stiffness vary with about +/- 20 to 25% relative to R = 30*ro. At high load levels, i,e, close to failure the effect decreases to even lower values.

REFERENCES

BENNETT, Richard H., FARIS, R.J. (1979): Ambient and dynamic pore pressures in fine-grained submarine sediments : Mississippi Delta. Applied Ocean Research, 1979, Vol.1, No.3.

RANDOLPH, M.F., CARTER, J.P., WROTH, C.P. (1979): Driven piles in clay - the effects of installation and subsequent consolidation. Geotechnique 29, No.4, 1979.



Scatter range of undrained shear strength, s_u

Estimated or "predicted" skin friction during insertion

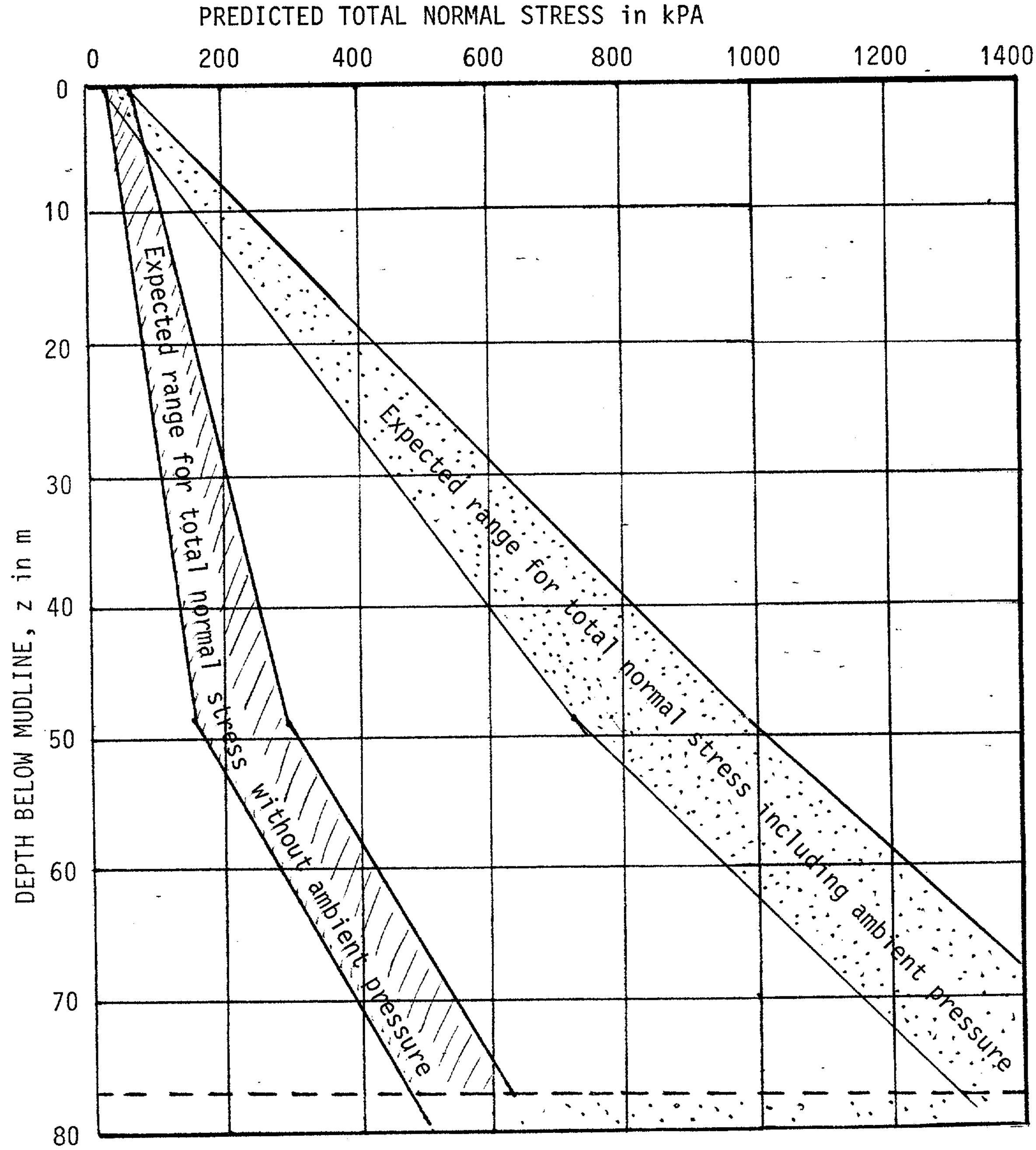
Sleeve friction from cone penetration test

ERTEC's best estimate of skin friction for pile design (API

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

Predicted skin friction during insertion as a function of installation depth.

DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Scale
	Approved	Date
		Fig. No. 1

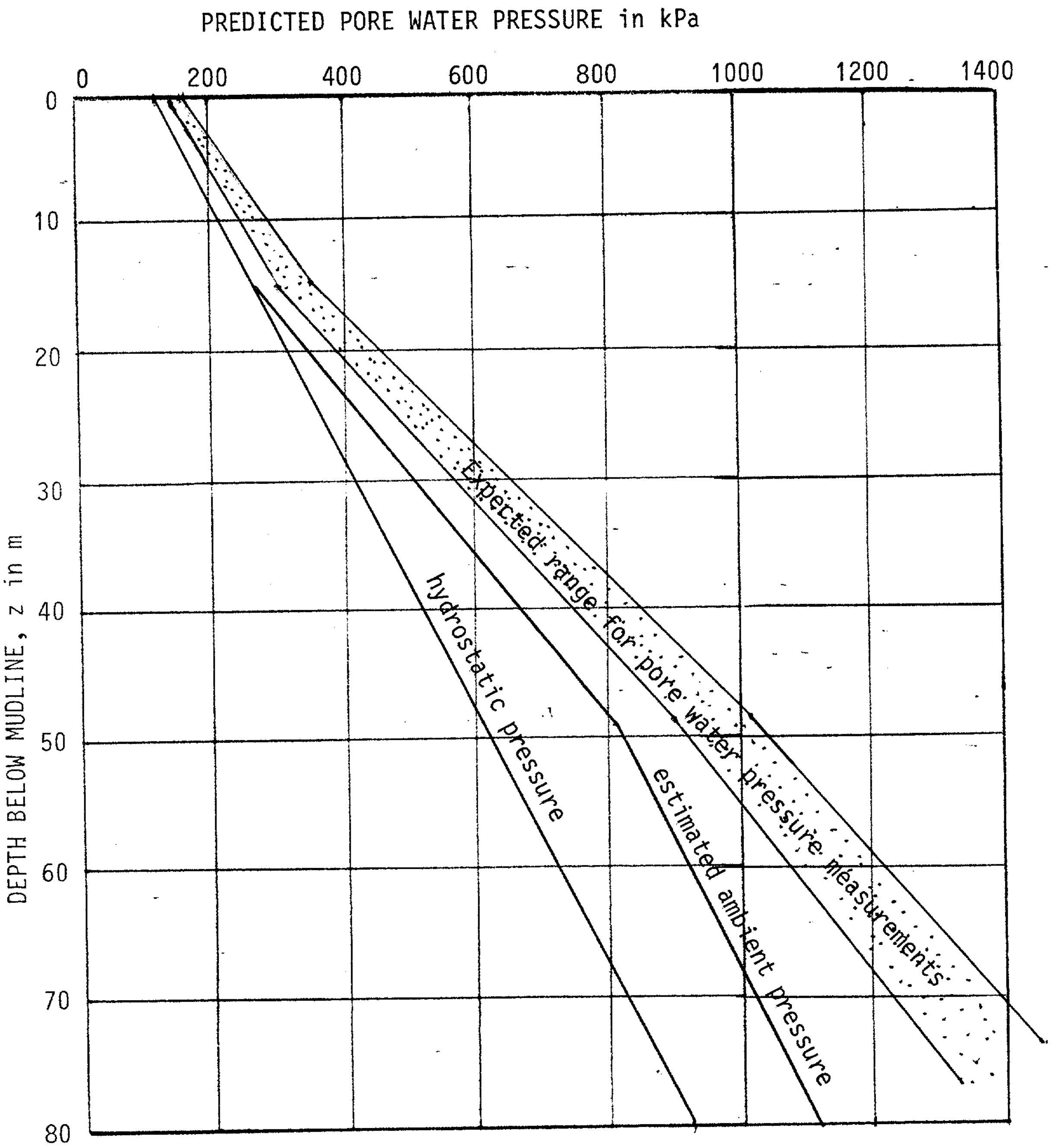


CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004

Predicted normal stress during insertion as a function of installation depth.

DET NORSKE VERITAS
Geotechnical Laboratory

Scale	
Drawn by	Date
Approved	Fig. No. 2



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

Predicted pore water pressure measurements as a function of installation depth

DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Scale
	Approved	Date
		Fig. No. 3

