INSTITUTT FOR GEOTEKNIKK. NTH
GEOTECHNICAL DIVISION

PROSJEKT NR.	NOTAT NR.	DATO
0.82.02	1	1.9.1982

PROSJEKTTITTEL:
SUBROJECT CNRD 13-2
TENSION PILE STUDY

GÅR TIL:	Orientering	Uttalelse	Behandling	Etter avtale	
T. J. Kvalstad, DnV					

NOTATET GJELDER:
Prediction of static behaviour of 3" diameter segment pile

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This technical note is restricted to the NTH-predictions of the static behaviour of the 3" diameter segment pile which is to be installed and tested by Ertec at Block 58 in the Gulf of Mexico. The segment pile will be installed at depths ranging from 57 to 207 feet below seabed in stratums of plastic and highplastic clay.

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1. INTRODUCTION

On the following pages are presented the NTH predictions in connection with the seqment pile tests of project CNRD 13-2. Only static behaviour is included herein. The predictions are based on the Ertec report No.82-200-1, the NGI report 81222-2 and our own report No.0.82.02-1.

The cyclic responce will be attempted predicted in a later technical note.

2. UNDRAINED SHEAR STRENGTH

As a supplement to the undrained shear strength profile in Plate 30 of the Ertec Report No.82-200-1, an evaluation of the undrained shear strength (c_u) by the "Undrained Effective Stress Approach" (Svanø 1981) is performed. The main assumption is that the undrained excess pore pressure (Δu) due to a change in total stresses is given by

$$\Delta u = \Delta\sigma_{oct} - D\,\Delta\sigma_d \qquad (1)$$

where

$$\sigma_{oct} = \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z)$$

$$\sigma_d = \sigma_1 - \sigma_3$$

D = dilatancy parameter, determined by triaxial tests. (Janbu, 1977)

Assuming an initial K_0' state of stresses, Eq.(1) can be developed into

$$\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_3) = \chi(p'_v + a) \qquad (2)$$

where

$$\chi = \frac{1}{2}(N-1)\;\frac{K_0' + \frac{1}{3}(1+b_0-3D)(1-K_0')}{1 + \frac{1}{3}(1+b-3D)(N-1)}$$

and

a = attraction = $c/\tan\phi$
c = cohesion
N = $\tan^2(45+\rho/2)$
$\tan\rho$ = mobilized friction
$\tan\phi$ = friction at failure
K_0' = $(p_h' + a) / (p_v' + a)$
p_v' = effective overburden pressure
p_h' = earth pressure at rest
b = $(\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3)$ (final state of stress)
b_0 = $(\sigma_{20} - \sigma_{30}) / (\sigma_{10} - \sigma_{30})$ (initial state of stress)

Eq.(2) is valid for $K_0' \leq 1$, and gives the undrained shear strength if $N = N_f = \tan^2(45+\phi/2)$.

Interpretation of the available triaxial tests gives the a, $\tan\phi$ and K_0' at Fig.1. D is judged to D = -0.3 in Stratum II and D = -0.5 in Strata I and III in average. With these parameters, and p_v' equal to the interpreted maximum past effective pressure σ_{vm}' in Plate 12 A of the Ertec report No.82-200-1, the undrained shear strength profile in Fig.2 is obtained. This approach gives a slightly higher c_u than the Ertec average c_u in Stratum II, but as a whole the differences are not scaring. Hence, the interpreted σ_{vm}' may be close to the correct value, but eventual separate porepressure measurements will confirm this.

3. STRESS CHANGES DURING INSTALLATION

The stress changes due to installation of the segment pile are computed according to expansion of cavities theory. Hence, the normal stress change at the pile surface is

$$\Delta\sigma_n = c_u\left(1 + 2\,\ell n\frac{R}{r_0}\right) \qquad (3)$$

where

$$\frac{R}{r_0} = \sqrt{\frac{r_0^{\,2} - (r_0 - \Delta r)^2}{r_0^{\,2}} \; \frac{G}{c_u}} \tag{4}$$

G is average secant shear modulus, r_0 is radius of pile, and Δr is radial soil displacement ($\Delta r \approx$ wall thickness).

The undrained excess pore pressure at pile surface due to installation is according to Wroth, Carter and Randolph (1979):

$$\Delta u = 2c_u \, \ell n \, \frac{R}{r_0} - \Delta\sigma'_{oct} \tag{5}$$

$\Delta\sigma'_{oct}$ is change in mean effective stress. $\Delta\sigma'_{oct}$ is easti-mated through Eqs. (1) and (2) resulting into

$$\Delta\sigma'_{oct} = -\;0.041\;(p'_v + a) \text{ for Strata I and III}$$

$$\Delta\sigma'_{oct} = -\;0.027\;(p'_v + a) \text{ for Stratum II}$$

The major factor of influence is the ratio G/c_u. Based on the triaxial and direct simple shear tests, a ratio between 40 and 60 is judged adequate for the expansion of cavities calculations. This results into the plots in Figs. 2, 3 and 4, giving pore pressure in excess of the ambient pore pressure, normal stress increase due to installation and expected normal stress during installation respectively.

