Delft Cluster

Title:	The reliability of global estimation of dynamic properties		
Author:	dr. ir. P. Hölscher	Institute:	GeoDelft
Author:		Institute:	
			May 2003

Number of pages	:	24	
Keywords (3-5)	:	vibrations, reliability, soil properties, field testing	
DC-Publication-number	:	01.05.02-11	
Institute Publication-number (optional)	:		
Report Type	:	☒	Intermediary report or study
	:	☐	Final projectreport
DUP-publication Type	:	☒	DUP Standard
		☐	DUP-Science

Acknowledgement
This research has been sponsored by the Dutch Government through the ICES-2 programme and the projectorganisatie HSL-Zuid The research is part of the Research programme of Delft Cluster.

GeoDelft	TNO	Holland Railconsult	TU Delft	HSL

Abstract

The soil prarameters needed for the advanced calculation of the wave transmission through the soil are considered. Several methods are compared:

- based on ordinary cone penetration testing
- based on vertical seismic profiling testing
- based on a undisturbed sample with laboratory testing

It is concluded that the first method is rather coarse. Better estimates can be obtained from more advanced methods. However, the comparison of the results shows that the determination of stiffness is hard and the reliability of the values is not fully known.

PROJECT NAME:	**Reliability of vibration prognosis and reducing measures**	PROJECT CODE:	**01.05.02**
BASEPROJECT NAME:	**Environmental impact of underground construction**	BASEPROJECT CODE:	**01.05**
THEME NAME:	**Soil and Structures**	THEME CODE:	**01**

Executive Summary

For reliable application of prognosis models the input parameters of the model must be known accurately. In general, several methods are available for determination. Often, only one method is choosen and assumed to be accurately. In this research several methods are compared.

The first method is the most generally used method. All properties are based on the cheap cone penetration test. This method requires a lot of enginereign judgement. It is applied by three partners in the project. The results are compared.

The second method is based on the vertical seismic profiling test. In this test the dynamic stiffness is determined of wave propagation axperiments. This method is believed to be more accurate than the method based on empirical correlations.

The third method exists of a more intensive field research. The cone penetration tests are inspected by an experienced geologist, a borehole is drilled and inspected visually. The volumetric masses, shearstiffness and damping are measured by laboratory testing.

It turns out that the generally applied method leads to many inaccuracy in parameter estimation.

Th eimportance of this error depends on the actual case studied. This is part of another studt within this project.

PROJECT NAAM:	**Reliability of vibration prognosis and reducing measures**	PROJECT CODE:	**01.05.02**
BASISPROJECT NAAM:	**Environmental impact of underground construction**	BASISPROJECT CODE:	**01.05**
THEMA NAAM:	**Soil and Structures**	THEMA CODE:	**01**

Table of contents

1 Introduction

1.1 Object of this report

For the estimation of vibration level in the soil around a vibrating source advanced models are available. These models needs a lot of input. This input is not always measured directly, but in normal engineering practice estimated by using the results of cone penetration tests. However the reliability of this method is not known.

This report points at the reliability of the soil-parameter estimation only. Of course the reliability of the calculated vibration levels depends also on the accuracy of the model and the source input, but this is studied in another part of the Delft Cluster project.

1.2 Content of the study

This study is carried out at a test field in Rotterdam North, where the vibration of many sources is studied in 2001. Many advanced calculations in order to find the influence of parameter and model deviations are carried out.

This study is historically build as follows:

1. the three partners (Holland Railconsult, TNO Building and Construction Research and GeoDelft) have modeled the soil independently, using the available cone penetration test (cpt) only
2. a vertical seismic penetration test (vspt) is carried out
3. the three partners have commonly made an improved estimation of the soil model
4. a more sophisticated study is done: a geological expert is consulted and a boring is carried out. The soil is classified, volumetric mass is measured and stiffness and damping is measured by free torsion vibration tests (ftv)

The results of this study is described in this report.

2 Normal procedure: estimates based on cone penetration test

2.1 Introduction

The partners have modeled the subsoil using the three available cpt (see appendix 1). The normal procedures for dynamical simulations are used.

This chapter presents the results and compares the differences and points in common. The results are presented per partner, which are called 1, 2 and 3. This numbering is used throughout the complete report.

2.2 Results

The results of the normal procedure are [Pruiksma,2002]:

Top [m] NAP	bottom [m] NAP	density [kg/m^3]	Young's modulus [MPa]	Poisson's ratio	Young's modulus for damping [Pa]
-5.0	-11.5	1600	33.4	0.45	3.94E3
-11.5	-16.5	2000	224.0	0.40	1.03E4
-16.5	-26.5	2000	280.0	0.40	1.05E4
-26.5	-45.0	2000	336.0	0.40	1.04E4

Table 2.1 : Partner 1 layering of the soil and soil parameters

top	bottom	ρ	E_{dyn}	ν	ξ_i
NAP [m]	NAP [m]	[kg/m^3]	[MN/m^2]	[-]	[%/m]
-5.00	-12.00	1500	17	0.48	0.05
-12.00	-13.00	1900	31	0.45	0.04
-13.00	-25.50	2000	230	0.40	0.03
-25.50	-34.80	2000	518	0.40	0.03
-34.80	-37.80	2000	500	0.40	0.03
-37.80	-60.00	1900	204	0.45	0.05

Table 2.2:Partner 2 layering of the soil and soil parameters.

Top [m] NAP	Bottom [m] NAP	Density [kg/m^3]	E [MPa]	Poisson [-]	Rayleigh (damping)	
					Alpha [1/s]	Beta [s]
-5	-12.5	1640	10	0.4	0.071	5.78E-5
-12.5	-14.5	1960	120	0.49	0.071	5.78E-5
-14.5	-17.5	1960	220	0.49	0.071	5.78E-5
-17.5	-21	1960	320	0.49	0.071	5.78E-5
-21	-24	1960	200	0.49	0.071	5.78E-5
-24	-26.5	1960	140	0.49	0.071	5.78E-5
-26.5	-34	1960	400	0.49	0.071	5.78E-5
-34	-37.5	1960	260	0.49	0.071	5.78E-5
-37.5	-42	1800	80	0.49	0.071	5.78E-5
-42	-50	1960	200	0.49	0.071	5.78E-5

Table 2.3 : Partner 2 layering of the soil and soil parameters

2.3 Comparison

2.3.1 Layering

The number of layers identified by each partner is different. The positions of the most important layer separations are identical, the difference is the fact that partners with more layers identify within these regions more layers. This is a common problem in interpretation of cpt.

2.3.2 Volumetric mass

Figure 1 shows the estimated volumetric masses on depth for the soil. In general partners agrees, but differences unto 5% are seen.

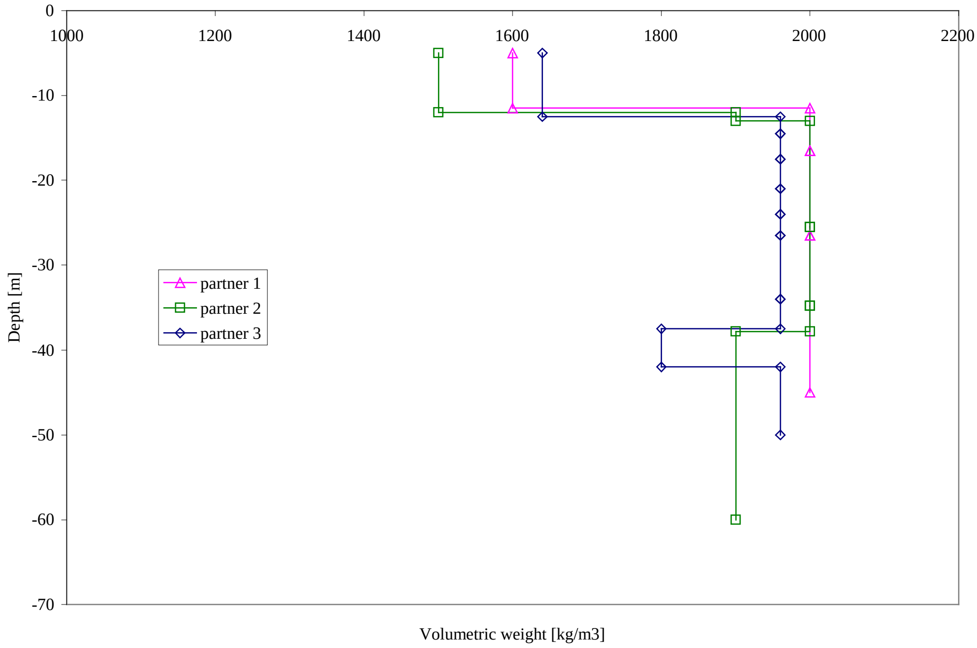


Figure 1 Volumetric mass from cpt

2.3.3 Stiffness

Figure 2 shows the estimated shearstiffness on depth. In the tables above the Youngsmodulus is mentioned, using the Poisson'sratio, these are recalculated to shearstiffness, a parameter which is more common in geotechnical engineering. Figure 2 again a common agreement on stiffer or weaker, but differences of 50% between partners are seen.