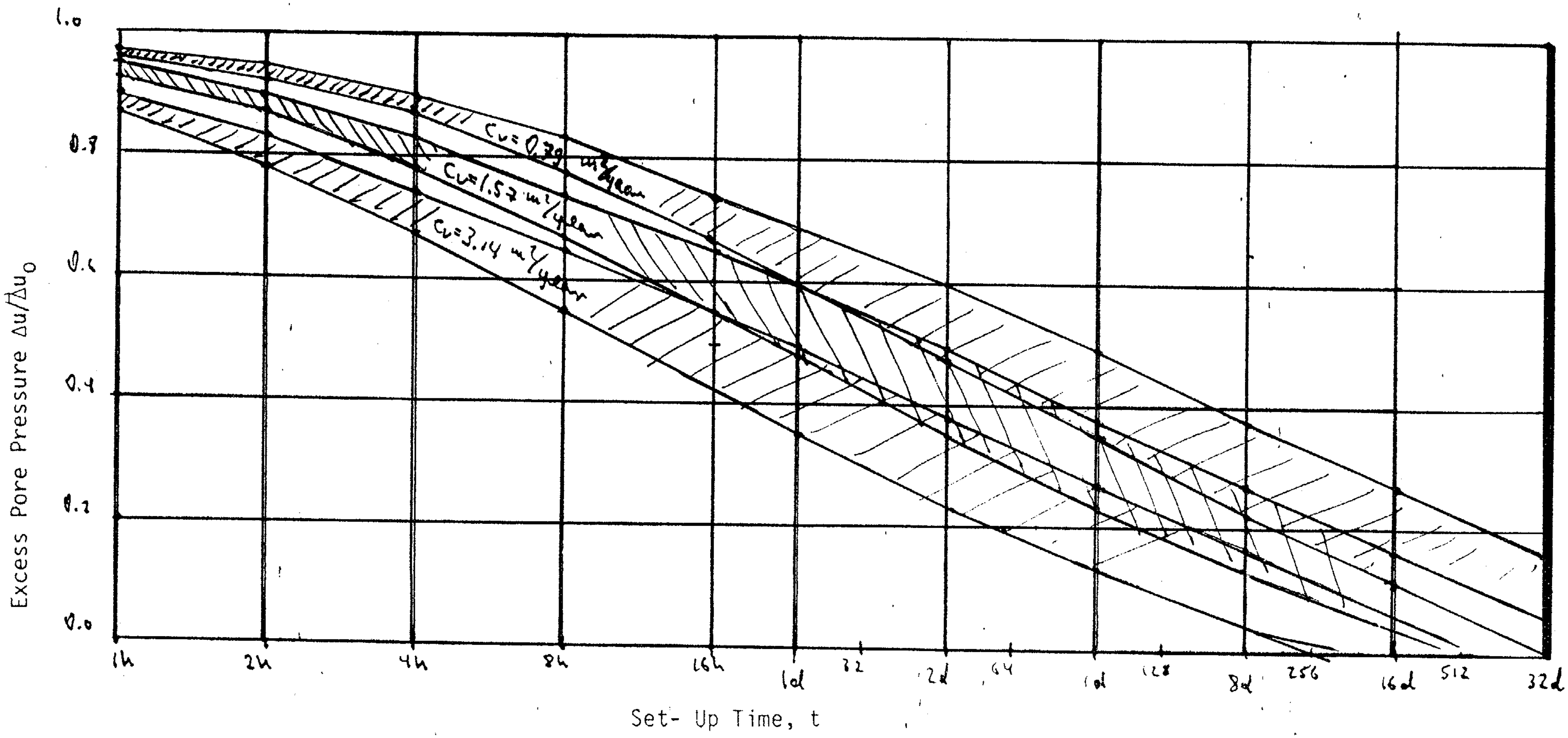
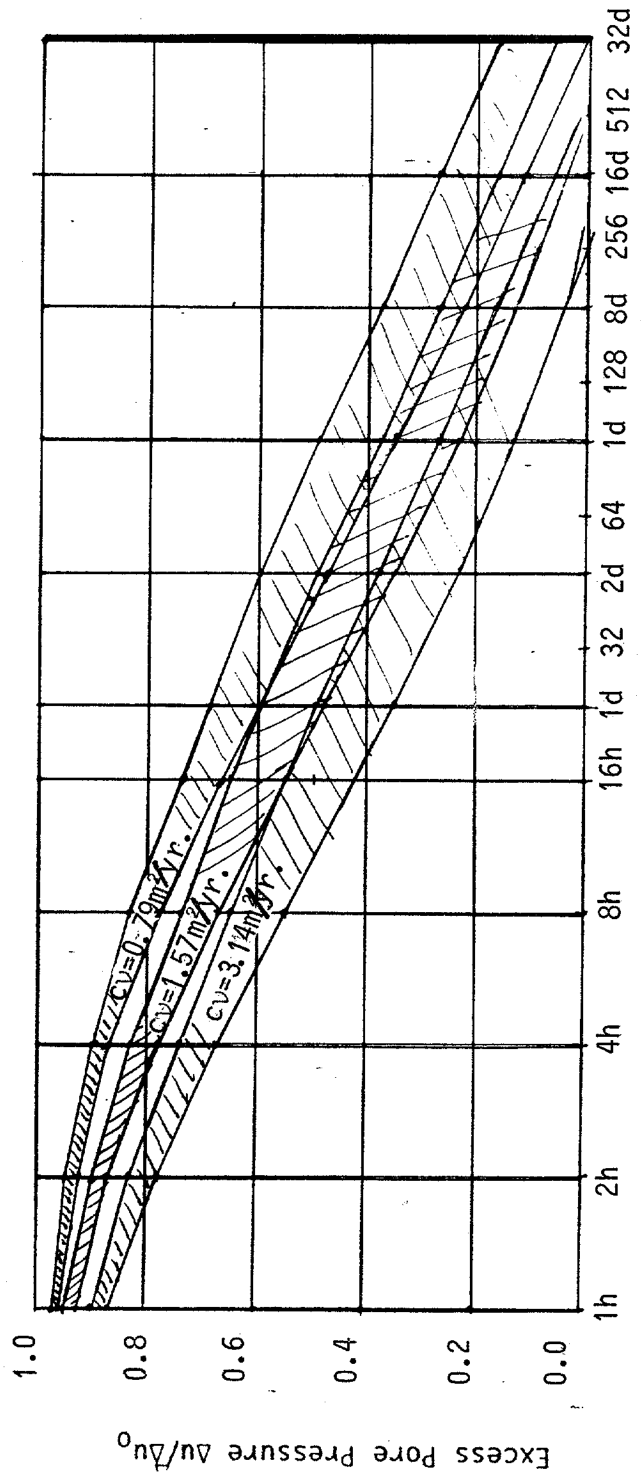


