OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

DIPL.-ING. Peter LECHNER
Staatlich befugter und beeideter Zivilingenieur für Bauwesen
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9 Tel.: 0316/81 85 25 DW 10 Fax: DW 9

20647

GEOTECHNICAL REPORT

CONCERNING THE DEPOSITION OF RED MUD DERIVING FROM THE ALUMINIUM-PRODUCTION

13 pages

4 appendixes

Graz, march 1994

by order of:

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

A-1400 VIENNA, AUSTRIA

1.) SUGGESTION

At the suggestion of UNIDO the undersigned person, Dipl.-Ing. Peter Lechner, had to make investigations about the deposition of red mud. Mr. Lechner should make a statement for two procedures.

Further statements about the stability and the permeability of the consisting dikes should be given.

2.) RECORDS/SUPPORTS

- Siteplan of the ponds in which the red mud is stored at the moment - designed by Interaluminia in September 1990.
- Inspection of the area by the undersigned on the 8th of February, 1994.
- Results of the laboratory from soil samples by the undersigned.
- Introduction of the system by the Maschinenfabrik Andritz Aktiengesellschaft company, A-8045 Graz, Austria.
- Introduction of the system from the deposition by the EIMCO Process Equipment Company, Salt Lake City, Utah, USA.

3.) GENERAL FACTS

During the production of aluminium there is a waste product which is a very liquid red mud (see pict. 8).

At the moment this red mud is stored in lagoons near the Orinoco (see pict. 9 and 10).

Due to the problems caused by this way of storage, and concerning the permeability

of the ground and of the dams which enclose it, another kind of storage is being sought. Also the area for this type of deposit is nearly exhausted.

As one of the five members of a commission of the UNIDO, the undersigned was in charge of the illustration of the geotechnical aspects of the two presented procedures; namely a wet and a dry deposit.

4.) STATEMENT CONCERNING THE "ANDRITZ" PROCEDURE

This procedure consists of drying the red mud that has to be stored. The result of the drying (filtering) may be seen in picture 7. The company Maschinenfabrik Andritz company has produced samples for testing the geotechnical characteristics of this dried red mud product on the spot.

The undersigned has already made some initial tests in Puerto Ordaz. These investigations were divided in two parts; uncompacted and compacted samples.

The compaction was done by a simple, available loader. The material has been driven over about 5 times (see pict. 1).

There are two different samples, since all samples were not available on one day. We had to distinguish between one sample 4 - 5 days old, and another new one, which was fresh before the investigations started (new area).

The difference between the areas in the now compacted condition is only in the liquid content of the samples.

These were:

at the old area **~ 29%**

at the new area **~ 31%**

in relation to the dry mass of the samples.

It can be seen that within 5 days the last 10 cm on the top are dried out a further 2%. The unit weight of soil of the uncompacted samples had already established for both parts

1,1 g/cm³

in Venezuela.

After the compaction using the loader (see pict. 4) the unit weight of soil for the

old area was **2,05 g/cm³** and for the

new one **1,93 g/cm³.**

This causes an average compaction of

1,8 times

with a resulting solid content of

~ 76,4%.

From this superimposed soil samples were taken and proctor compaction tests were done in the geotechnical laboratory.

The result was that the liquid content should be

19%

for getting an optimal compaction (see app. 1) to get the density of

~ p = 1,85 g/cm³.

You can see by these results that the density made by the loader is higher than the investigation in the laboratory - although the liquid part is higher as the optimal value. To check the compaction we made driving tests, vane shear investigations and loadplate tests (see pict. 2 and 3). After all these investigations we discovered an improvement of the storage condition.

Back calculations of these results and also the results of the laboratory (see app. 4) show better deformations- and loading qualities from the compacted materials.

Up to the height of about 50 m there are deformations which would only be expected in range of "dm".

The compaction with the loader by means of driving over it 5 times is a good compaction method. The result is a good and resistant surface against the influence of the weather (see picture 5 and 6).

To get further information of the possible shape of deposit, direct shear tests with different densities have been made in the laboratory and the following results have been received:

In the case of a liquid content of about 20% to 30% the angle of internal friction was at least 30° with a minimum cohesion of 2,8 N/cm², if we take as a minimum density of the red mud approx. 1,7 g/m³.

If the density goes down and the liquid content increases the angle of internal friction suddenly goes down. In this case we obtained an angle of internal friction less then 7°.

The result of this process shows, that because of the reduction of the liquid content a compaction with a loader is possible. You can reach slope inclinations up to 30°. Because of the low liquid content, the contractions decrease and the cracks on the surface are reduced and consequently the erosions through rain will also be reduced to a tolerable scale.

Above all the surface of the deposit can be used immediately. This is a particularl advantage because the surface of the deposit can be recultivated at once. The undersigned recommends a layer of soil (about 40 - 60 cm high) where native plants and grasses may be set. This is therefore one optimal way to include this area into the existing country.

5.) STATEMENT REGARDING THE EIMCO PROCEDURE

The aim of this procedure is to thicken the liquid red mud with a super thickener. Through gravitation the floating part sinks down, it is then collected and transported to the deposit by means of pipes. In order that pumping is possible, there must be liquid conditions.

The pipes end at the deposit and the air should reduce the liquid part through surface evaporation.

More compaction should not be done. As you can see in the test in the laboratory, which was done in the investigations of dry mud, the angle of friction goes down with an decreasing density, so that you get an immense loss of security.

It was not possible for the undersigned to make comparison tests in relation to the filtering machine, because there was no suitable material and no filtering machine was available.

The undersigned states once more, that statements about the depositing of this redmud can only be carried out in a large scale investigation. Tests made in laboratories can not be compared with natural conditions.

The large cracks have to be considered as resulting from the change of the liquid content of the red mud as a consequence of evaporation. Due to the rain a scouring will be made, and a deposit of mud will be very difficult.

The undersigned would like to say, that experiences of similar red mud deposits can give a good reference point, but cannot give established statements for an other red-mud deposit.

Also, one has to consider that in the case of a wet deposit the heavy parts sink further than the lighter smaller parts of the red-mud mass. Therefore, there are layers with rougher parts and layers with fine particles with strongly marked glide zones, because the finer particles have a smaller angle of friction.

In conclusion it can be said, that a wet-deposit with *this red mud* has never been carried out before.

Geotechnical investigations could not be made, because there were no samples available.

Concerning the tests in the laboratory with the dry red mud it can be said, that if the density is lower as in case of wet red mud deposits, a smaller angle of friction is reached and the safety decreases.

6.) SAFETY OF EXISTING DAMS OF THE LAGOON STORAGE.

Concerning the reports which were given to the undersigned it can be seen that the slopes of the dams are 3,75 : 1. The height is 6,5 m. The problem of these dams is not the stability, it is the permeability.

There is really only one possiblity of checking permeability, and that is by taking water samples from the area between the Orinoco an the dams - but in the region closer to the dams. The best way to take water samples would be to drill holes at different levels at different times.

In dependence on the decreasing or the increasing level of contamination, sealing measures can be taken, for instance with diaphragma walls or with thin bentonite walls.

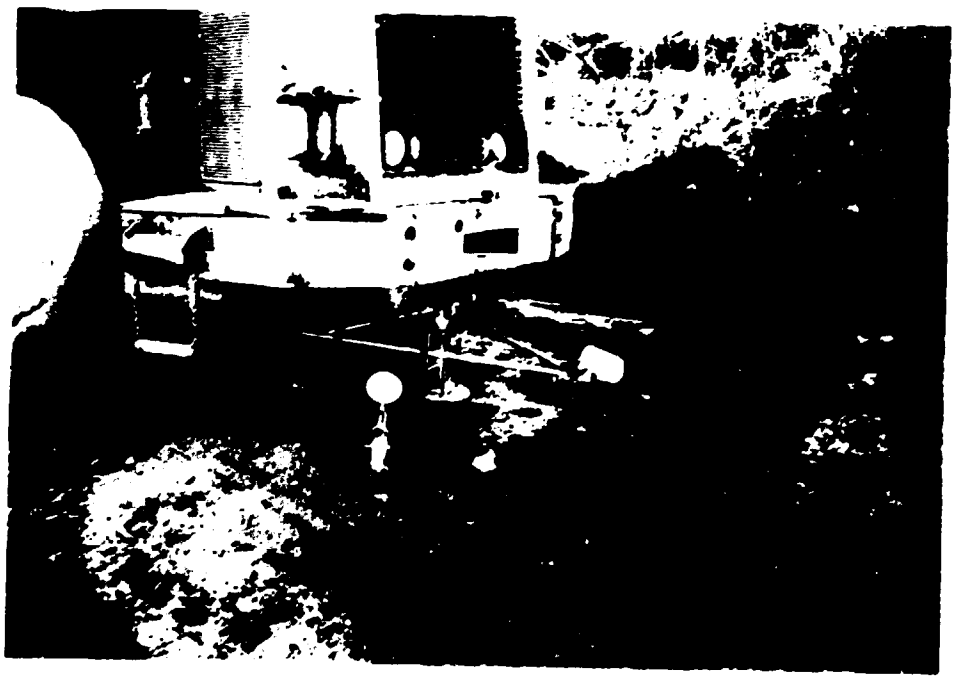
The stability of dams can be easily controlled by the installation of inclinometer measurements.