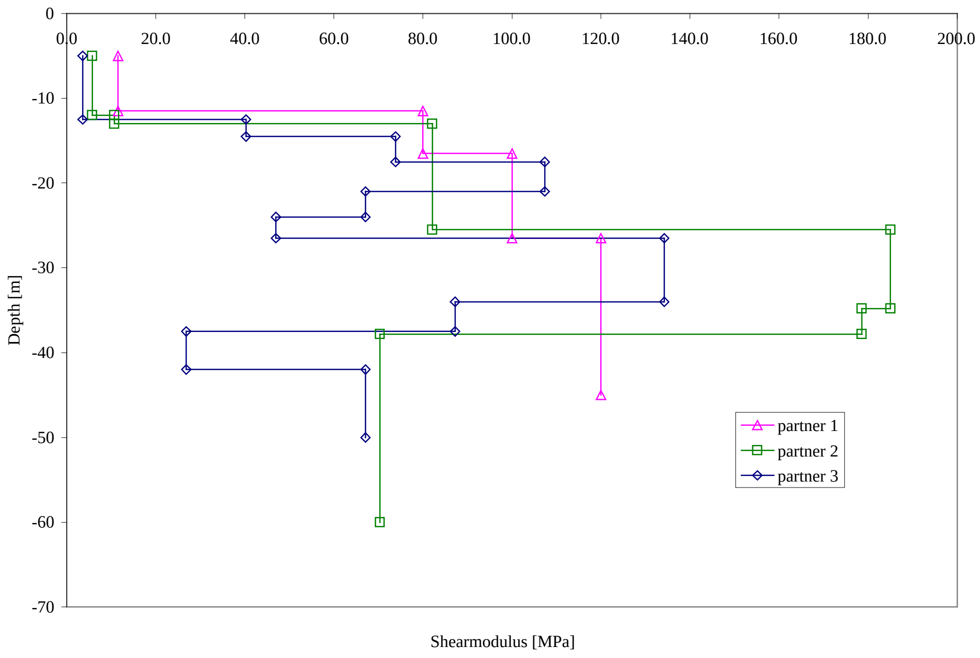


Figure 2 Shearmodulus from cpt

2.3.4 Poisson's ratio

Figure 3 shows the Poisson's ratio on depth. It seems that the information on this correlation is insufficient, the only agreement is the fact that Poisson'sratio is expected to be within the interval from 0.40 and 0.49.

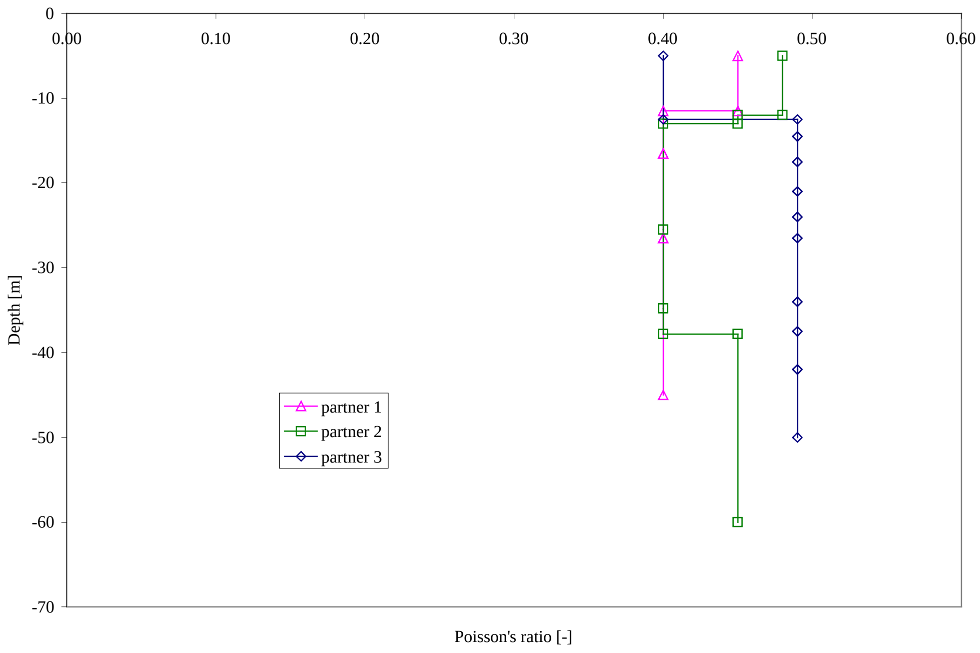


Figure 3 Poisson's ratio on depth from cpt

2.3.5 Damping

The damping values in Table 2.1, Table 2.2 and Table 2.3 shows that even the definition of damping is not identical for the partners. Therefore, a separate study for damping is carried out [Hölscher,2002].

3 Alternative procedure: using vertical seismic profiling test

3.1 Introduction

An alternative method to obtain information on the stiffness of the soil is the vertical seismic profiling. In this test the time a downward traveling artificially generated (shear)wave uses to travel from one transducer to another transducer is measured. The distance between the transducers is exactly known. So the shearwavevelocity is known, and using the (estimated) volumetric mass, the shear modulus can be estimated.

The vspt transducer available at GeoDelft has a vibration transducer spacing of 1 m. Thus the measured value is a mean value over 1 m soil (in depth). The transducers are pushed 1 m further after each measurement, so for each meter one value is available.

3.2 Results

Appendix 2 shows the vertical seismic profiling test (vspt) results [Pruiksma, 2002]. Measured is the shearwave velocity as a function of depth. The vspt is carried out until 13 m depth (from surface).

Figure 4 shows the profile based on the volumetric mass from cpt and shearwave velocity from vspt measurement. In this case only one case is made in discussion between the partners. For comparison the originally estimated profiles are also shown in Figure 4.

The measurements of vspt are not exact. The measurement is carried out at three positions in the field (distance about 10 m) and several blows are given. This leads to insight in the accuracy. This is shown in Appendix 2.