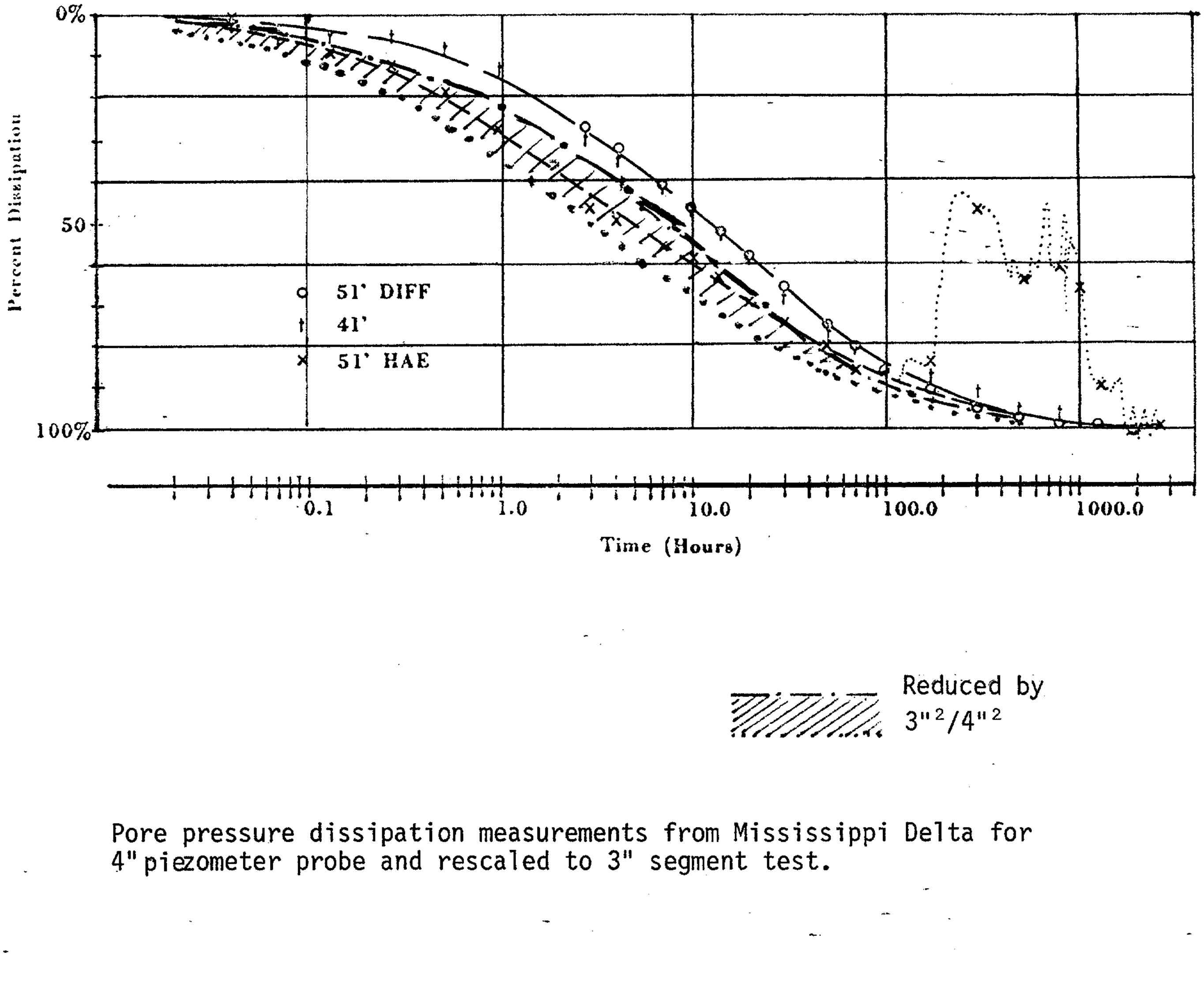
Figure 3 Dissipation of excess pore water pressure at the pile surface vs log time for various values of the coefficient of consolidation and for $R = 8\ r_0$ and [illegible] r_0 respectively.