Through these inclinometer measurements the speed of deformations and the areas of gliding zones can be ascertained.

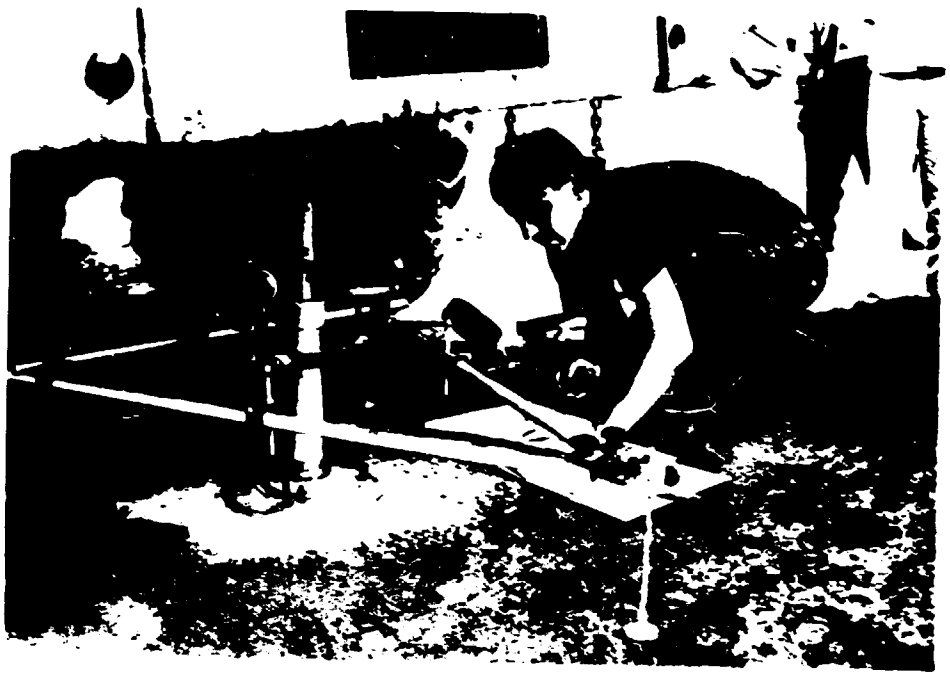
Graz, March 1994

Dipl.-Ing. Peter LECHNER

Picture1: Loader for compaction

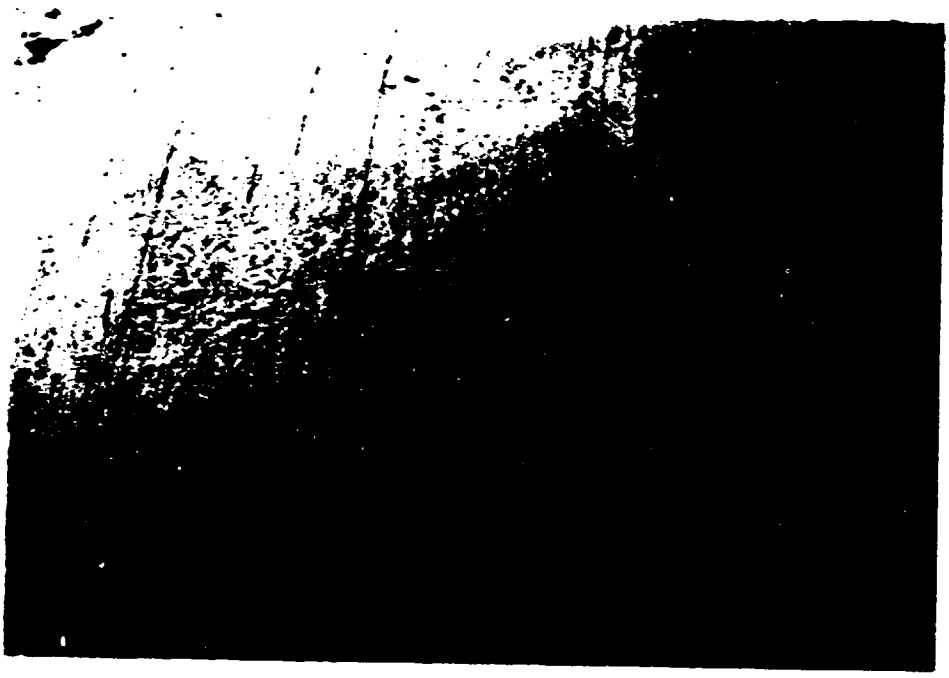


Picture 2: Performance of loadplate compaction tests



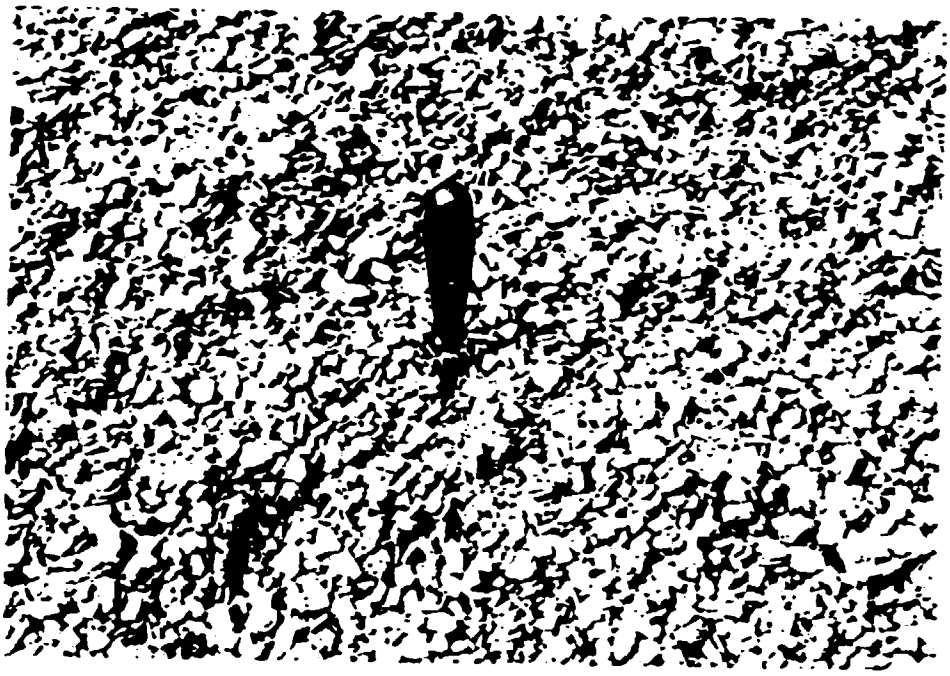
Picture 3: Performance of loadplate compaction tests

Picture 4: Deposit after compaction



Picture 5 : Surface after compaction

Picture 6: Surface after compaction



Picture 7: Filtered sample, procedure "Andritz"

Picture 8: Red-mud produced at the moment

I T270

95 07 18

Picture 9: Deposition in the lagoons

Picture 10: Deposition in the lagoons

employer: APPENDIX 4

Unido

project:

Interaluminia

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PROCTOR - COMPACTION - TEST

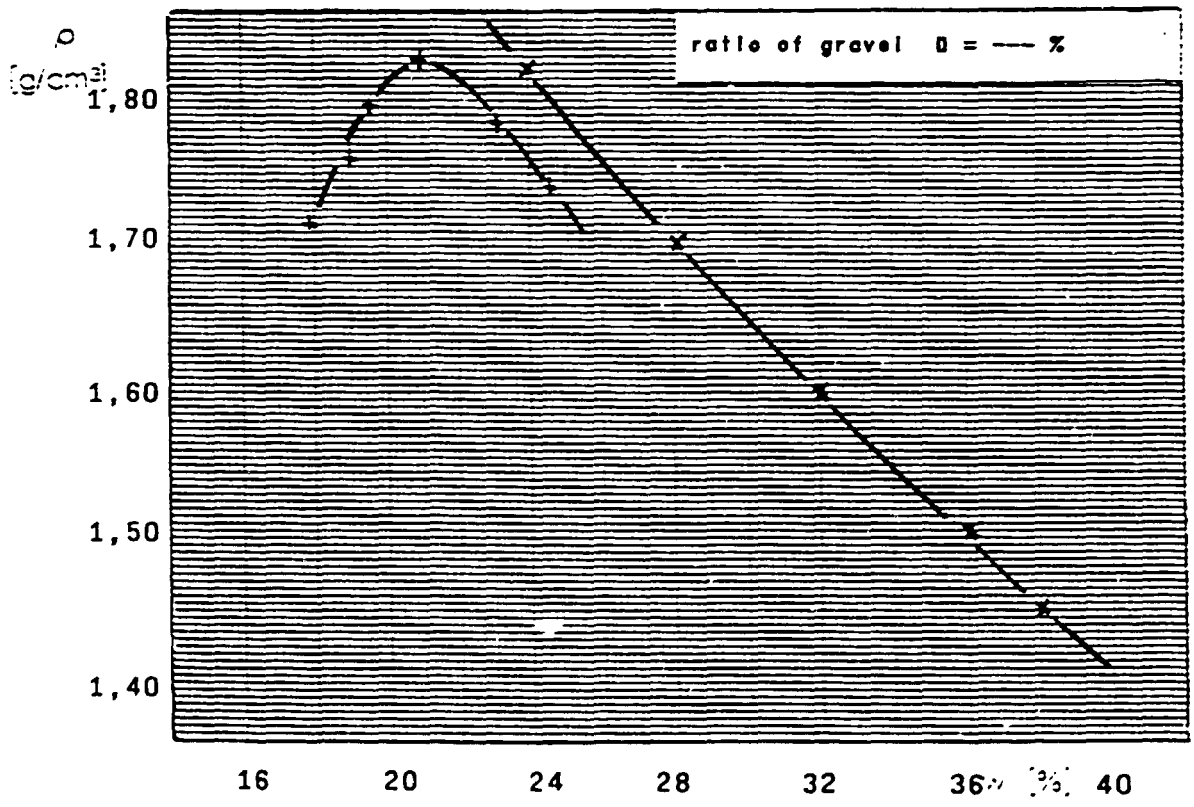
kind of soil: red - mud	indication: 7.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94

machine

diameter : 100 mm
height : 120 mm

compaction energy

0.6 MNm/m³



result: w_{pr} = 21.1 %
ρ_{pr} = 1.82 g/cm³

employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PROCTOR - COMPACTION - TEST

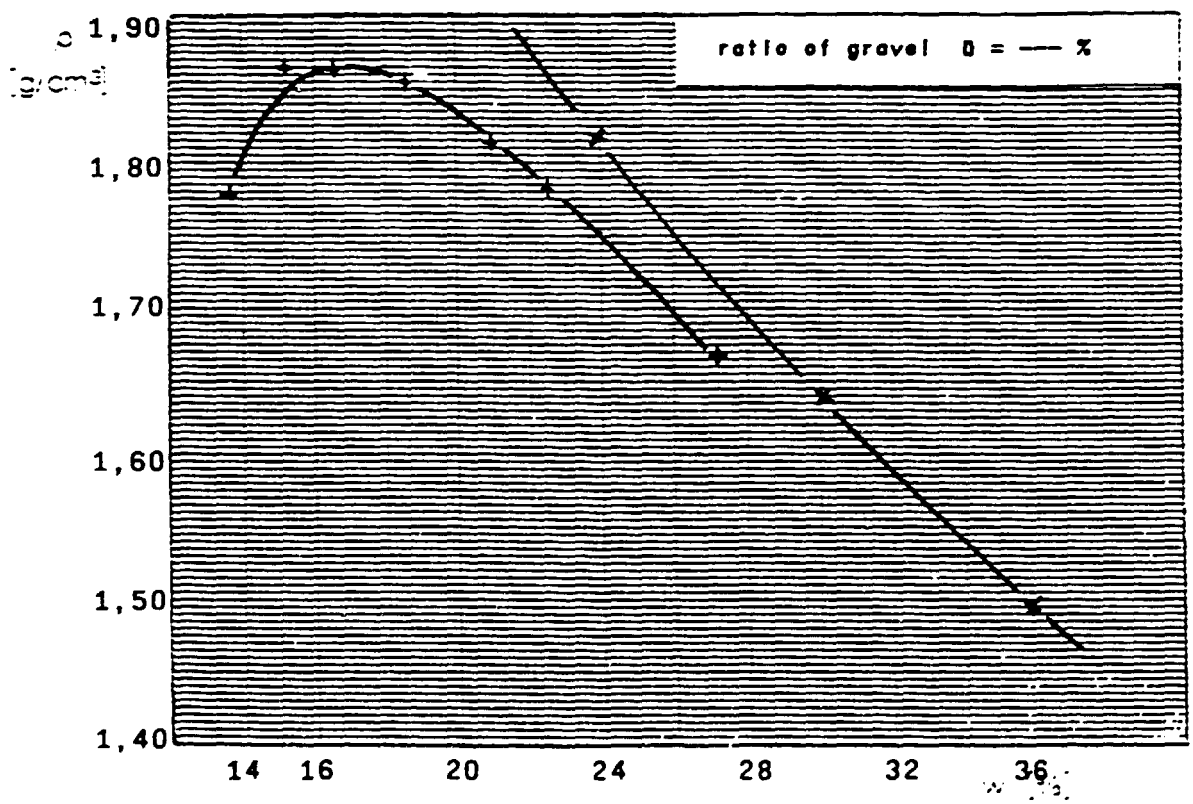
kind of soil: *red - mud*	indication: *8.2.94*	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: *18.3.94*