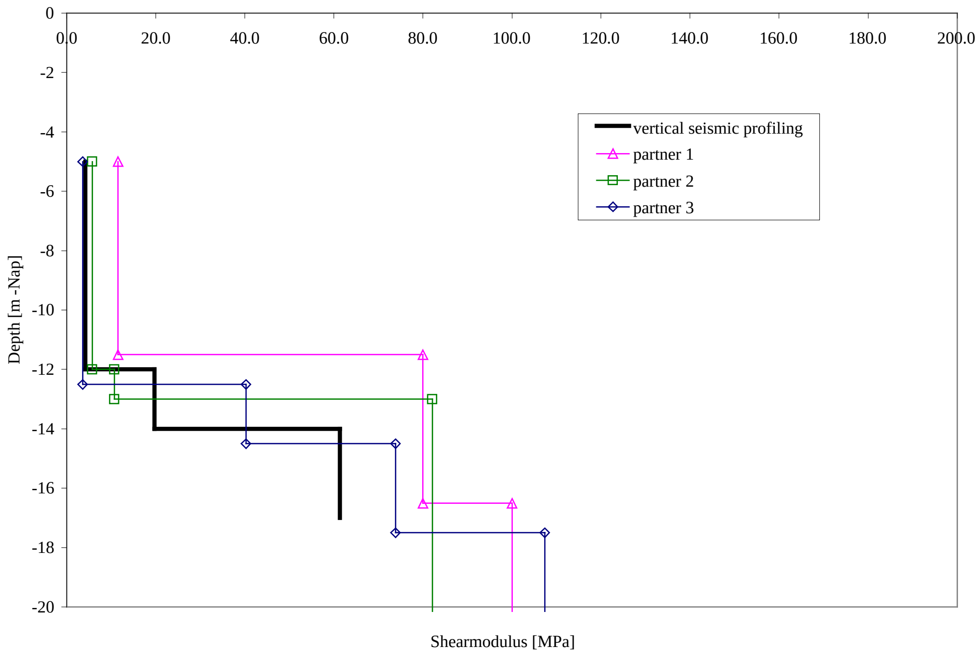


Figure 4 Shearstiffness profile based on vspt and compared with first estimates

3.3 Interpretation

Figure 4 shows that in general the estimated shearmoduli are quite reasonable, compared with the measured values. Differences unto 50% can be expected. It is interesting to note that some of the sub-layers identified by some partners are also identified in the vspt, others however are not identified by the vspt.

4 More intensive study of the soil properties using a boring

4.1 Introduction

As a last step it is tried to generate a very advanced description of the soil. The following activities are carried out:

- an experienced geologist is consulted
- an undisturbed boring is made
- the layering is based on the boring
- the volumetric mass of each meter boring measured
- for four layers the soil is tested by free torsion vibration test obtaining the Shearmodulus and the damping of the soil.

The results of these activities are presented in this chapter and the consequences are discussed.

4.2 Experienced Geologist

The experienced geologist is consulted. He studied the cpt and vspt measurements. He was asked to give a general description of the site. Of course he used his general geological knowledge of the region.

The most remarkable results are:

- the geologist directly identified the peat layer which is in the profile
- the geologist clearly identified a non-horizontal layering, which had an angle of about 45° with the directions used in the measurements.

In general is seems useful to consult an experienced geologist for dynamical applications.

4.3 Visual inspection of the boring

Appendix 3 shows the picture of the boring. The layers are exactly identified, Table 4.1.

top	bottom	material
[m NAP]	[m NAP]	
-5.00	-5.30	disturbed toplayer
-5.30	-6.00	layer with roots
-6.00	-6.25	peat
-6.25	-7.40	clay
-7.40	-8.25	peat
-8.25	-11.85	clay (with peat layers)
-11.85	-12.15	clay
-12.15	-12.70	silty clay
-12.70	-14.65	sand

Table 4.1 Layering based on visual inspection of boring

These layers can be compared with values from the vspt and the volumetric mass, see Figure 5. In this Figure the measured shearwave is shown, together with the volumetric mass (divided by 20) and the location of the visually identified layers from the boring.

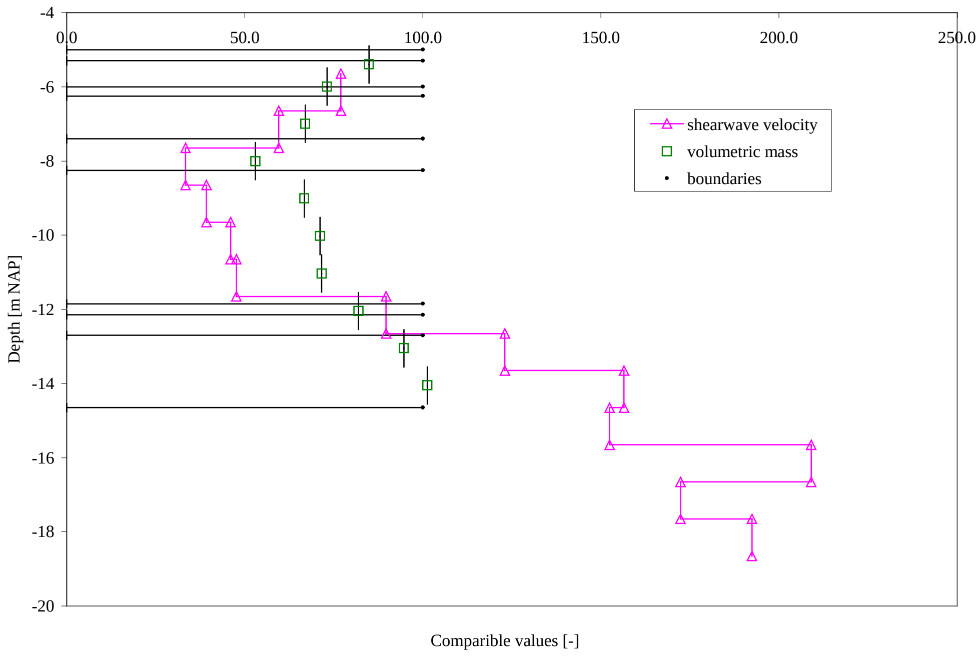


Figure 5 Comparison several methods for layering

It should be mentioned that for some visually identified layers both the vspt and the volumetric mass interval (each are 1 m) are to rough. However, we should evaluate the importance of such thin layers in dynamics. For the thicker layers a reasonable accordance between the methods is found, taking into account that the material property 'shearstiffness' depends on the product of volumetric mass and (squared) shearwave velocity and both measurements are not exact.

4.4 Volumetric mass

Figure 6 compares the estimated and measured volumetric mass for the location. In the soft layers the volumetric mass is strongly overestimated. It should be taken into account, that if the stiffness is calculated from the measured shearwave velocity and the estimated volumetric mass, this error propagates into the estimation of the shearstiffness.

Both values in this figure have a confidence interval. For the measured values this interval is estimated from standard error analysis. For the estimated values this is the value the engineers expect to know the values. It turns out that the engineers are to optimistic about the correlation from cpt to volumetric mass.

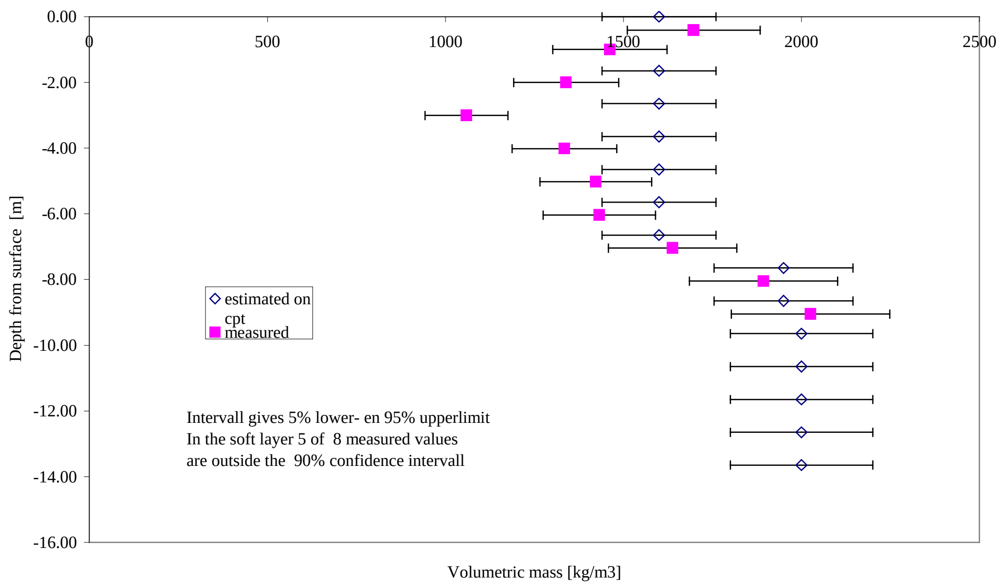


Figure 6 Comparison estimated volumetric mass and measured volumetric mass

4.5 Shearstiffness and damping

The Begeman boring gives undisturbed samples over 9 m depth. From top to bottom we find a mixed toplayer, and then four layers: 2 m clay, 1 m peat, 3 m clay and sand. From each of these four layers a sample is tested dynamically.