Dissipation of excess pore water pressure at the pile surface vs log time for various values of the coefficient of consolidation and for R = 8 r_o and 15 r_o respectively.

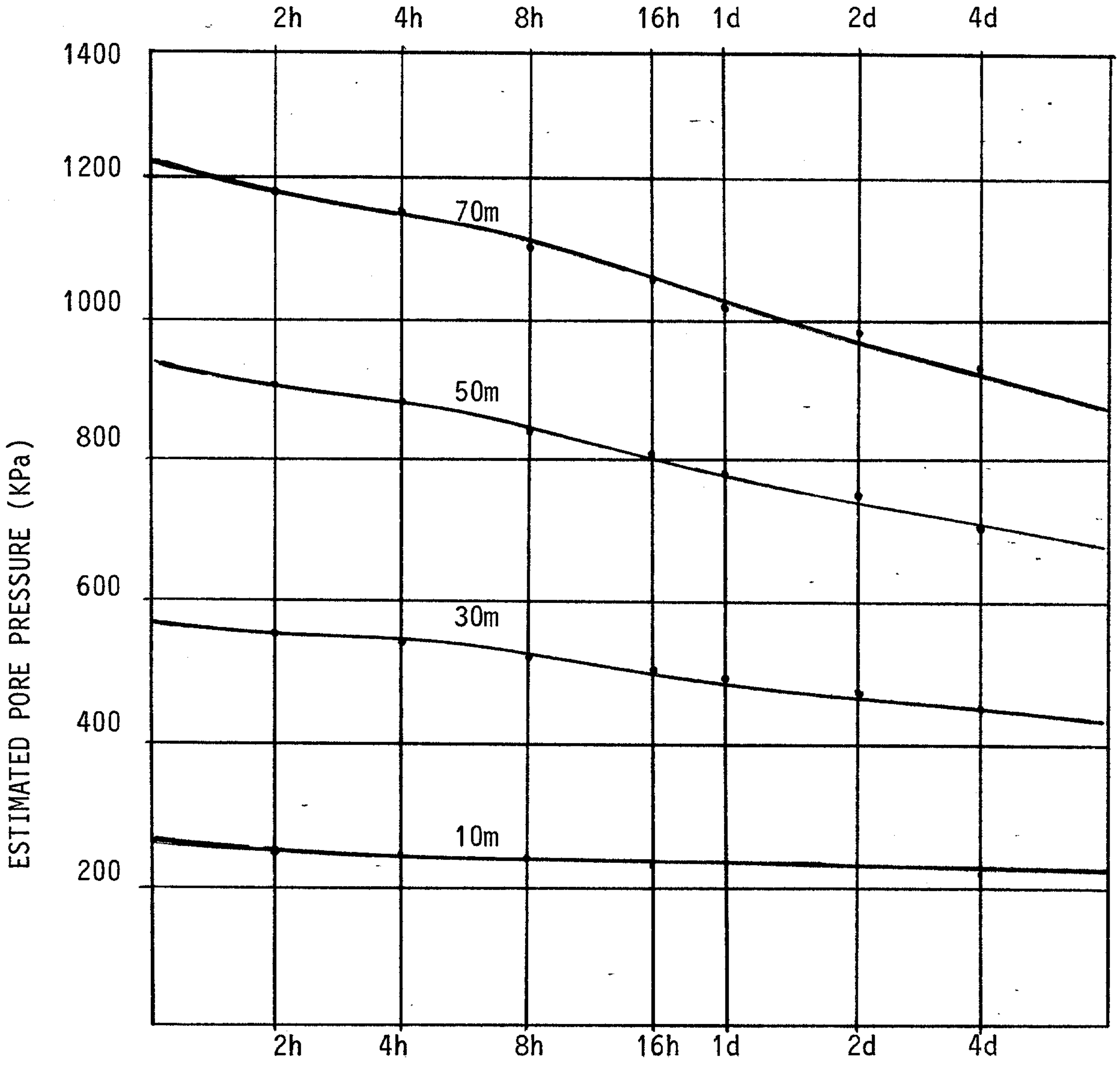
CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004		
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 4

Pore pressures in fine-grained submarine sediments: R. H. Bennett and J. R. Faris



Pore pressure dissipation measurements from Mississippi Delta for 4" piezometer probe and rescaled to 3" segment test.