machine

diameter : 100 mm
height : 120 mm

compaction energy

0.6 MNm/m³



result: w_{pr} = 16.5 %
ρ_{pr} = 1.87 g/cm³

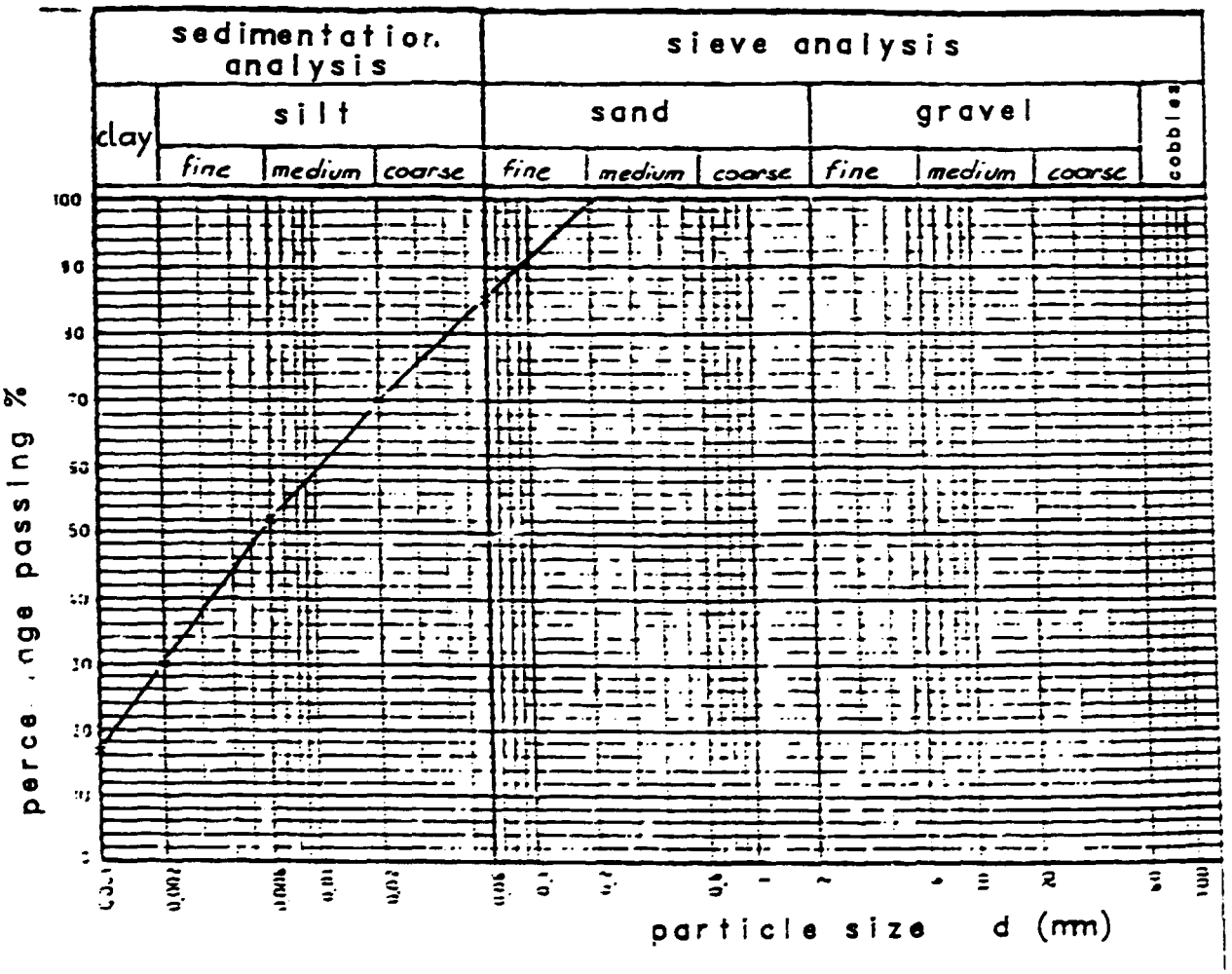
employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PARTICLE - SIZE - DISTRIBUTION

kind of soil: red - mud	indication: 236/sand	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



uniformity coefficient $U = \frac{d_{60}}{d_{10}}$

effective size d = (mm)

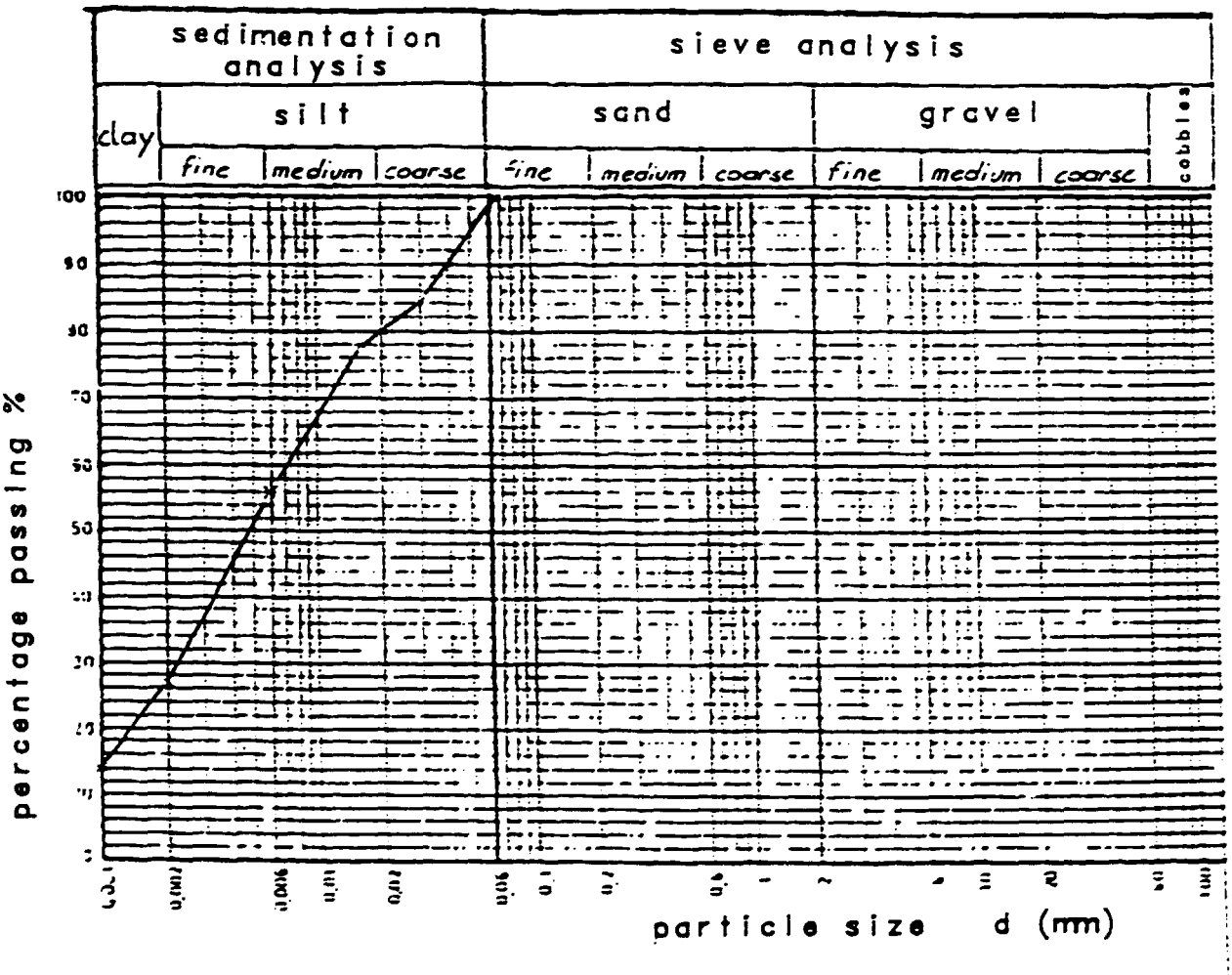
employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PARTICLE – SIZE – DISTRIBUTION

kind of soil: red – mud	indication: 7.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



uniformity coefficient $U = \frac{d_{60}}{d_{10}}$

effective size d = (mm)

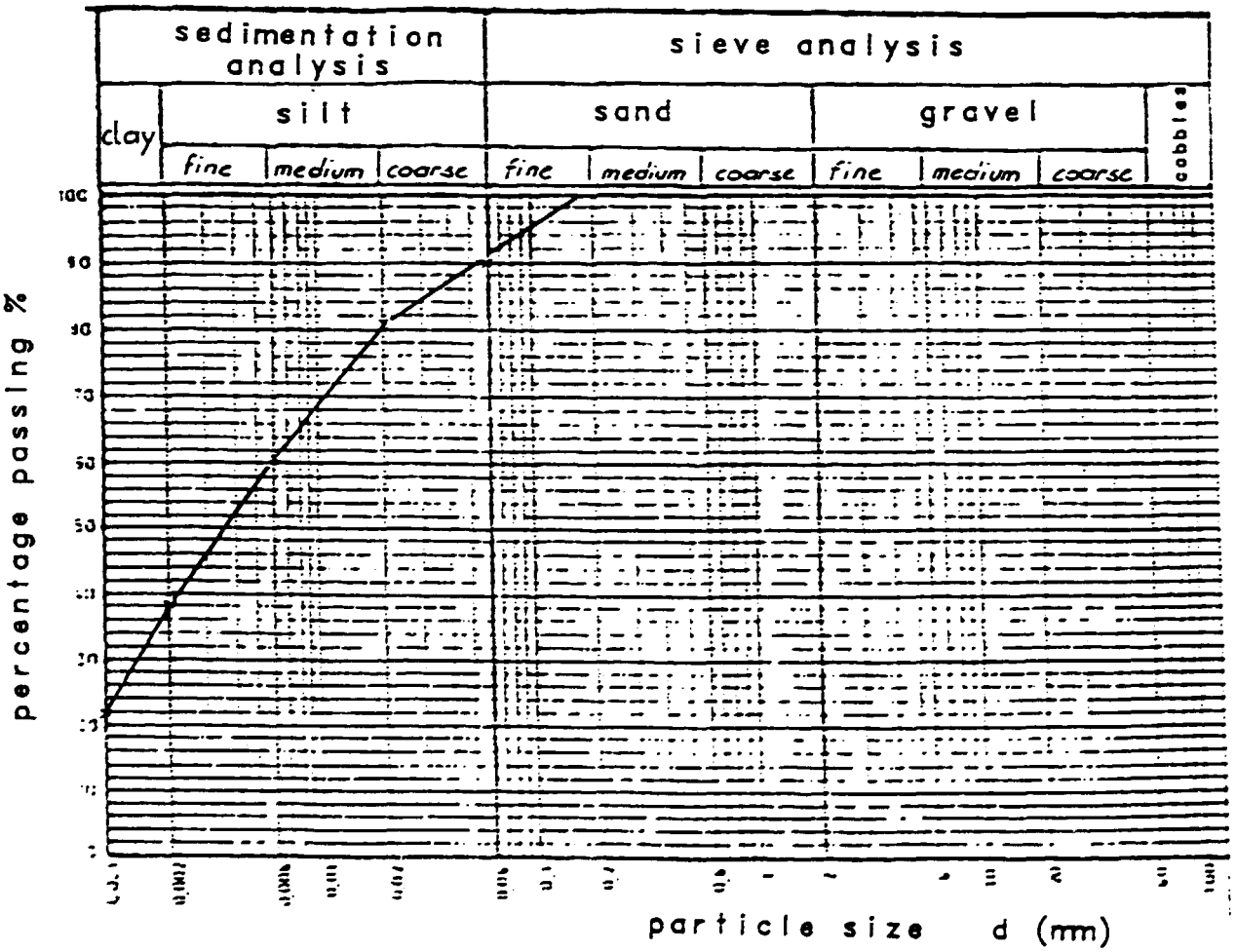
employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PARTICLE - SIZE - DISTRIBUTION