The clay and peat samples are undisturbed. The sand sample is remoulded and recreated to original density. All samples are loaded isotropically to 2/3 of vertical stress in the field (thus the coefficient of horizontal stress is assumed to be 0.5) and consolidated. After consolidation the samples are tested with several masses on top. A small additional vertical force is applied during all tests.

The stiffness and damping at very small amplitudes are required. This amplitude is that small, that it is hard to measure. By application of the non-linear constitutive model descibed by [Hölscher, 2002b], the required values can be found by extrapolation to small amplitudes.

4.5.1 Sand

In total five masses on top are tested, and one case (2*20 kgf) is repeated. Annex 9.1 and 9.2 shows the measured displacements and the fitted displacement for sand. The model fits well with the measurement, so it is concluded that the model is applicable for this sand. Figure 7 shows the stiffness of the sample and **Error! Reference source not found.** shows the damping of the sample for several amplitudes, extrapolated from the model.

It is concluded that for small shearstrain (10^{-6}) the shearmodulus is 87 MPa and the damping is 1.9 %. The curve found here is relatively flat compared with values from literature [Das, 1983]

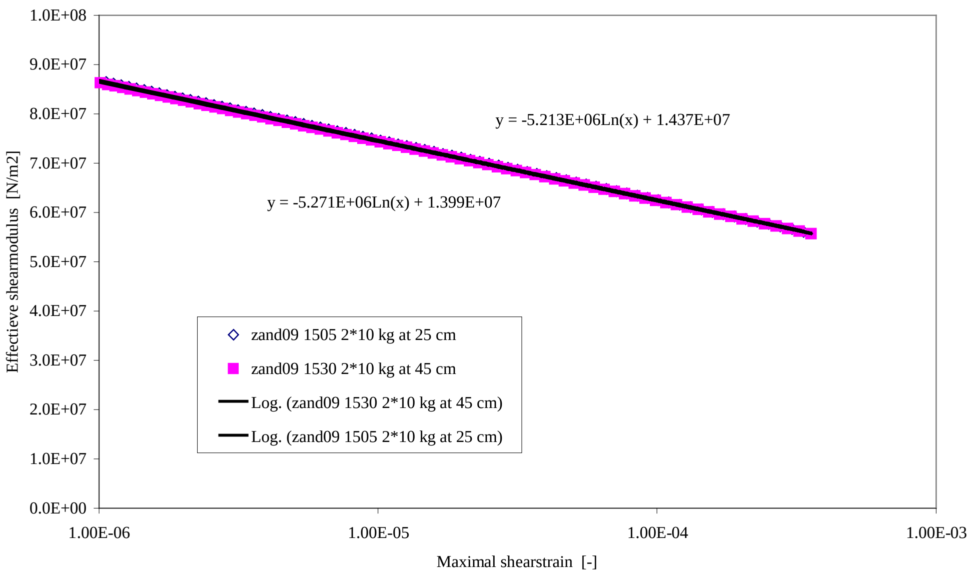


Figure 7 Shearmodulus of sand on maximum shearstrain

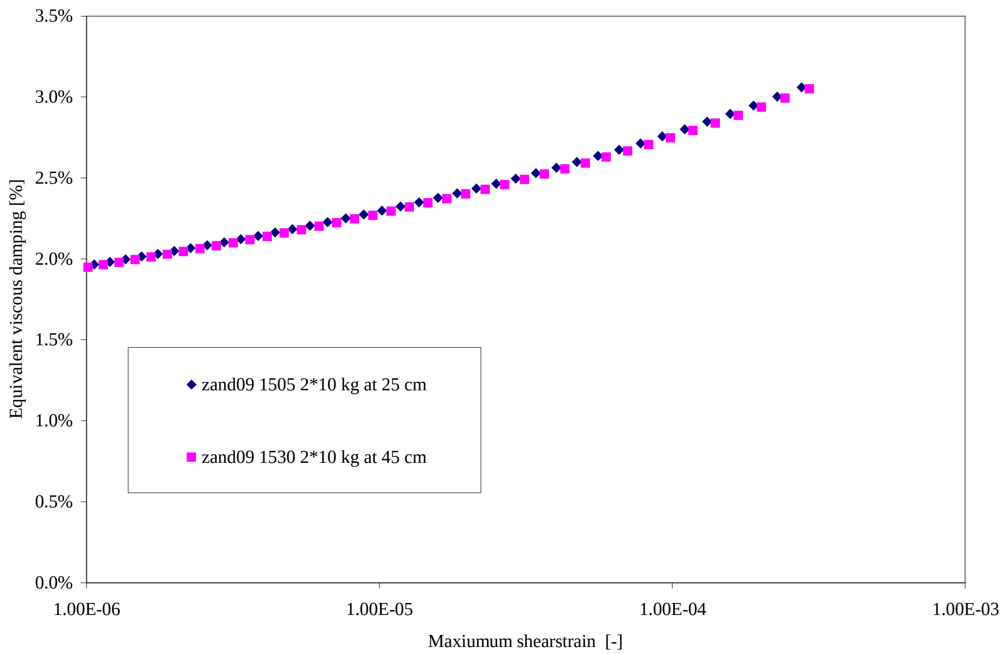


Figure 8 Viscous damping of sand on maximum shearstrain (frequency 2-3 Hz)

4.5.2 Deep Clay layer

In total five masses on top are tested, and one case (2*5 kgf) is repeated. Annex 6.1 to 6.6 shows the measured displacements and the fitted displacement for clay. The model fits well with the measurement, so it is concluded that the model is applicable for this clay. Figure 9 shows the stiffness of the sample and Figure 10 shows the damping of the sample for several amplitudes, extrapolated from the model.

For very small shearstrain amplitudes (10^{-6}) the shearmodulus is 10 MPa, and the dampingratio is 3.1 %. This dampingratio is in good agreement with general values from literature [Das, 1983].