4. EXCESS PORE PRESSURE DISSIPATION

The excess pore pressure dissipation is estimated based on linear elastic theory and radial transport of excess water (Torstenson 1978), Randolph and Wroth (1979)). The major factors of influence are the ratio between radius of plastified zone and radius of the pile (R/r_0), and the radial coefficient of consolidation (c_h).

For the test site, McClelland, NGI and NTH report vertical c_v in the order 0.8 to 1.5 m^2/year at the relevant effective stress levels. The Ertec c_v-values are significantly higher (3 to 7 m^2/year). Based on the lower c_v-range, the consolidation plot in Fig. 5 has been developed. Observe that the time needed for 90% consolidation (t_{90}) is 4 to 12 days. Only if c_h is greater than 3 m^2/year, t_{90} will be 72 hours or less.

5. NORMAL STRESS CHANGES DURING CONSOLIDATION

According to linear elastic theory, very high normal effective stresses will occur at the pile surface at the end of consolidation, leading to local K_0' values considerably greater than unity. These high K_0-values are highly questionable. The stress increase is restricted to a rather small zone around the pile, and as the consolidation proceeds, creep, relaxation and stress redistribution effects may easily counterbalance most of the effective stress increase tendencies.

To illustrate, the free creep between t_{70} and t_{90} would be $\Delta\varepsilon = 0.75\%$ according to Janbu's (1970) formula $\Delta\varepsilon = \frac{1}{r_s} \ell n \frac{t}{t_{ref}}$ $\approx \frac{1}{r_s} \ell n\, t_{90}/t_{70}$ ($t_{90}/t_{70} \approx 4.6$). The creep number r_s is set equal to 200 as obtained by reinterpreting test 1NOD1, NTH Report No. O.82.02-1. (Typical ranges for r_s is 100 to 500 for NC-clays, 1000 to 5000 for OC-clays). Multiplying $\Delta\varepsilon$ with a swelling modulus of 10 times the compression modulus gives an effective stress reduction at 35 meters depth of 100 kPa, i.e. of the same order of magnitude as the total normal stress increase due to pile insertion.

This highly tentative (and theoretically incorrect) estimate gives the background for assuming an earth pressure coefficient $K_0' \approx 0.7$ to 0.8 at the end of consolidation. (Assumed initial $K_0' \approx 0.55$ to 0.6).

6. ULTIMATE CAPACITY OF SEGMENT PILE

Total stress analysis.

The undrained shear strength after reconsolidation is not expected to be much different from the c_u before pile installation in this plastic to highplastic underconsolidated clay. If so, the α-factor giving the estimated unit skin friction τ_u by the formula $\tau_u = \alpha\ c_u$ could be 0.65 to 0.8, giving τ_u equal to 0.18 to 0.2 times $(p'_v + a)$. τ_u is plotted in Fig. 6. This τ_u is lower than the API unit skin friction in Plate 31 of Ertec's Report No. 82-200-1, where $\alpha = 1$ has been assumed.

Effective stress analysis according to Janbu.

Janbu's effective stress method is generally a method for estimating the longterm capacity of piles in clay, silt or sand, and it does strictly not apply to the shortterm capacity of piles in clay, and especially not in highplastic clays with high clay contents. However, if the method is used it gives a negative skin friction factor S_{vn} in the order of 0.12 to 0.14 for a roughness ratio r = 0.7 to 0.9 (see Janbu, 1974). The corresponding ultimate unit skin friction $\tau_u = S_{vn}\ (p'_v + a)$ is dotted in Fig. 6, where p'_v equal to Ertec's interpreted maximum part effective vertical stress has been used. This serves as as estimate of the longterm capacity of the segment pile.

7. LOAD - DISPLACEMENT CURVES

A single slice model is used for the computation of t - w curves, t beeing skin friction per meter (kN/m) and w vertical displacement. Here, the displacement increment Δw due to a unit skin friction increment $\Delta\tau_0$ at the pile surface becomes

$$\Delta w = \int_{r_0}^{r_1} \frac{\Delta\tau}{G}\, dr = \Delta\tau_0\, r_0 \int_{r_0}^{r_1} \frac{dr}{r\,G} \tag{6}$$