kind of soil: red - mud	indication: 8.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



uniformity coefficient $U = \frac{d_{60}}{d_{10}}$

effective size d = (mm)

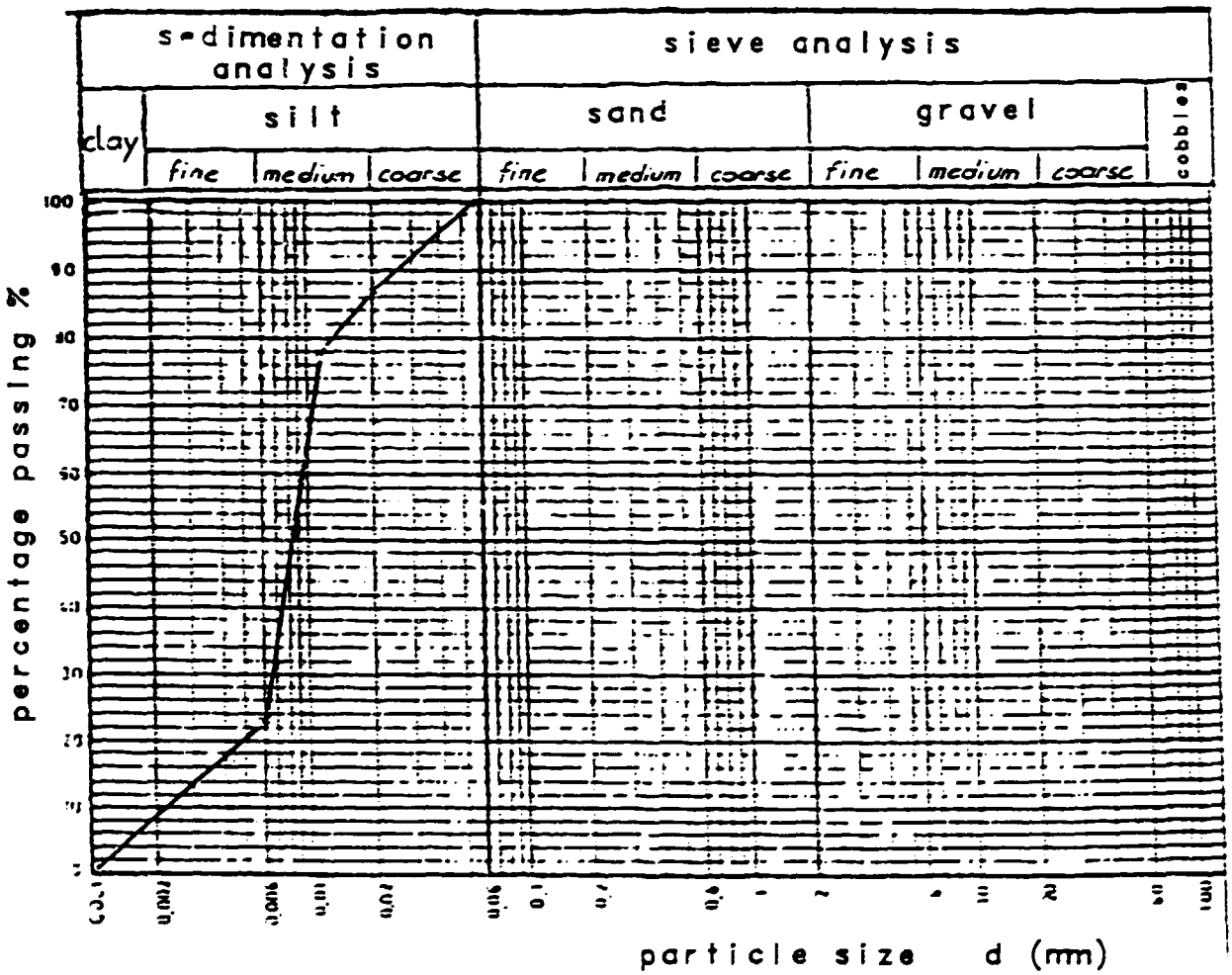
employer: Unido

project: Interaluminia

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

PARTICLE - SIZE - DISTRIBUTION

kind of soil: red - mud	indication: lagune	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



uniformity coefficient $U = \frac{d_{60}}{d_{10}}$

effective size $d =$ (mm)

APPENDIX 3

employer: Unido

project: Interaluminia

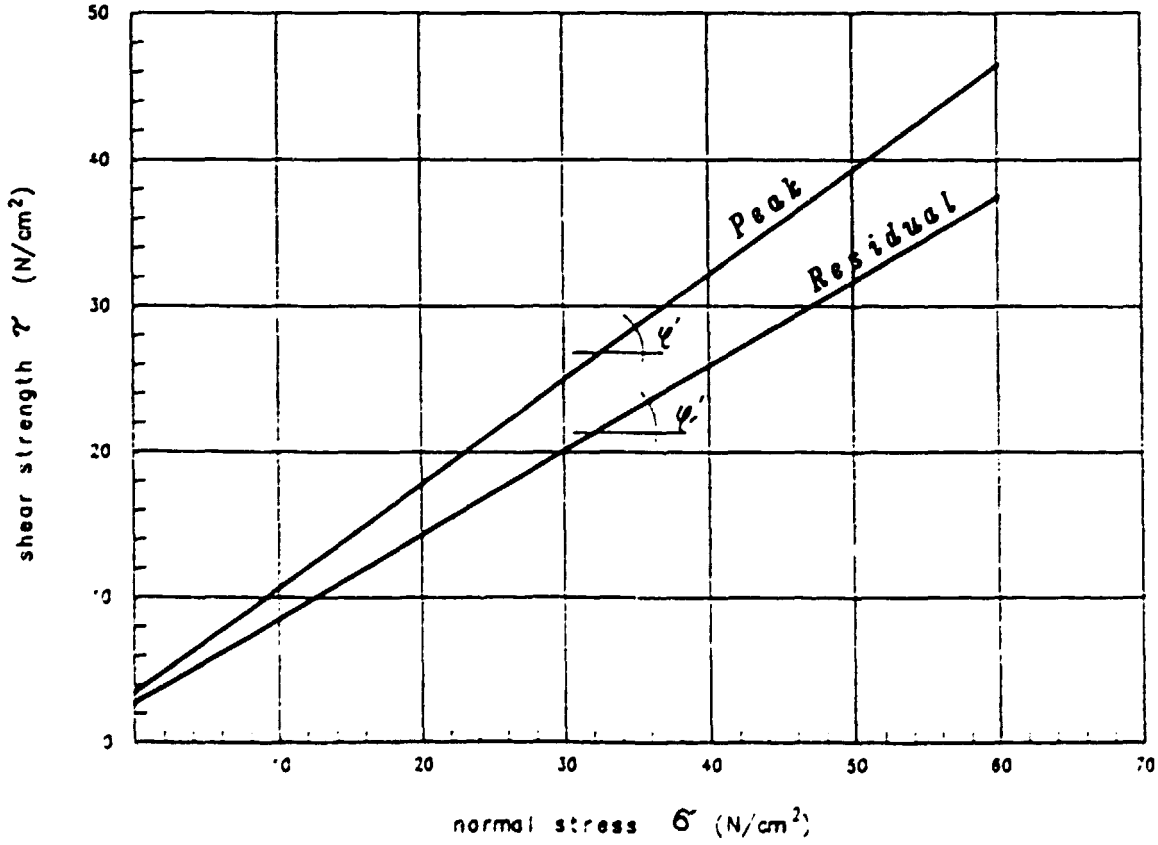
Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