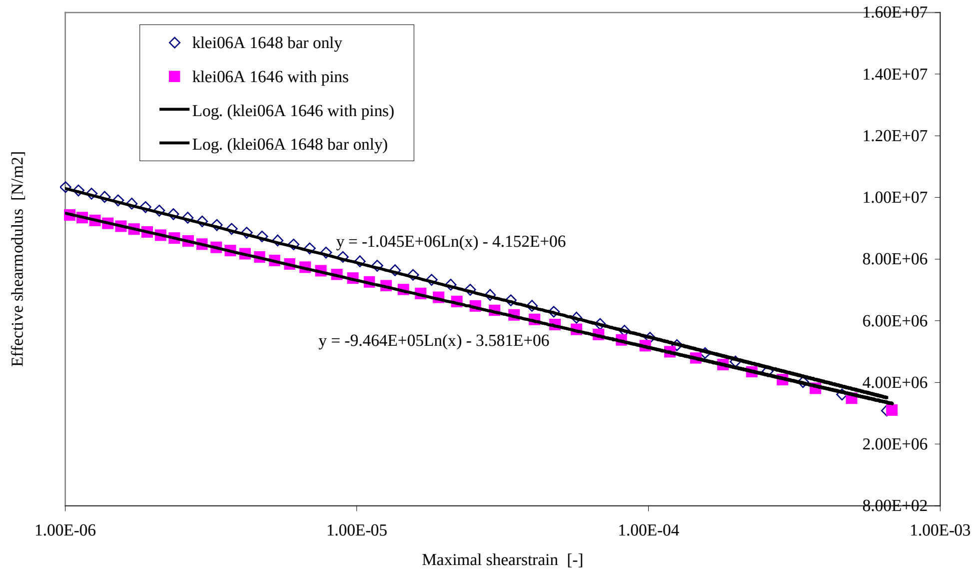


Figure 9 Effective shear modulus of deep clay on maximum shearstrain

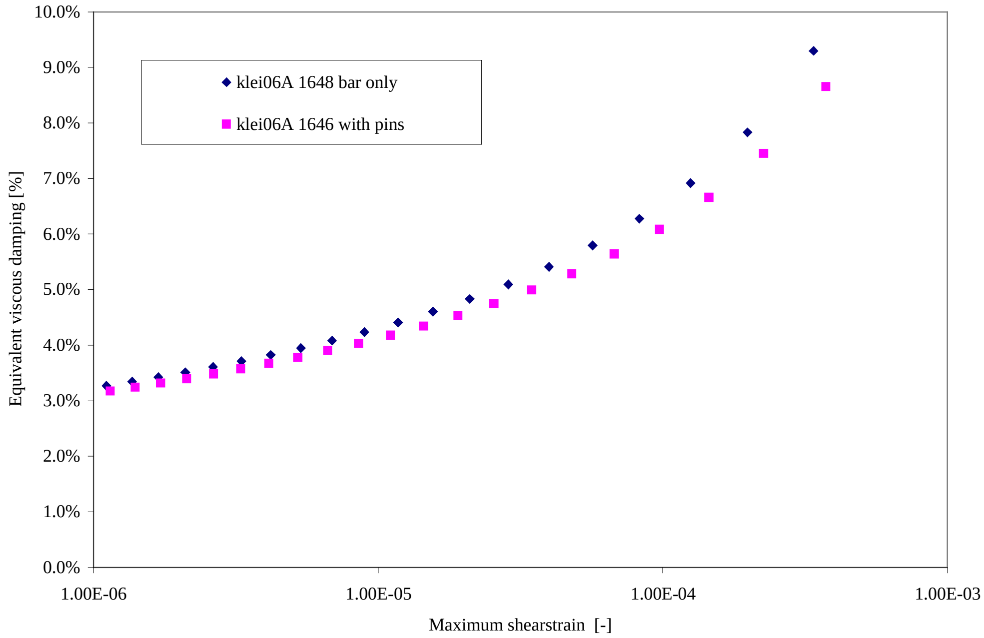


Figure 10 Equivalent viscous damping of deep clay

4.5.3 Peat

In total two masses on top of the peat sample are tested. Annex 4.3 and 4.4 shows the results of the measurements and the fitted curves. It turns out that the model cannot describe the results of the measurement. Figure 11 shows the results of one typical measurement, the fit with the model and the fit with the viscous model. The standard viscous model is much better. Therefore, it is concluded that the damping of peat should be preferably described with the standard viscous model. The viscous damping ratio is about 18%. The shearmodulus is about 3 MPa.

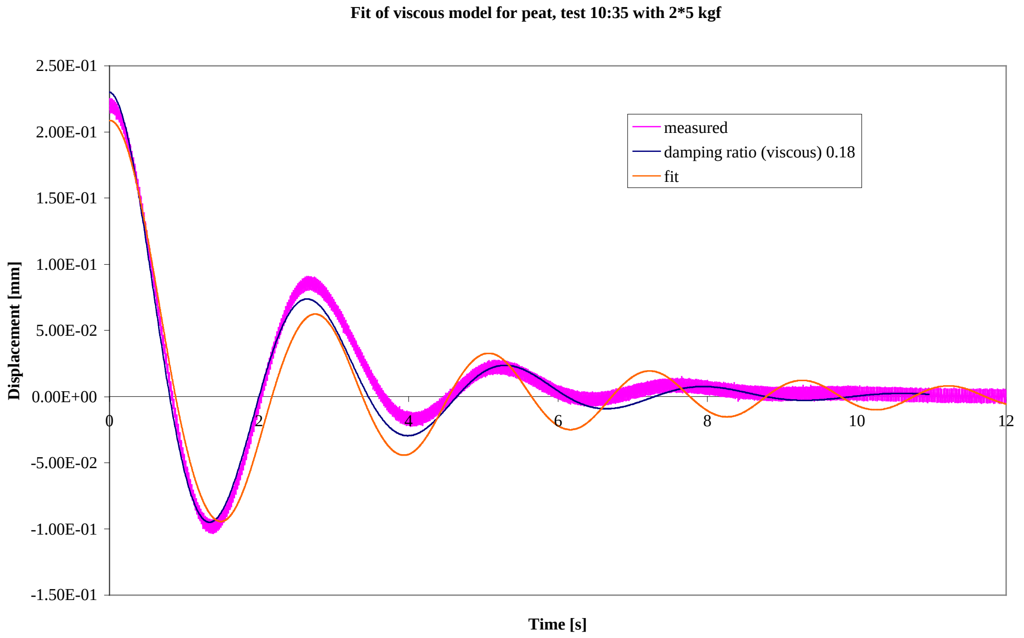


Figure 11 Comparison viscous and new model for peat

4.5.4 Shallow clay layer

Form this layer two tests are elaborated: with 2*5 kgf and 2*20 kgf. The results are shown in Annex 3.3 and 3.5. For this clay the model fits good. Figure 12 shows the shearmodulus on maximum shearstrain, Figure 13 shows the viscous damping ratio on maximum shearstrain.

It is concluded that for very small shearstrain (10^{-6}) the shearmodulus is 8 MPa, and the viscous damping ratio is 3.0 %. This dampingratio is in good agreement with general values from literature [Das, 1983].

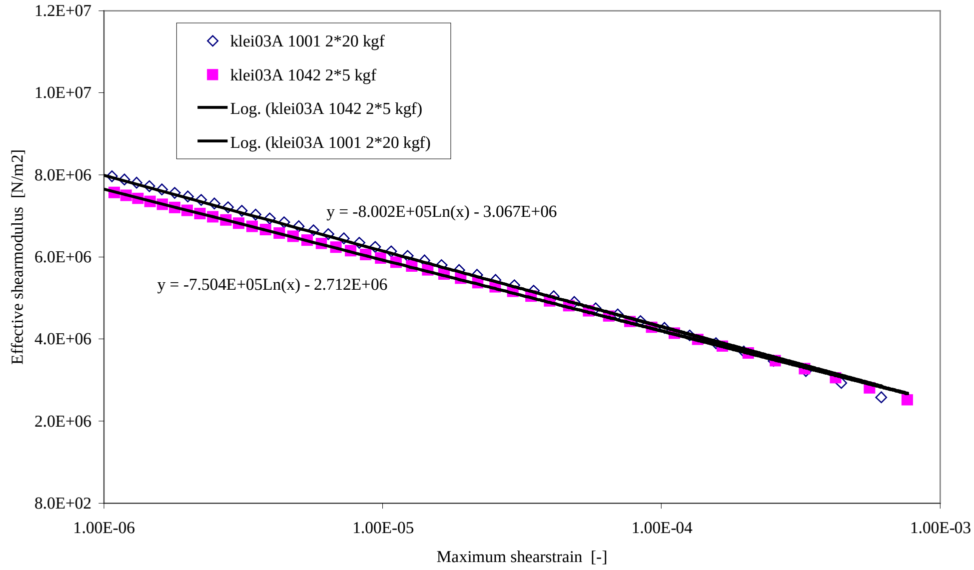


Figure 12 Shearmodulus of shallow clay layer on maximum shearstrain

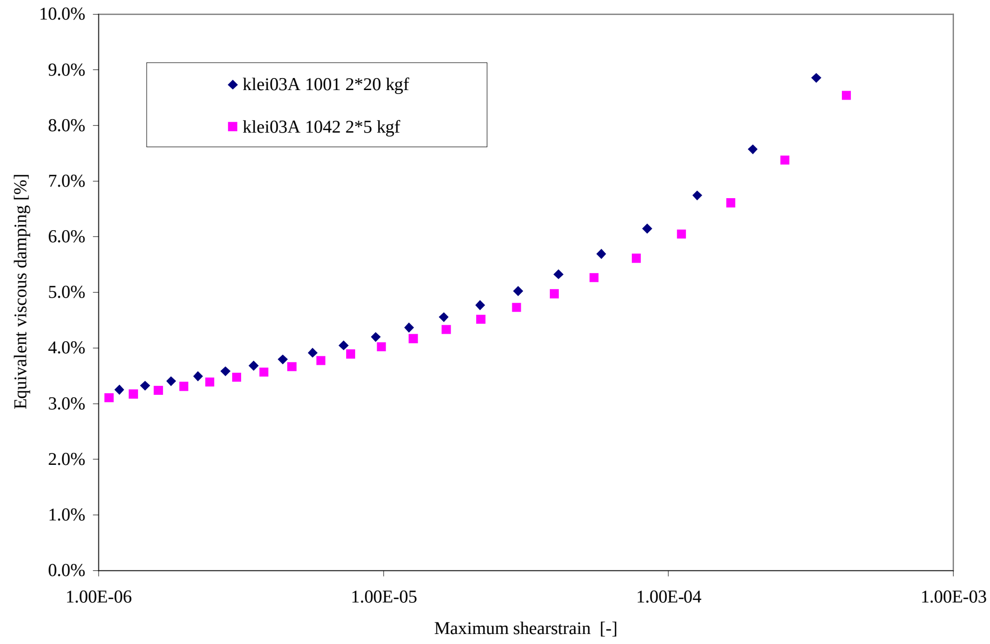


Figure 13 Equivalent viscous dampingratio for shallow clay layer

4.5.5 Discussion

The laboratory experiments are summarised in Table 4.2. The shearmodulus from the field measurement is calculated from the shear wave velocity measured in the field and the volumetric mass measured in the laboratory. It turns out that the laboratory values are generally lower than the field values.