Here it is assumed that the shear stress increment at a distance r from the pile centerline is $\Delta\tau = \Delta\tau_0\, r_0/r$, r_0 being the pile radius. Expressing the tangent shear modulus as $G = G_i\,(1 - \frac{\tau}{\tau_u})^n$, where τ_u is ultimate skin friction, and expressing τ at a radial distance r as $\tau = \tau_0\, r_0/r$, Eq. (6) becomes after rearrangements

$$\frac{\Delta\tau_0}{\tau_u} = 2\,\frac{G_i}{\tau_u}\;\frac{1}{\kappa}\;\frac{\Delta w}{d} \tag{7}$$

where

$$\kappa = \int_1^{\xi_1} \frac{d\xi}{\xi\left[1 - \dfrac{\tau_0}{\xi\,\tau_u}\right]^n}$$

and $d = 2\,r_0$ = pile diameter

$\xi = r/r_0$

$\xi_1 = r_1/r_0$

Judged from the triaxial, direct simple shear and consolidation tests as a whole, suitable pairs of G_i/τ_u and n seem to be 155 and 2.25 or 100 to 115 and 2.0 for Stratum II, and 105 and 2.25 or 75 to 85 and 2.0 for Strata I and III, respectively. (Note, τ_u is ultimate unit skin friction, and not undrained shear strength). The resulting normalized t - w curves are given in Fig. 7. An axis for absolute displacement in mm of 3" segment pile is included.

8. REFERENCES

Janbu, N. (1970): "Grunnlag i geoteknikk". Tapir forlag, Trondheim.

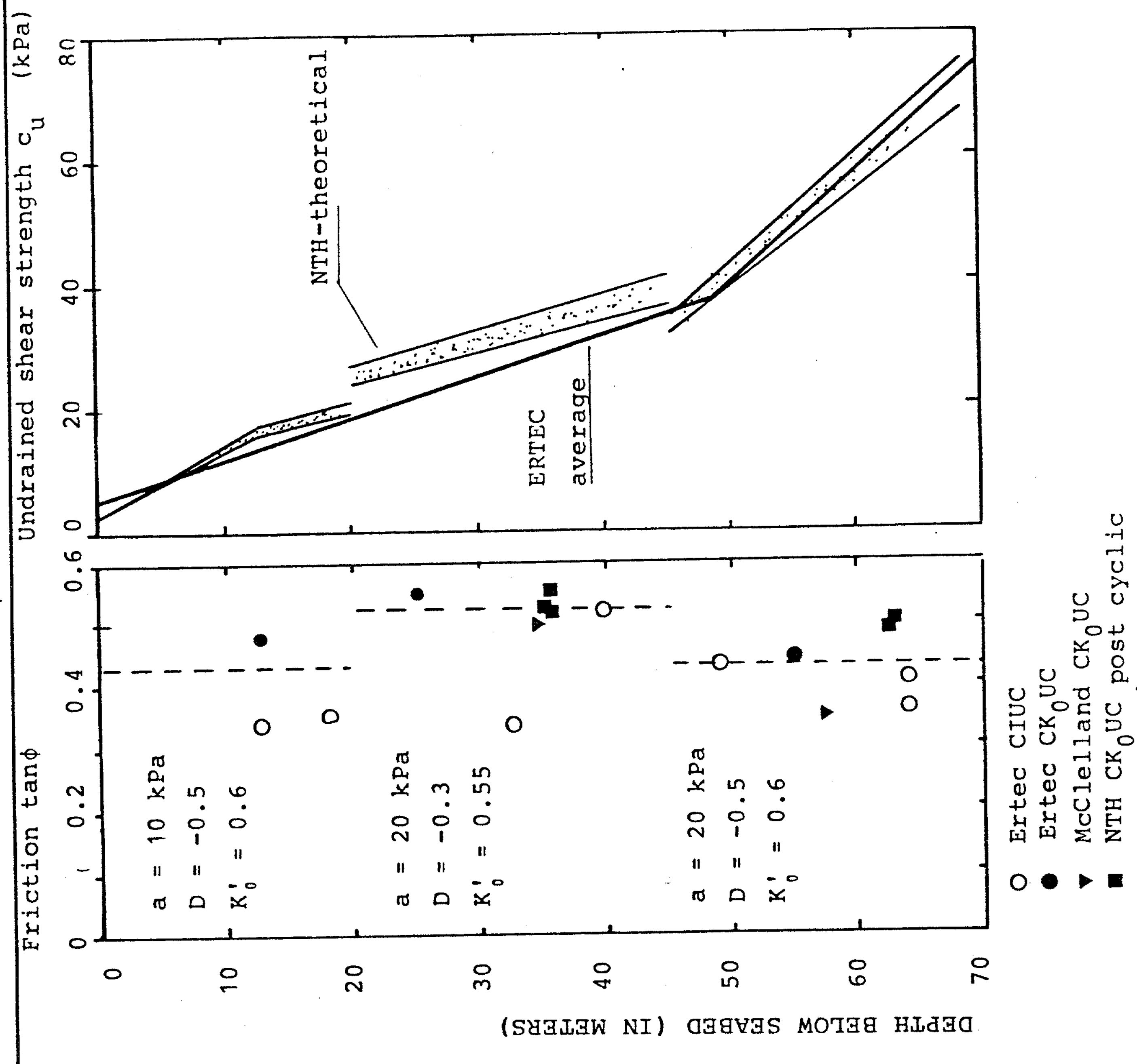
Janbu, N. (1977): "Slopes and excavations". Re. General report, Main Sess. 3, Proc. 9th ICSMFE, Tokyo, Vol. 2, pp. 549 - 566.