DIRECT SHEAR TEST

kind of soil: dry place	indication: 8.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94

			TEST 1	TEST 2	TEST 3
normal stress	σ	N/cm²	5.0	20.0	50.0
shear strength	τ_f	N/cm²	6.5	19.6	39.4
displacement	s1	mm	44.4	45.2	13.7
shear strength	τ_r	N/cm²	5.5	16.0	32.0
displacement	s2	mm	16.6	20.4	17.0

angle of internal friction = 35.8°
cohesion = 3.8 N/cm²
residual angle of friction = 30.2°



employer: Unido

project: Interaluminia

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

DIRECT SHEAR TEST

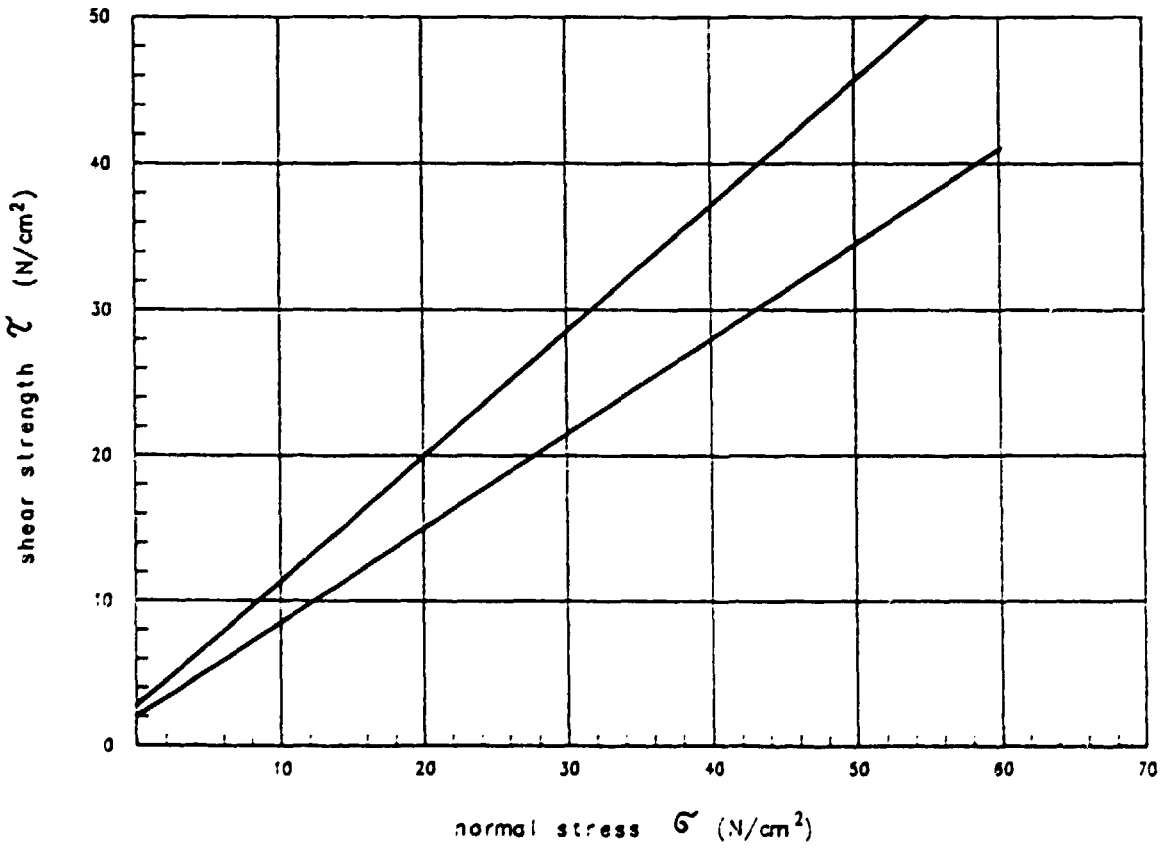
kind of soil: dry place	indication: 7.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94

			TEST 1	TEST 2	TEST 3
normal stress	σ	N/cm²	5.0	20.0	50.0
shear strength	τ_f	N/cm²	6.7	20.9	46.0
displacement	s1	mm	29.3	27.3	62.0
shear strength	τ_r	N/cm²	4.5	16.0	34.5
displacement	s2	mm	19.8	16.5	14.0

angle of internal friction = 41.0 °

cohesion = 2.8 N/cm²

residual angle of friction = 33.1 °



employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

DIRECT SHEAR TEST

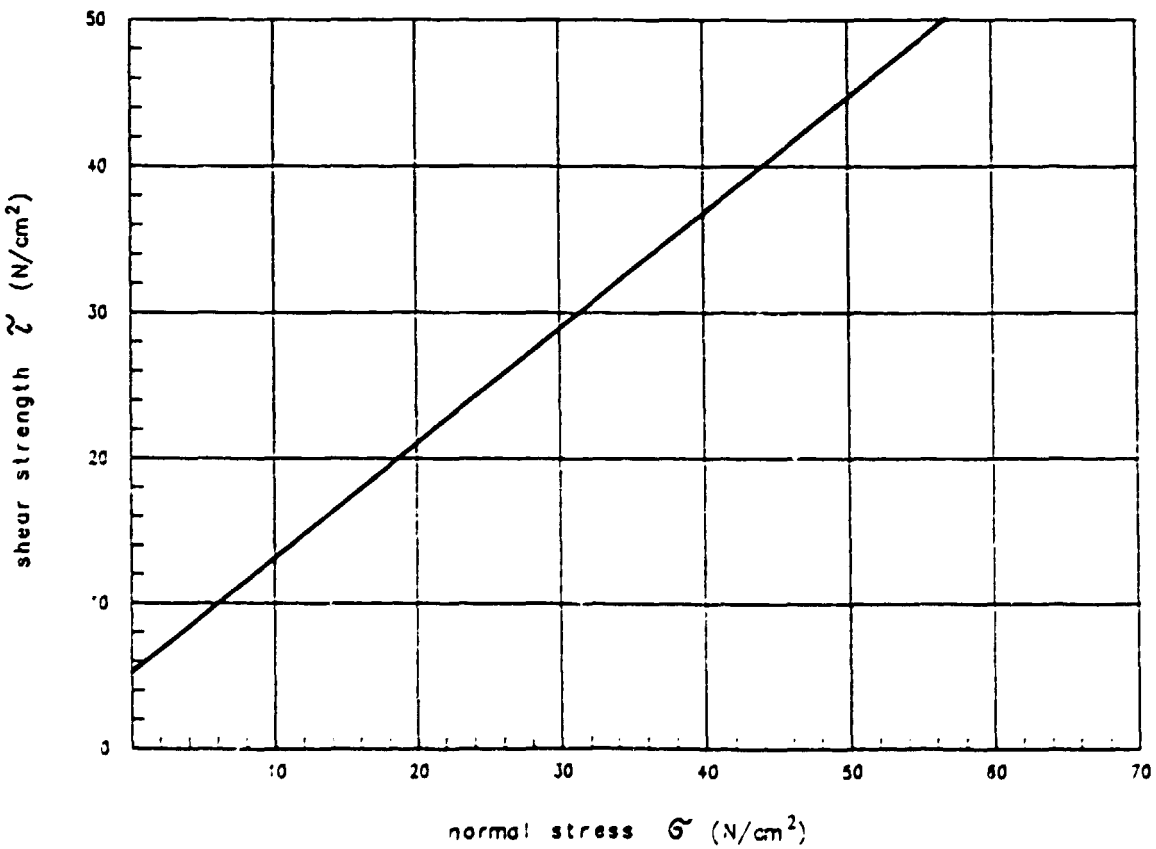
kind of soil: plastic place	indication: 7.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94