SET UP TIME



Best estimate of pore pressure dissipation curves at various depths below mudline.

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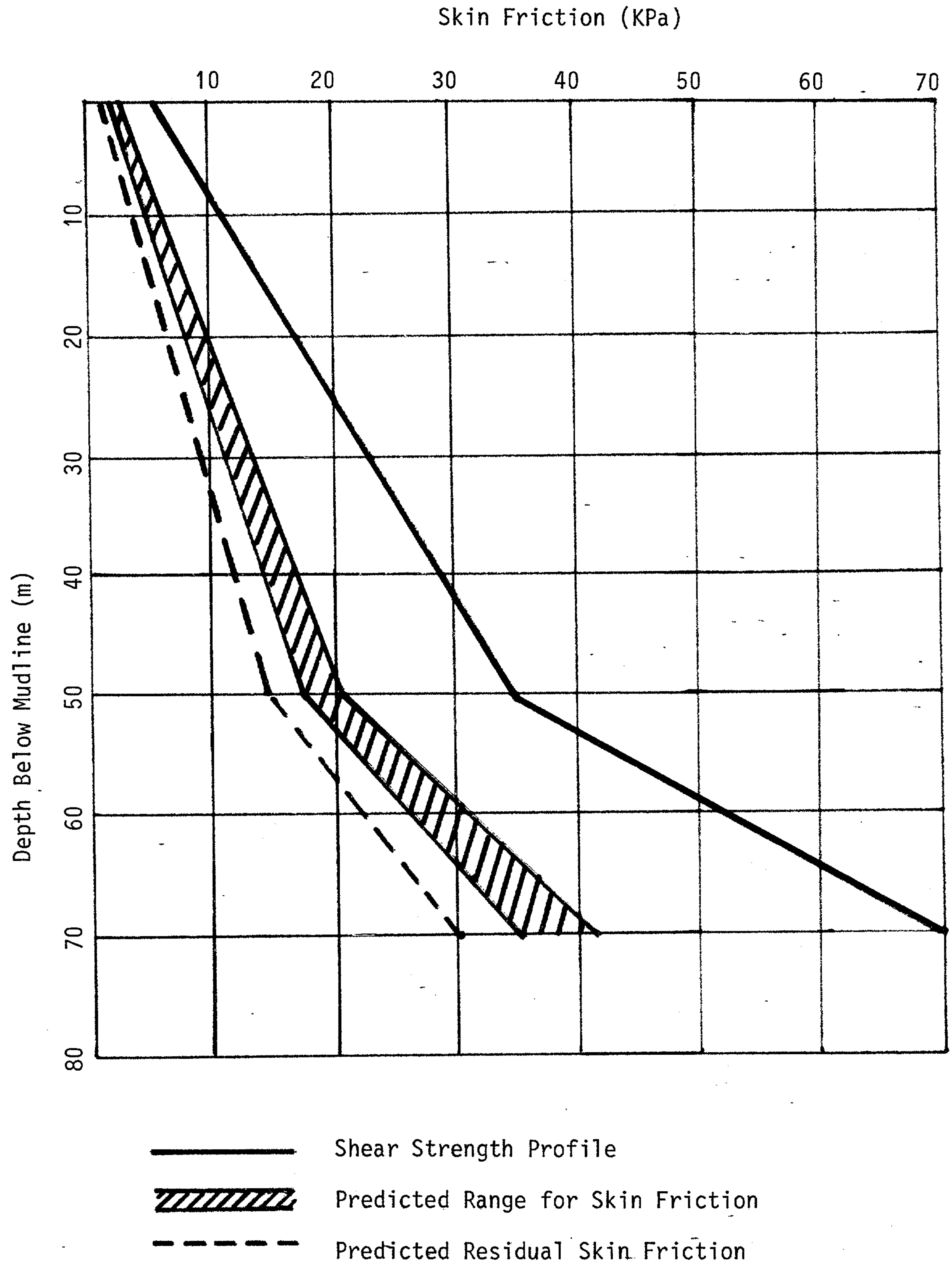
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 6