Randolph, M.F. and C.P. Wroth (1979): "An analytical solution for the consolidation around a driven pile". Int. Journal for Numerical and Analytical Methods in Geomechanics, Vol. 3, No. 3.

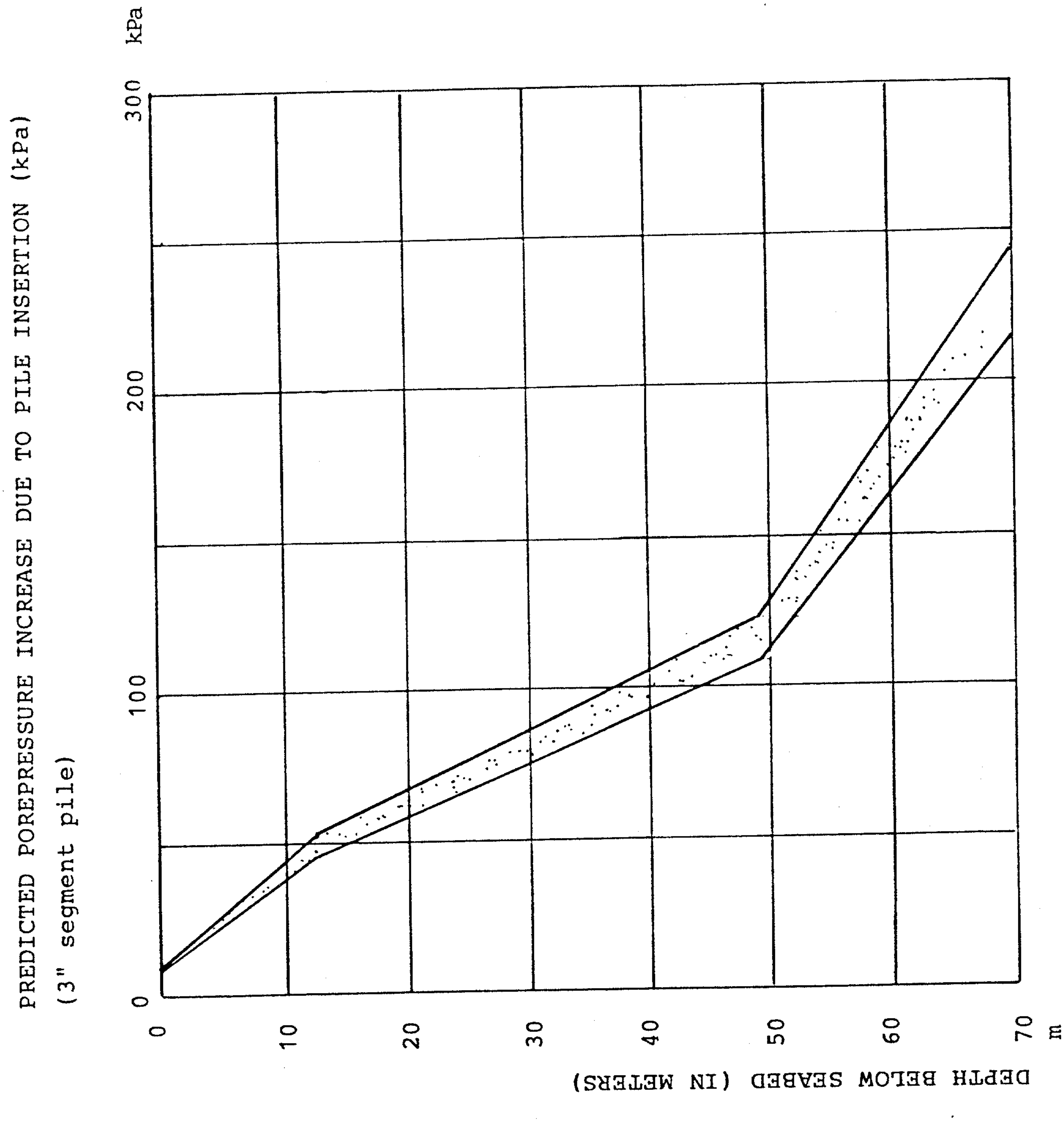
Svanø, G. (1981): "Undrained effective stress analysis". Dr.ing. thesis, NTH.

Torstenson, B.A. (1978): "The pore pressure Probe". Geoteknikkdagen, Norsk Geoteknisk Forening, Oslo, 11 nov. 1977, pp. 34.1 - 34.15.

Wroth, C.P., J.P. Carter and M.F. Randolph (1979): "Stress changes around a pile driven into cohesive soil". Recent developments in the design and construction of piles. 21 - 22 March 1979, London, pp. 255 - 264.