			TEST 1	TEST 2	TEST 3
normal stress	σ	N/cm²	5.0	20.0	50.0
shear strength	τ_f	N/cm²	9.8	19.8	44.8
displacement	s1	mm			
shear strength	τ_r	N/cm²			
displacement	s2	mm			

angle of internal friction = 38.2°

chesion = 5.2 N/cm²

residual angle of friction = ...



employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

DIRECT SHEAR TEST

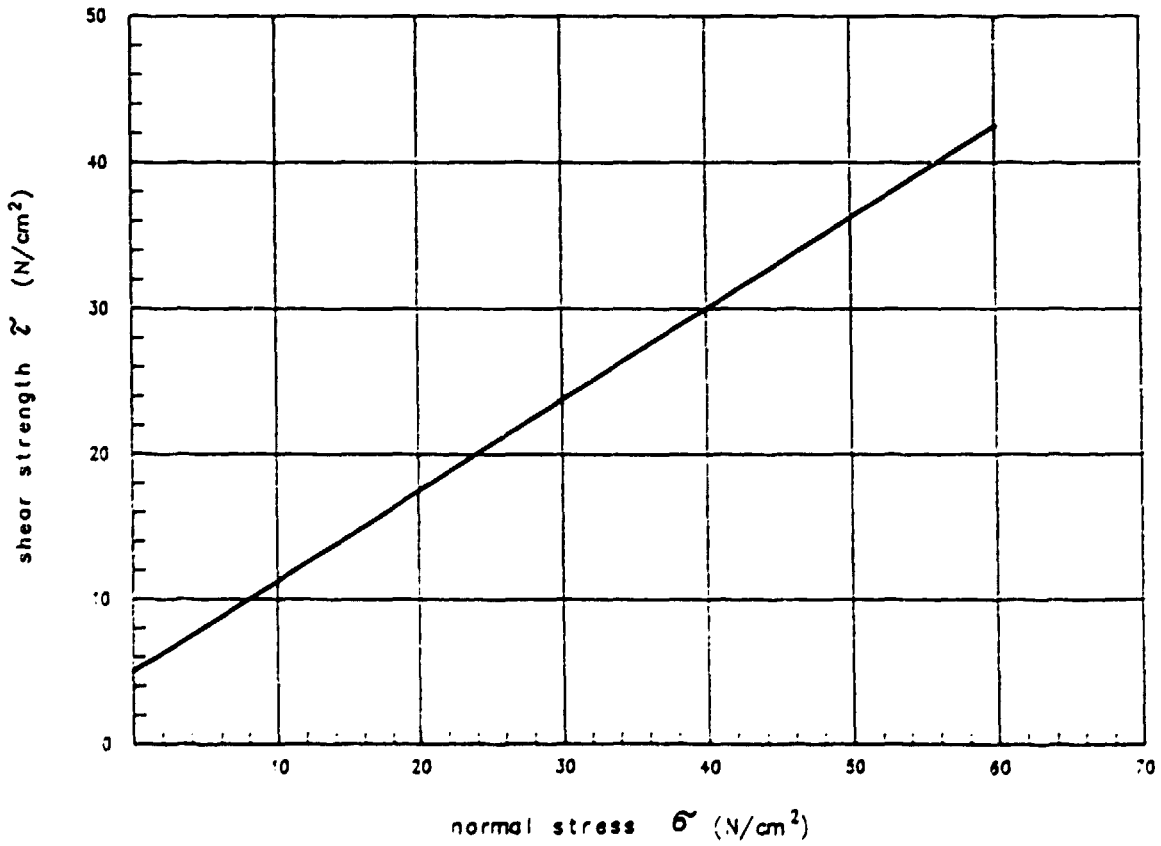
kind of soil: plastic place	indication: 8.2.94	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94

			TEST 1	TEST 2	TEST 3
normal stress	σ	N/cm²	5.0	20.0	50.0
shear strength	τ_f	N/cm²	7.8	17.9	37.0
displacement	s1	mm			
shear strength	τ_r	N/cm²			
displacement	s2	mm			

angle of internal friction = 32.9°

cohesion = 4.7 N/cm²

residual angle of friction = ...



employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

DIRECT SHEAR TEST

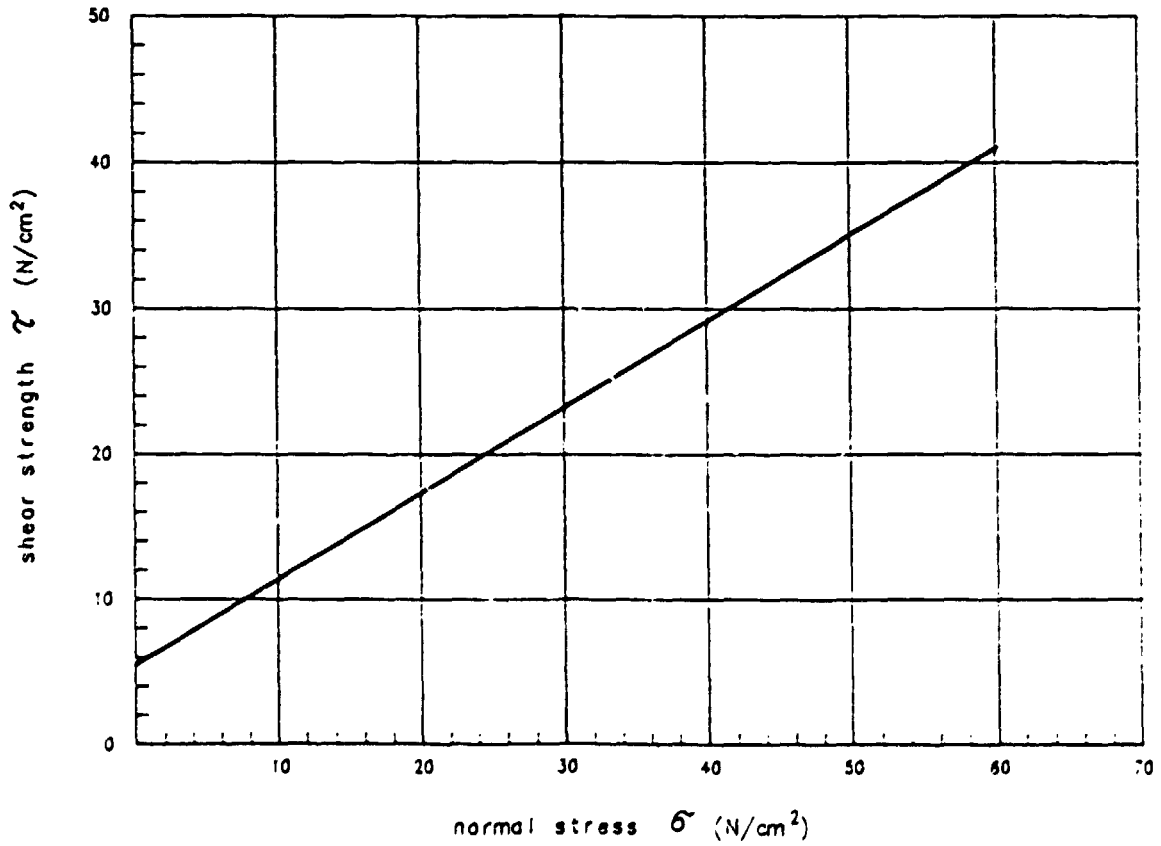
kind of soil: *plastic piece*	indication: *lagune*	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: *18.3.94*