layer	depth	shear modulus lab.	volum. mass	shear wave lab.	shear wave field.	shear modulus vspt	damping
	m	MPa	kg/m^3	m/s	m/s	MPa	%
shallow clay	1.8	8	1365	77	59	4.8	3.0
peat	2.7	3	1080	53	33	1.2	18.
deep clay	4.7	10	1450	83	83	10	3.1
sand	9.0	87	1930	212	156	47	1.9

Table 4.2 Overview laboratory tests and comparison with field data

The difference between the values measured in the field and in the laboratory might be explained from the assumption that the shearmodulus is calculated at a shearstrain level 10^{-6}. The model results in a constant increasing stiffness with decreasing shearstrain, which is not realistic. Generally, it is assumed that the curve for shearmodulus flattens at shearstrain levels from $5*10^{-5}$ to $1*10^{-6}$. Assuming that the value at shearstrain $5*10^{-5}$ is the maximum value, the results of Table 4.3 are found. This table leads also to a realistic estimation of the deviation which can be expected in parameter estimation.

Table 4.3 Result compared for shearstrain $1*10^{-5}$

layer	depth	shear modulus lab. shearstrain $1*10^{-5}$	shear modulus vspt
	m	MPa	MPa
shallow clay	1.8	5.9	4.8
peat	2.7	3	1.2
deep clay	4.7	7.5	10
sand	9.0	75	47

5 Conclusions and recommendations

This project is started with a general estimation of soil properties based on cpt. These estimations are strongly engineer dependant, and large differences are encountered.

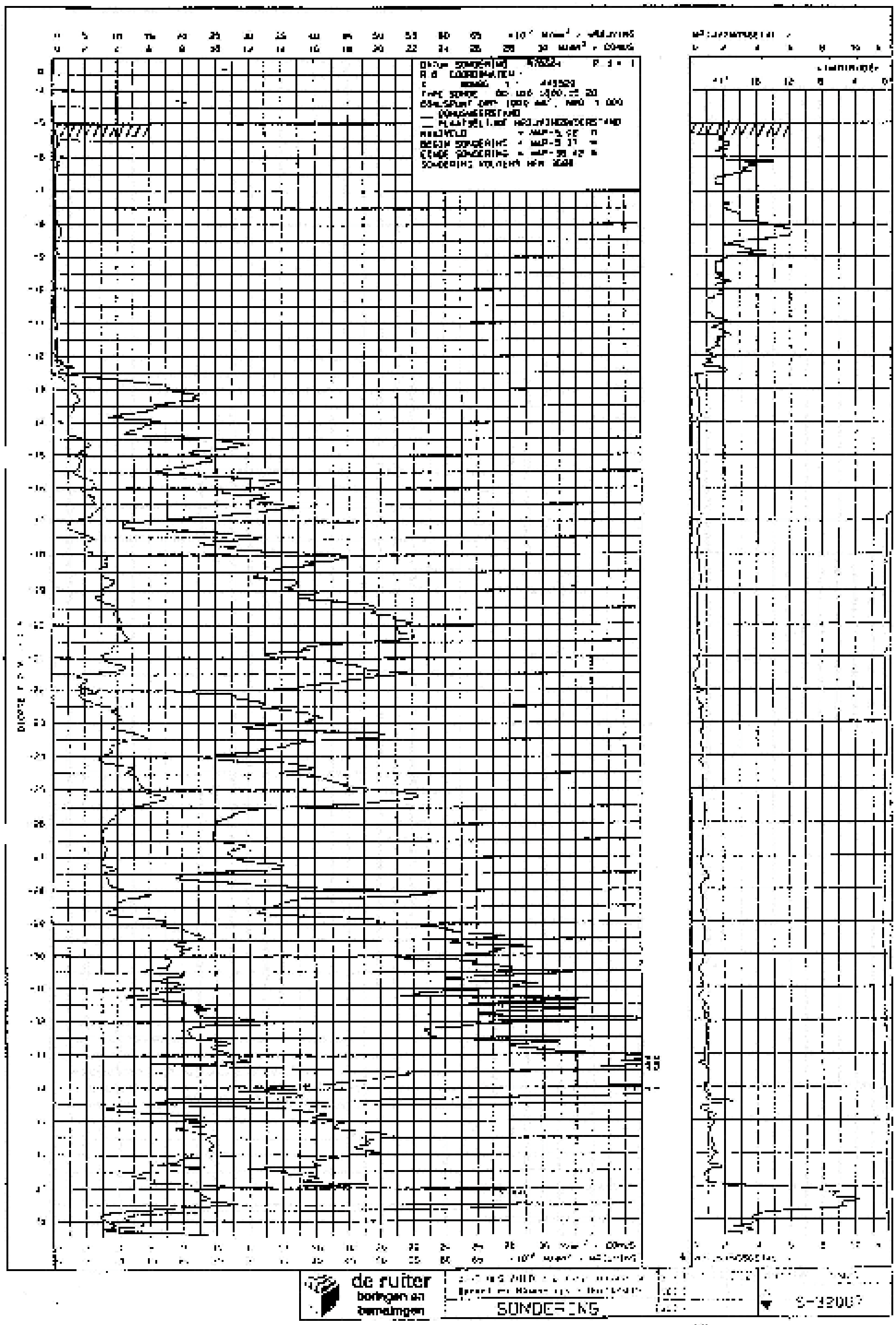
The vertical seismic profiling is seen as a more reliable method for estimation of the shearstiffness. In that case, it must be taken into account that the volumetric mass must be estimated with a comparable accuracy.