CNRD 13-2 TENSION PILE STUDY NTH-PREDICTIONS, SEGMENT PILE	PROSJEKT 0.82.02
	DATO 1982.08.31
INSTITUTT FOR GEOTEKNIKK, N-7034 TRONDHEIM - NTH	FIG. 1



CNRD 13-2 TENSION PILE STUDY
NTH-PREDICTIONS, SEGMENT PILE

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FIG.	2

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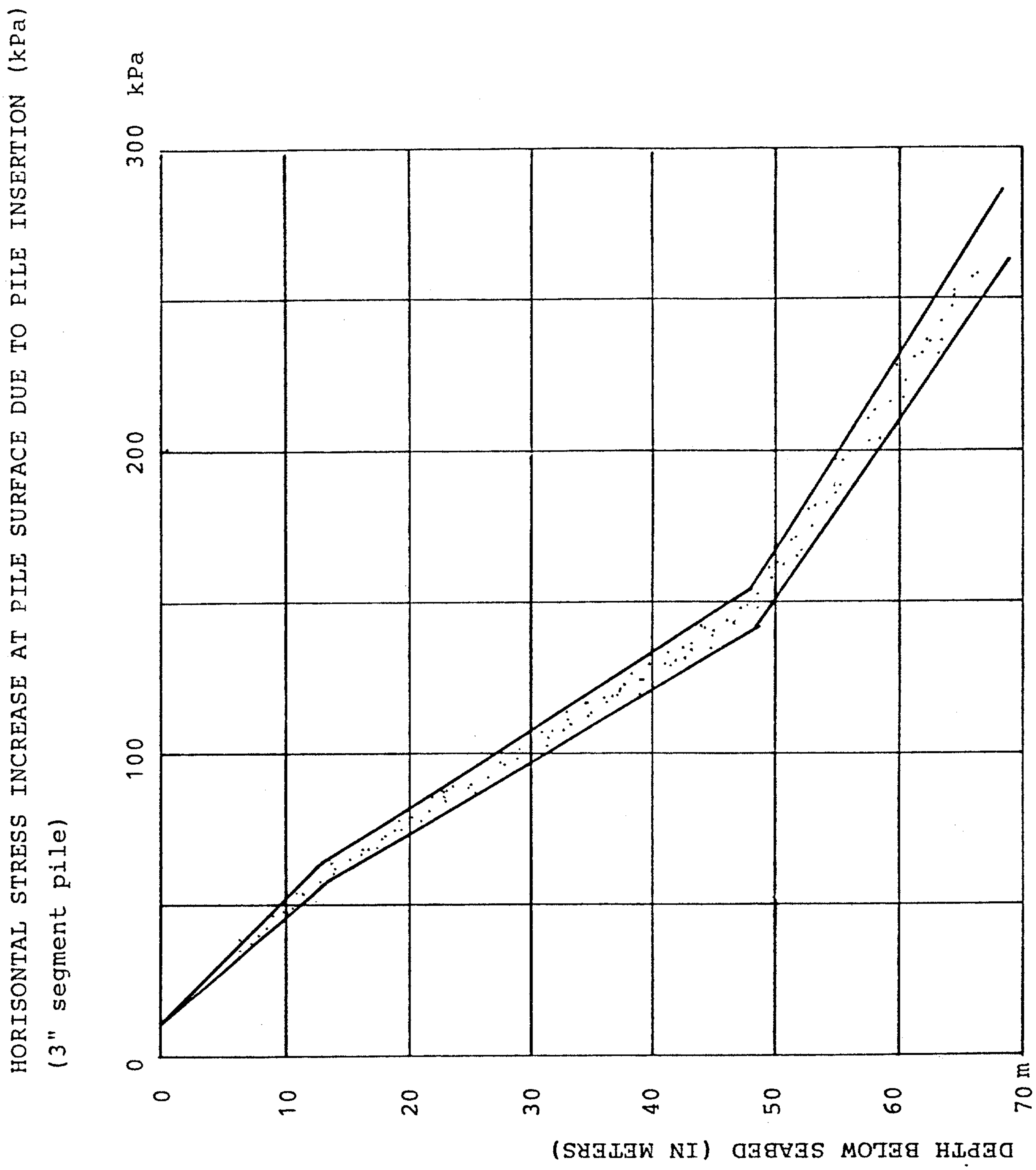