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

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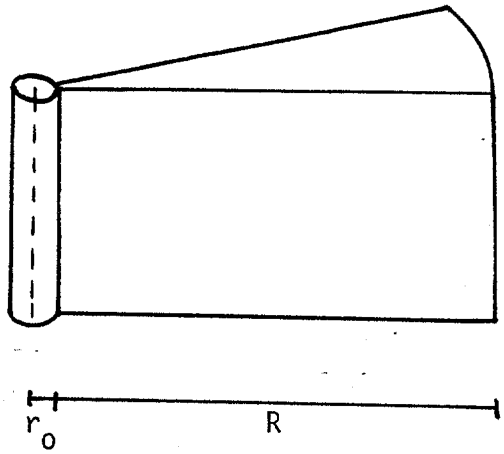
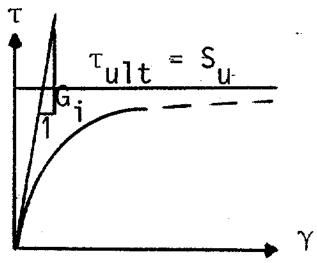
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 7

Single Slice Model for
Segment Pile

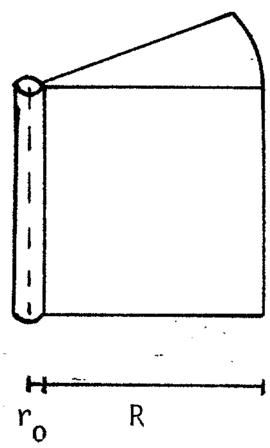


r_o=1,5" R/r_o=20
R =30"

Hyperbolic Material Model



Single Slice Model for
Laboratory Model Pile



r_o=1,25cm R/r_o=8
R =10cm

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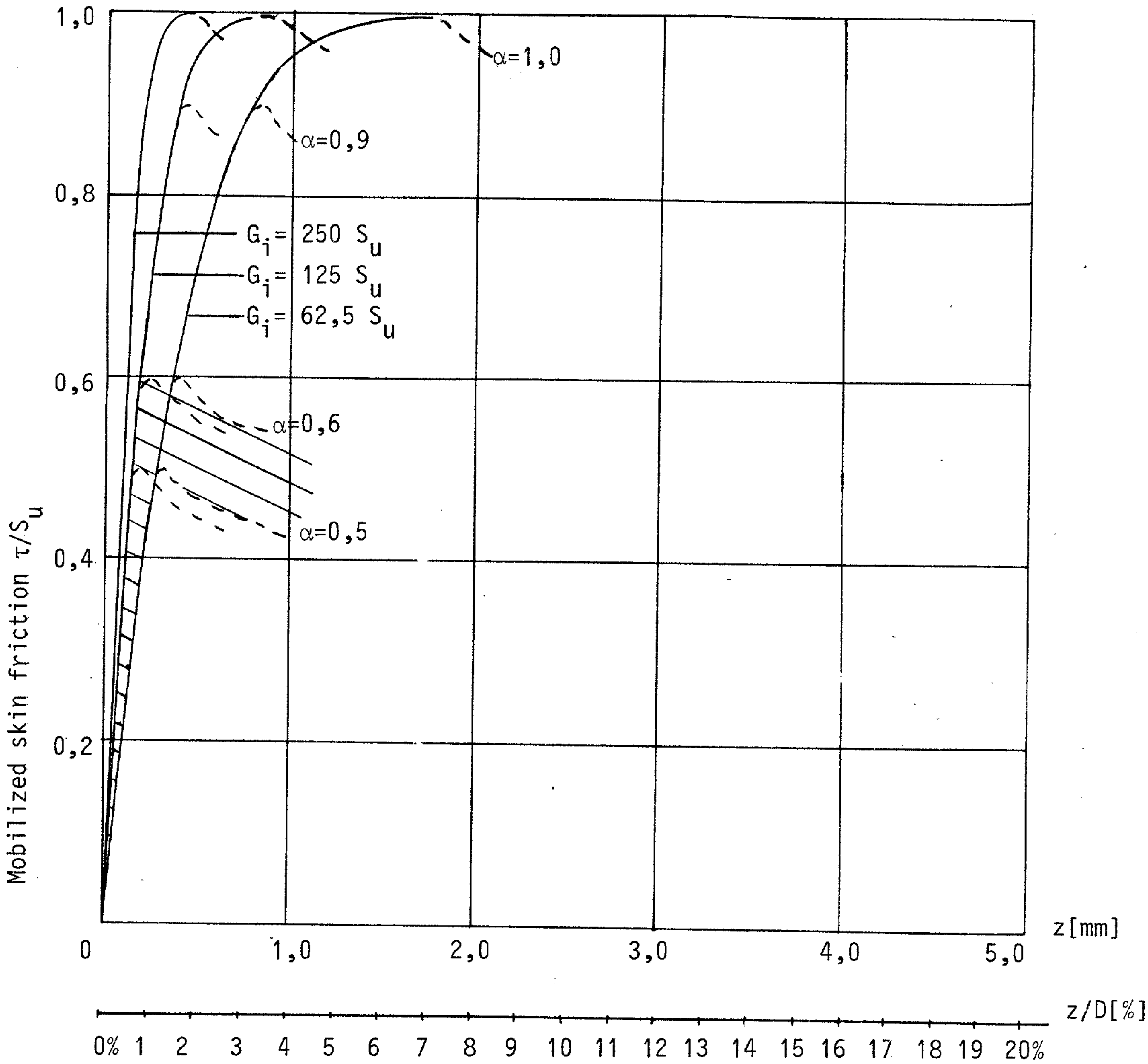
Single slice models with hyperbolic material modelfor prediction of laboratory model pile and segment pile.		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 8



Normalized τ-z curves predicted for laboratory model pile.