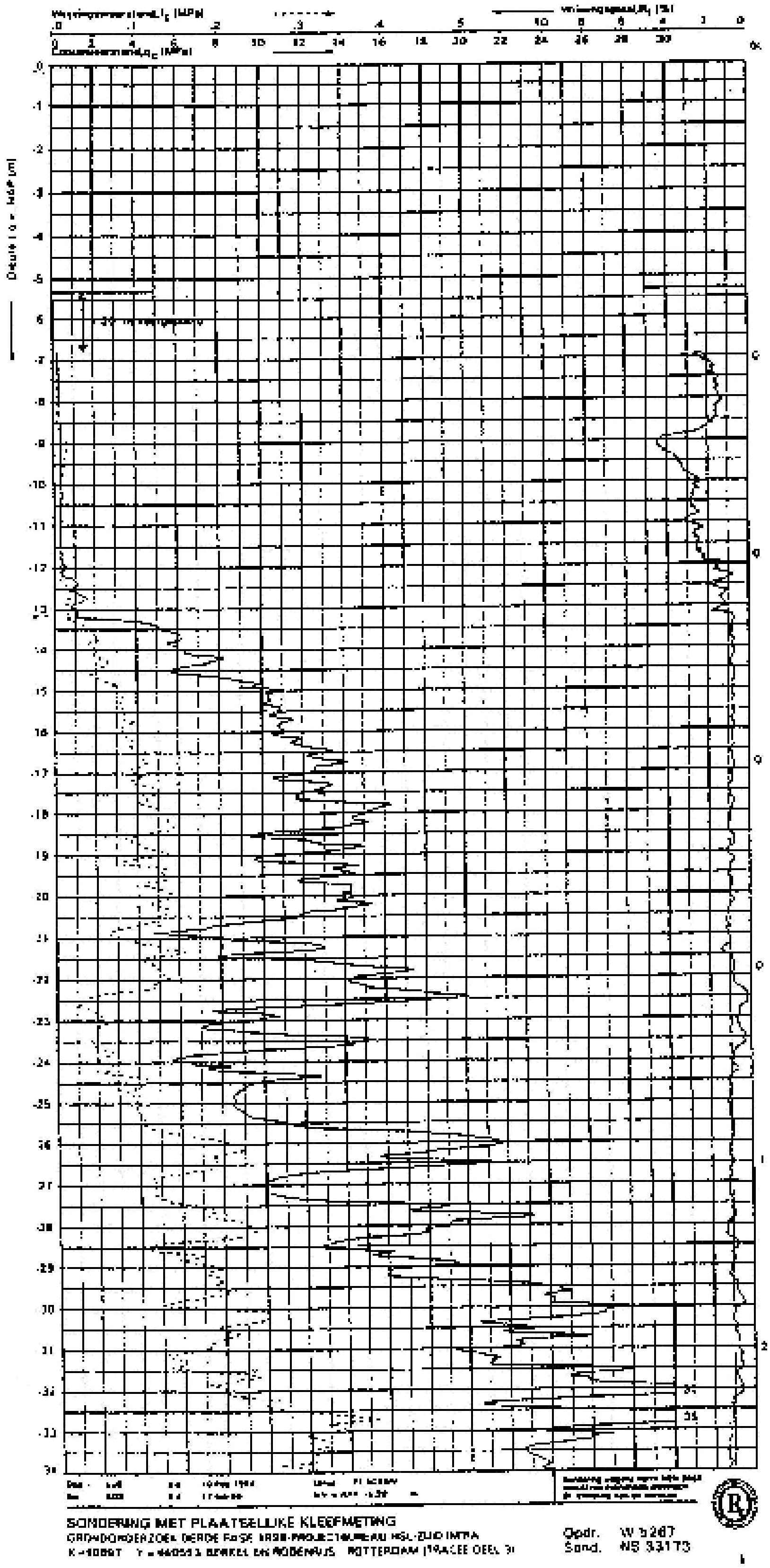
A boring offers useful information on the soil layering. It is recommended to always carry out a boring for identifying the layers, the type of materials and the volumetric mass.

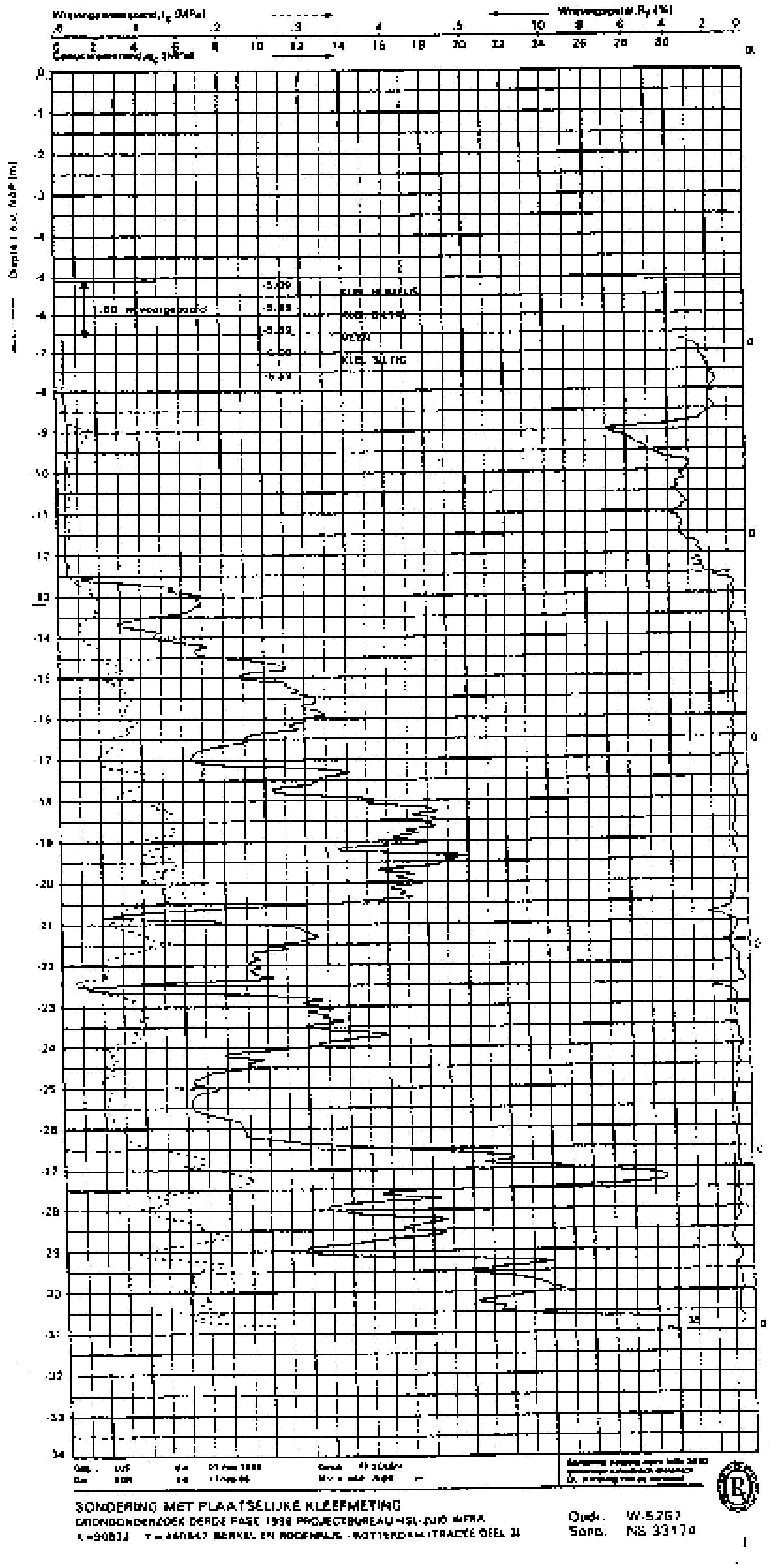
A boring offers a good possibility to test samples in the laboratory. From the free torsion vibration tests it follows that the estimated shearmoduli are reasonable. The damping is also reasonable estimated, omitting the error due to the fact that the peat layers were not identified.

The values in this report give a good starting point for the input for parameter studies for soil transmission.

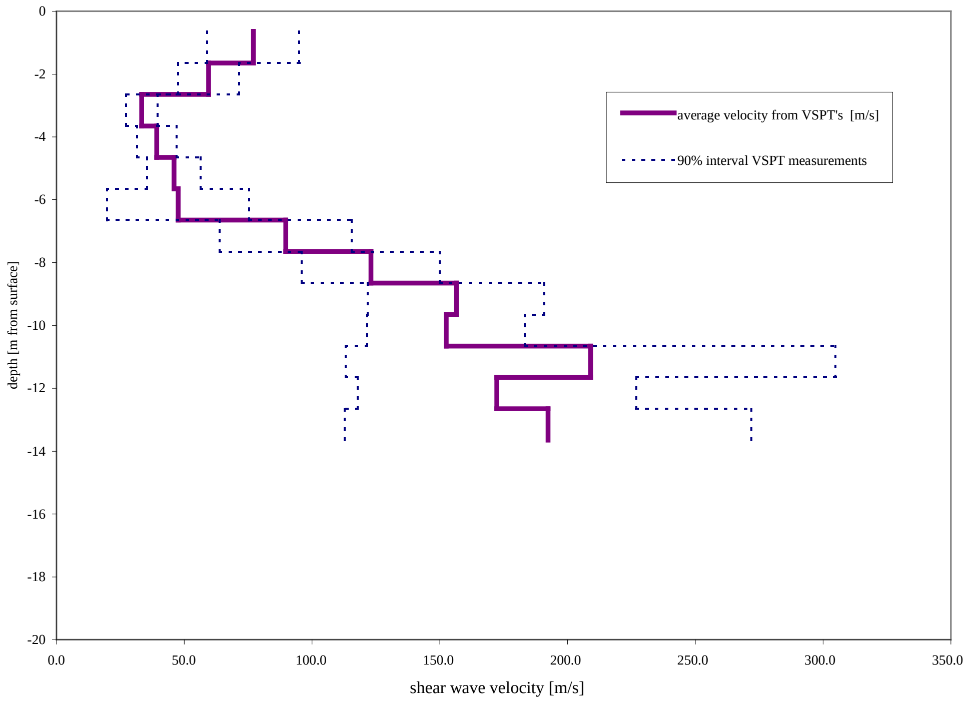
Appendix 1 Results of cone penetration tests