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FIG.	3

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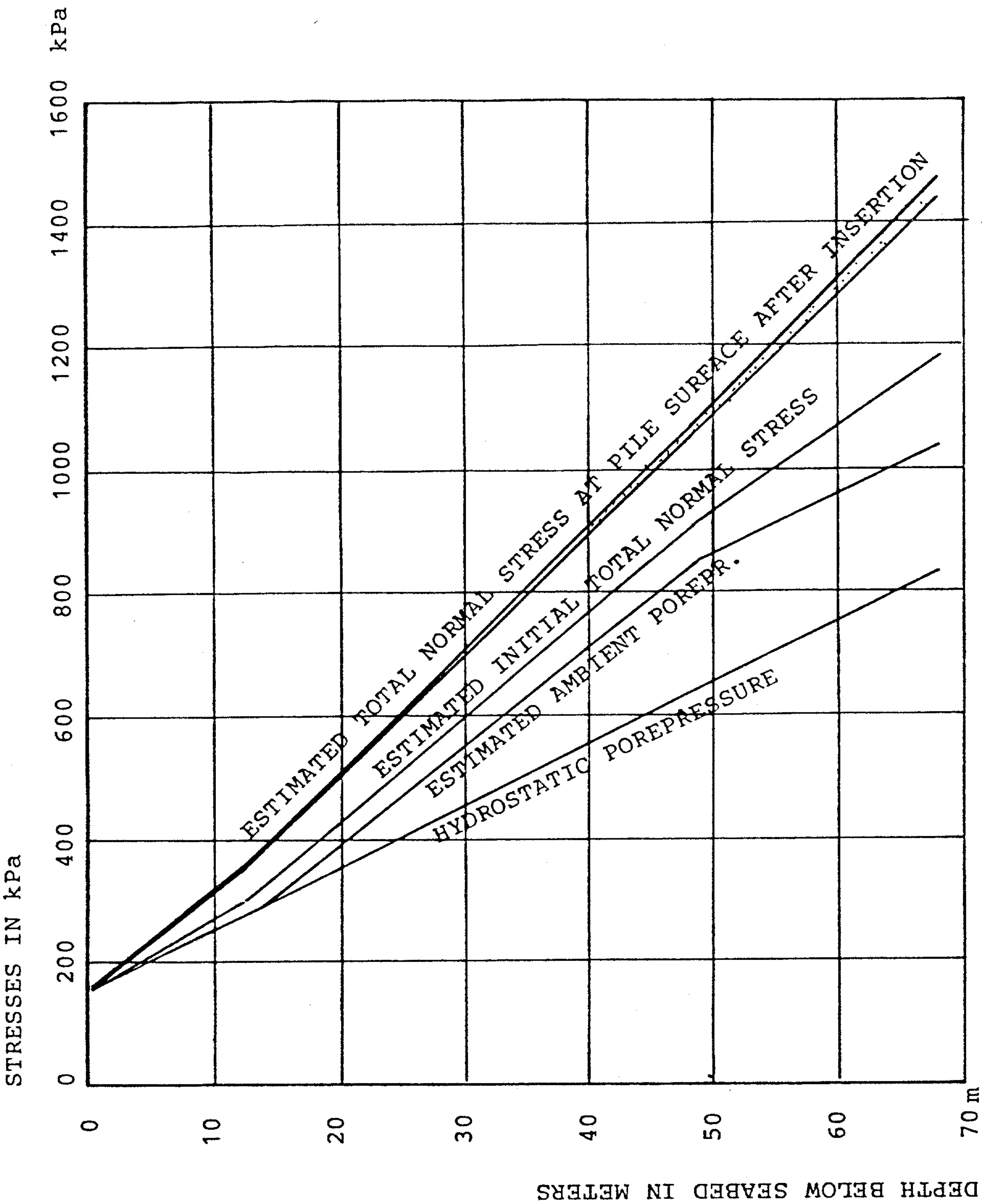