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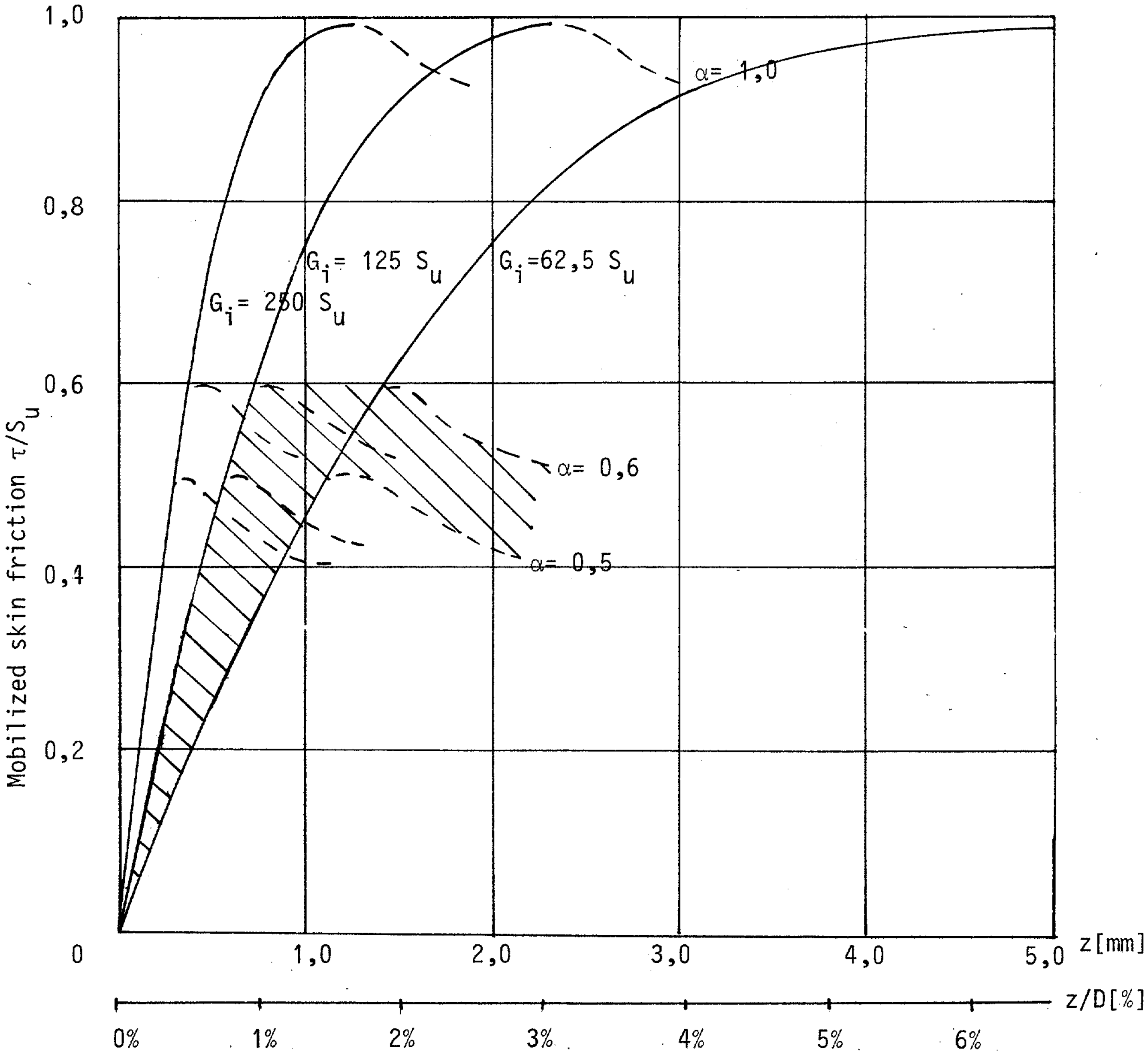

Normalized τ-z curves predicted for segment tests.

CNRD 13-2 TENSION PILE STUDY LABORATORY MODEL PILE TESTS 231004		
		Scale
DET NORSKE VERITAS Geotechnical Laboratory	Drawn by	Date
	Approved	Fig.No. 10