SONDERING MET PLAATSELIJKE KLEEFMETING
Opdr. W 5287
Sond. NS 33173

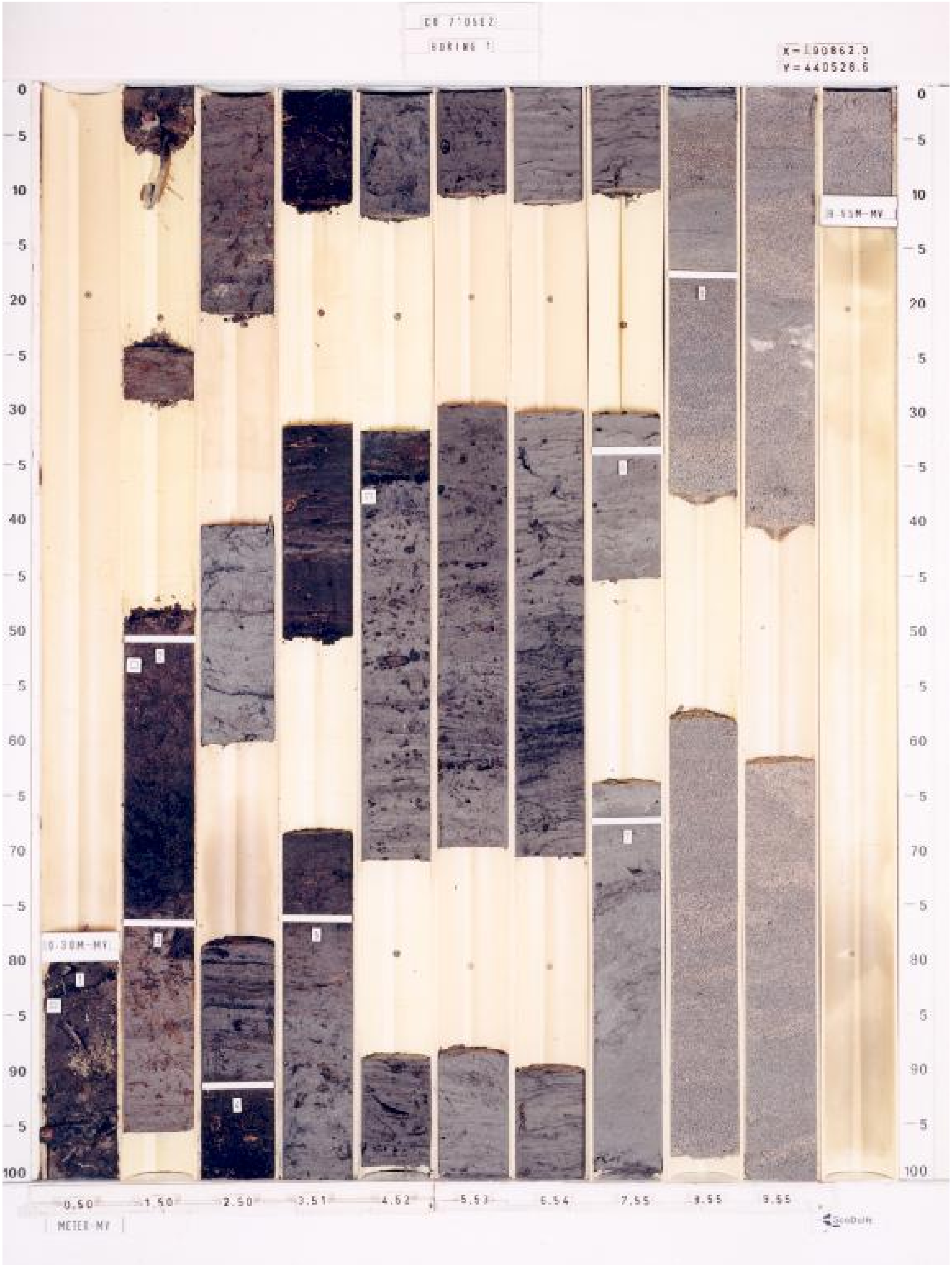


Appendix 2 Results of vertical seismic profiling test



Appendix 3 Picture of boring

The holes in this picture are due to the fact that many samples are reserved for (future) laboratory research.



Appendix 4 References

[Das, 1983]
Das, B.M.
Foundations of soildynamics
Elsevier Science Publishers Co. Inc.,
New York, U.S.A., 1983

[Hölscher, 2002]
Demping in Grond (in Dutch)
Delft Cluster report 01.05.02, number 10
Delft, the Netherlands, 2002

[Hölscher, 2002b]
Uitbreiding toepassingsmogelijkheden van het model voor hystereze demping (in Dutch)
Delft Cluster report 01.02.03, draft
Delft, the Netherlands, 2002

[Pruiksma, 2002]
Vergelijking trillingsprognoses case Rotterdam Noord
Delft Cluster report 01.05.02, draft
Delft, the Netherlands, 2002

General Appendix: Delft Cluster Research Programme Information

This publication is a result of the Delft Cluster research-program 1999-2002 (ICES-KIS-II), that consists of 7 research themes:
►Soil and structures, ►Risks due to flooding, ►Coast and river , ►Urban infrastructure, ►Subsurface management, ►Integrated water resources management, ►Knowledge management.

This publication is part of:

Research Theme	:	Soil and structures		
Baseproject name	:	Environmental impact of underground construction		
Project name	:	Reliability of vibration prognosis and reducing measures		
Projectleader/Institute		dr. ir. P. H. Waarts		TNO-Bouw
Project number	:	01.05.02		
Projectduration	:	01-03-2000	-	31-06-2003
Financial sponsor(s)	:	Delft Cluster		
		TNO-Bouw		
		GeoDelft		
		TUDelft		
		Holland Railconsult		
		Projectorganisatie HSL-Zuid		
Projectparticipants	:	TNO-Bouw		
		GeoDelft		
		TUDelft		
		Holland Railconsult		
Total Project-budget	:	€ 588.000		
Number of involved PhD-students	:	0		
Number of involved PostDocs	:	0		

Delft Cluster is an open knowledge network of five Delft-based institutes for long-term fundamental strategic research focussed on the sustainable development of densely populated delta areas.

Keverling Buismanweg 4
Postbus 69
2600 AB Delft
The Netherlands

Tel: +31-15-269 37 93
Fax: +31-15-269 37 99
info@delftcluster.nl
www.delftcluster.nl

Theme Managementteam: Ground and Construction

Name	**Organisation**
Dr. P. van den Berg	GeoDelft
Dr. J. Rots	TNO-Bouw

Projectgroup

During the execution of the project the researchteam included:

Name	**Organisation**
1 prof.dr.ir. A.C.W.M. Vrouwenvelder	TNO-Bouw
2 Ir. R.J. Aartsen	Projectorganisatie HSL-Zuid
3 ir. E.C. Klaver	Projectorganisatie HSL-Zuid
4 prof.dr.ir. C. Esveld	TU Delft

Other Involved personnel

The realisation of this report involved:

Name	**Organisation**
1 dr. ir. P. Hölscher	GeoDelft
2	
3	