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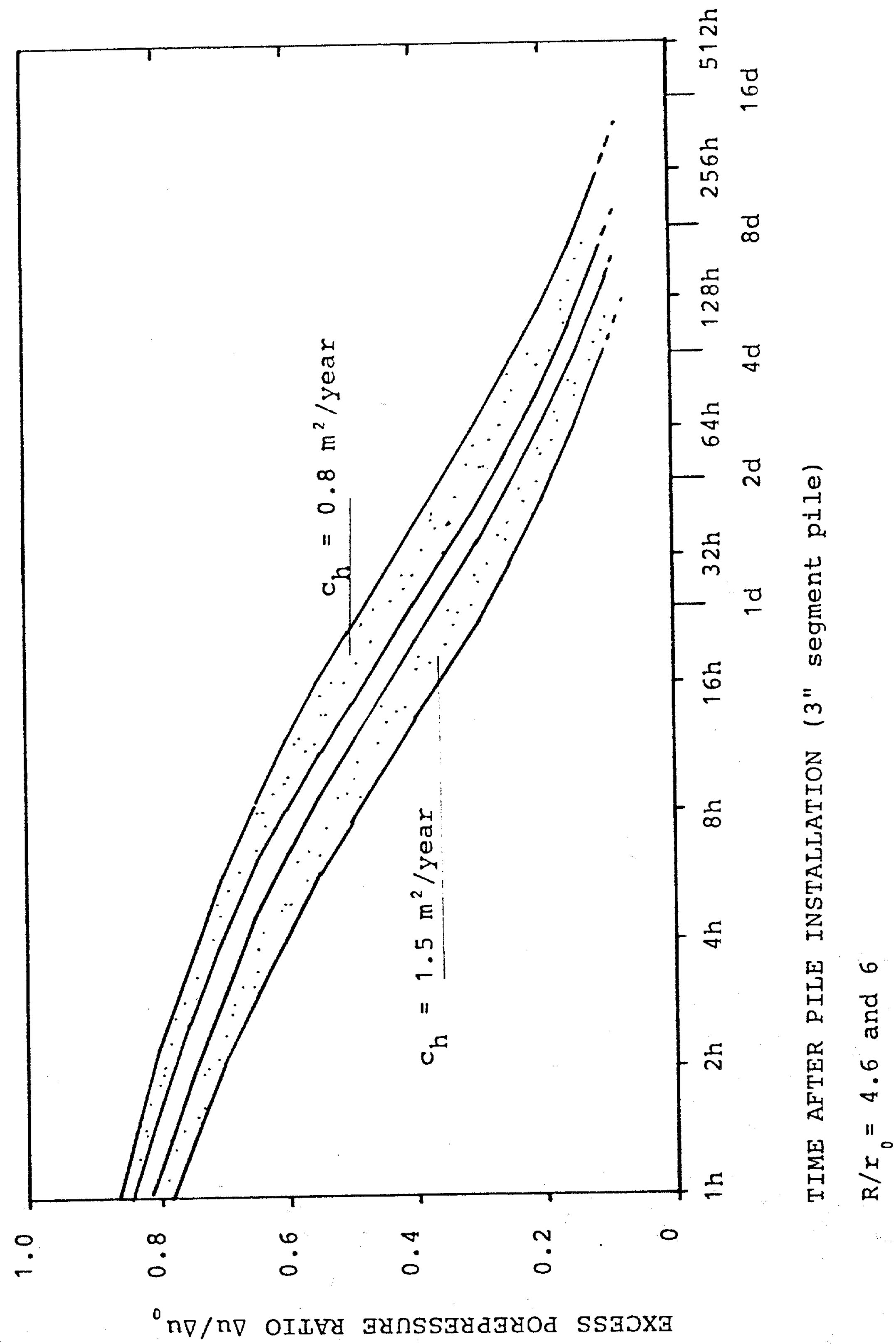

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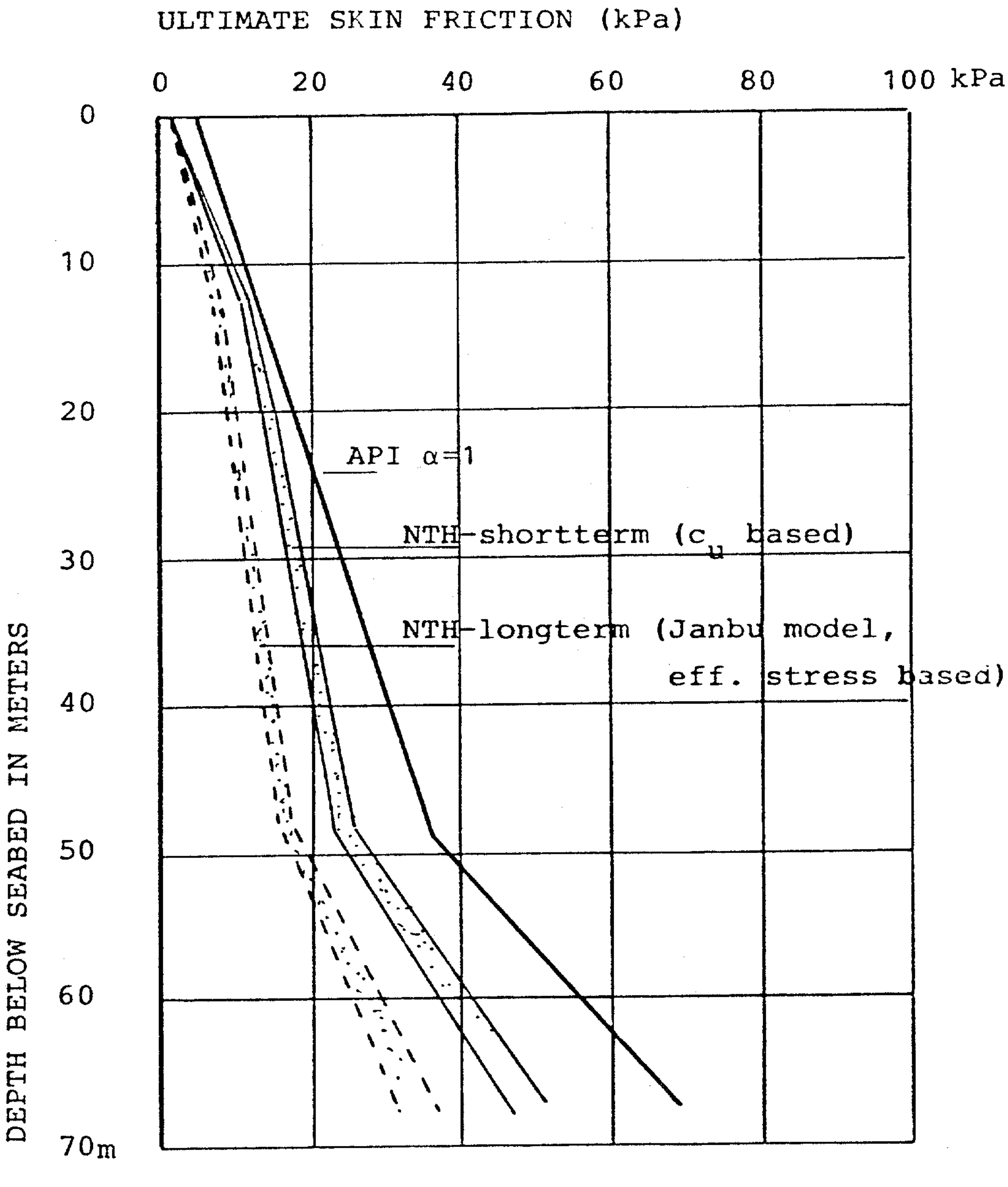
INSTITUTT FOR GEOTEKNIKK, N-7034 TRONDHEIM - NTH	FIG 5