			TEST 1	TEST 2	TEST 3
normal stress	σ	N/cm²	*5.0*	*20.0*	*50.0*
shear strength	τ_f	N/cm²	*7.2*	*19.0*	*34.8*
displacement	s1	mm			
shear strength	τ_r	N/cm²	*3.0*	*13.4*	*33.0*
displacement	s2	mm			

angle of internal friction = *31.0* °

cohesion = *5.3* N/cm²

residual angle of friction = *31.0* °



APPENDIX 4

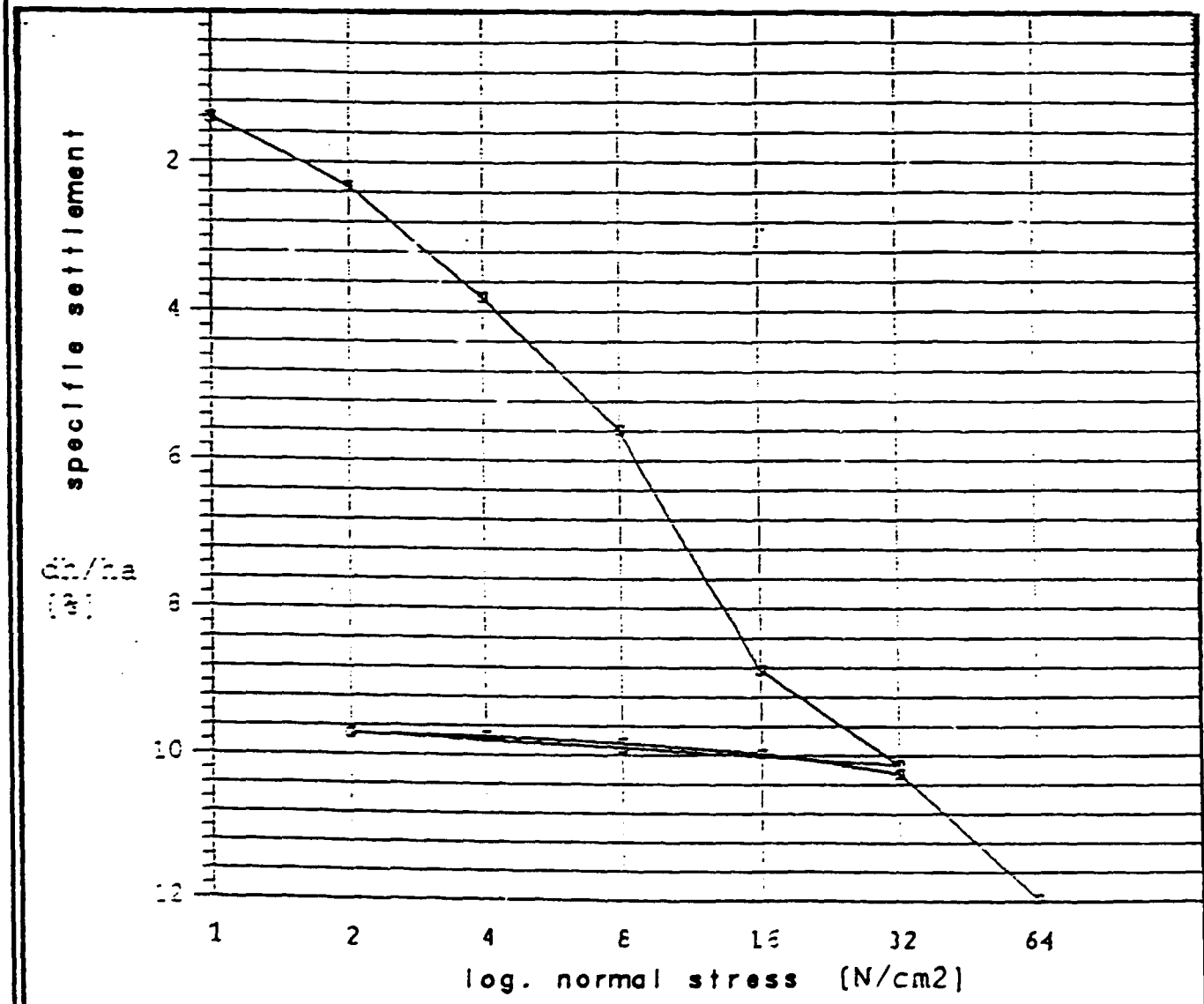
employer: Unido

project: Interaluminia

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

OEDOMETER CONSOLIDATION

kind of soil: red - mud	indication:	person responsible:	commision number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



ho = 20.000 mm ha = 19.334 mm

Es [N/cm2]	109	131	217	232	1122	
		4815	4247	5062	5238	1677

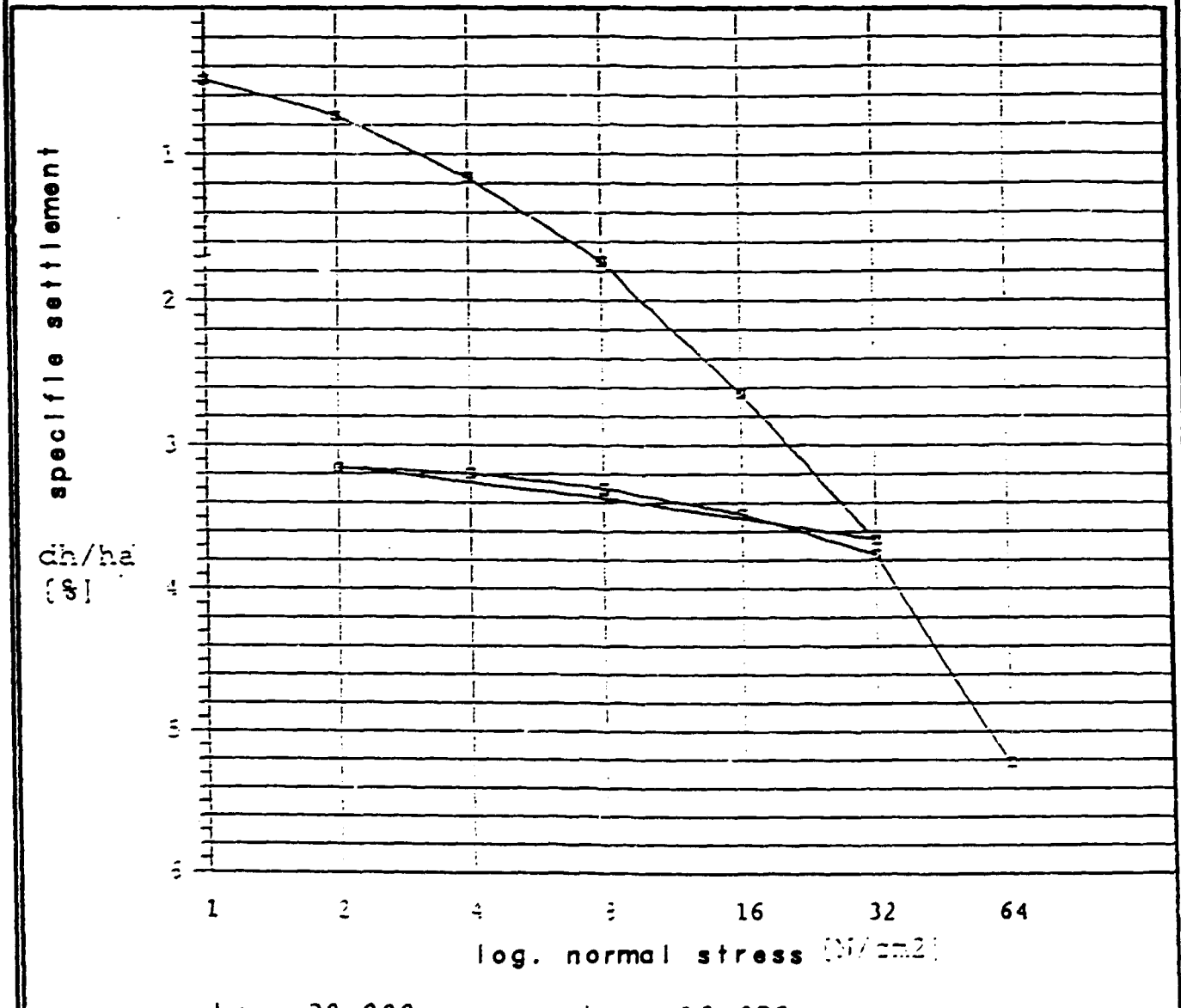
employer: *Unido*

project: *Interaluminia*

Dipl.-Ing. Peter LECHNER
A-8010 GRAZ, JAKOB-REDTENBACHERGASSE 9
TEL: 0316/81 35 35-10 FAX: DW 9

OEDOMETER CONSOLIDATION

kind of soil: red - mud	indication:	person responsible:	commission number:
disturbed sample	depth:	laboratory number:	date: 18.3.94



ho = 20.000 mm ha = 19.972 mm

Es [N/cm2]	402	470	688	869	1535	
		4557	3872	4358	5467	2117