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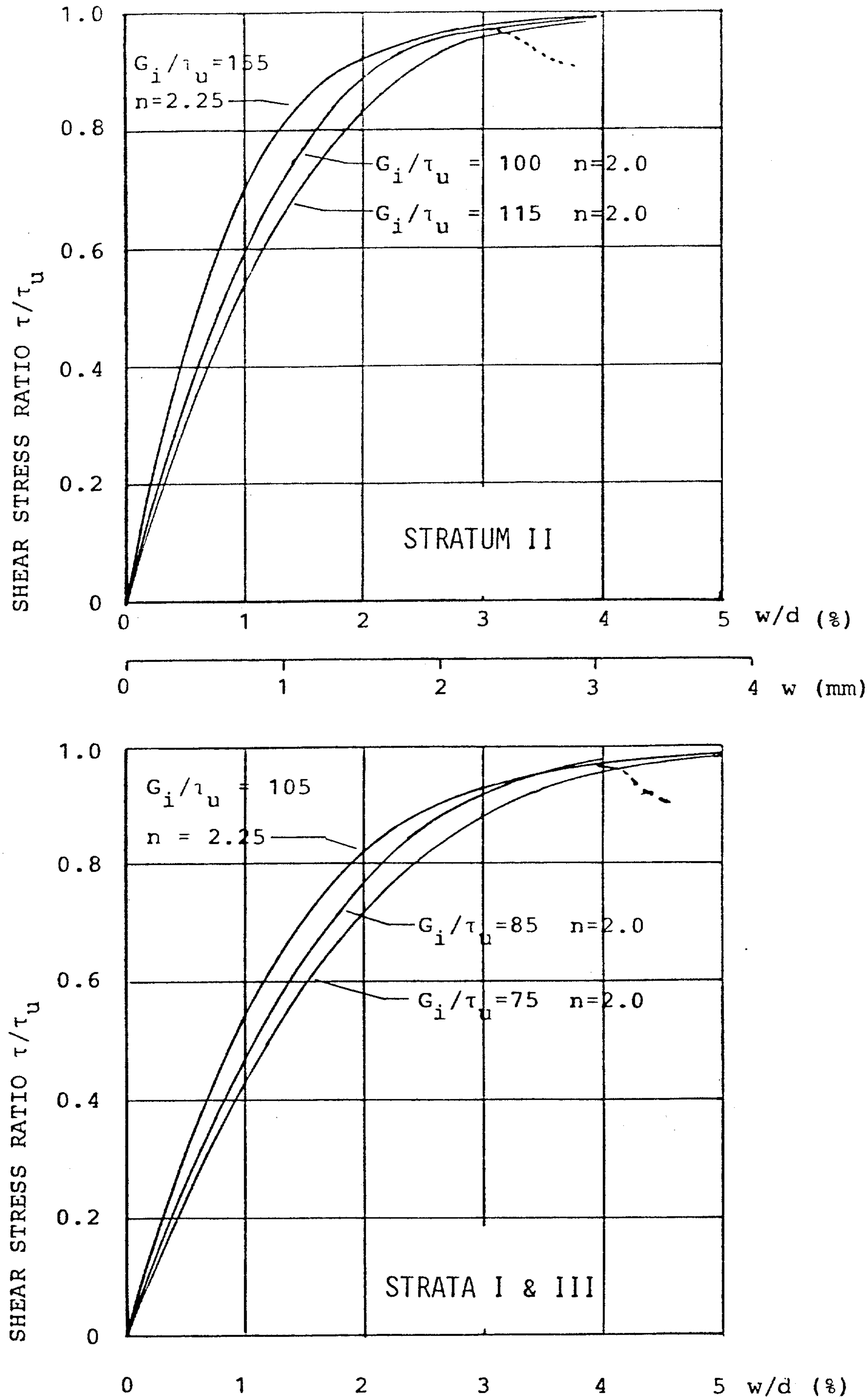

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