news ingeo letter

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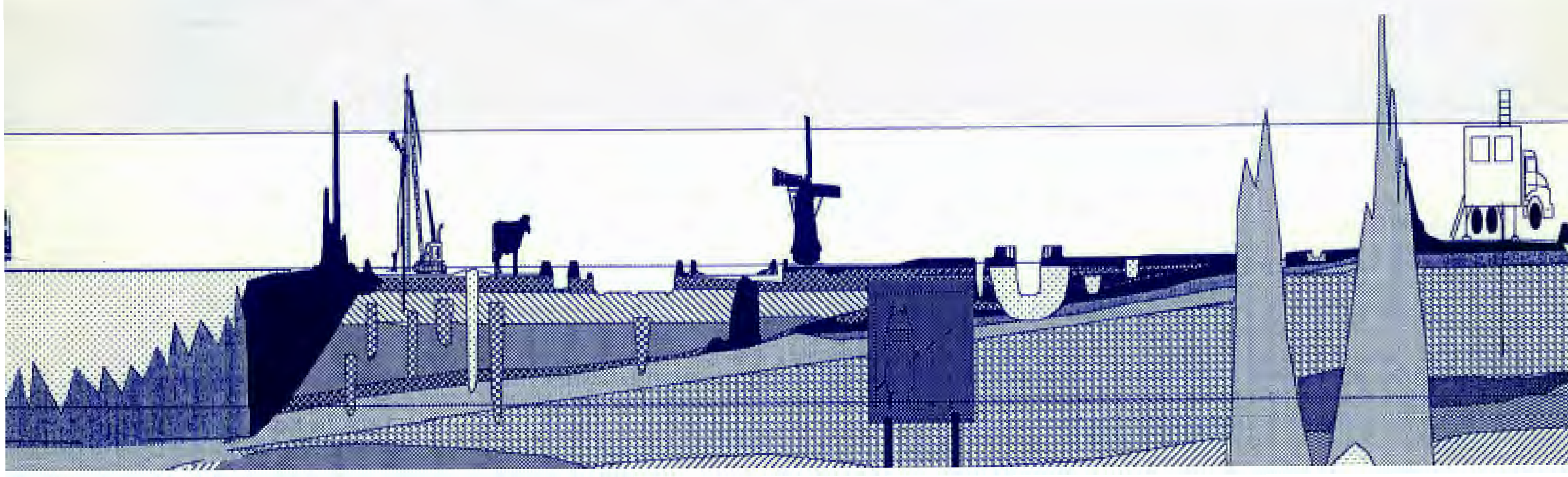

Objective of the Newsletter

The objective of the Newsletter is to inform the members of the IngeoKring, and other interested parties, on topics related to engineering geology and the developments in this field. The Newsletter wants to make engineering geology better known by the public and help improve the understanding of the different aspects of engineering geology.

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Notes for the authors

- Authors should send their contributions with their names and addresses, as a WP 5.1 text file to the editorial board.
- Authors are free in choosing the subject of their contribution with the following restraints:
  - The subject is related to engineering geology.
  - The manuscript is not a commercial advertisement (announcements are allowed).
- Layout
  - All figures and tables should be handed in as hard copies of high quality, each printed separately on A4 size. The author should remember that figures will be reduced in size.
  - Drawings can be delivered as a separate Drawperfect file or PCX file.
  - When photographs are used, the originals should be handed in (these will be returned)
  - The article should be delivered as a WP5.1 text, without any formatting or layout-codes, accompanied by a hard copy.
  - Each article must be accompanied by a short abstract (<100 words).

Cover: section through The Netherlands and the North Sea from the Achterhoek to the East coast of England.

Some words from the board and the editors

We are glad to present you the Newsletter of the Ingeokring. After a steady increase of the quality of the contents of the "Nieuwsbrief" over the last couple of years the board of the Ingeokring and the editors decided to improve the appearance of the Nieuwsbrief. Firstly, the language in the Newsletter will be English instead of the mix of Dutch and English texts used previously. Secondly, the lay-out of the different contributions will be made in such a way that the Newsletter will be attractive to read.

The extra costs for the improvement of the Newsletter are covered by the positive financial result of the IAEG Congress 1990. In consultation with the board of the "Stichting" which organized the IAEG congress, the board of the Ingeokring decided to transfer the sum to the account of the Ingeokring and to use the interest to upgrade the Newsletter.

In the Newsletter you will find more items besides the usual articles, reports, announcements and comments. Apart from the annually published membership list, profiles of companies and engineering geologists will be given. Job information and abstracts from publications of the members are also included.

The editorial board consists of Peter Verhoef, some members of DIG (Dispuut Ingenieurs Geologie) and Alexander van de Wall (researcher at the section Engineering Geology at the TU Delft). Alexander will concentrate on the quality of contents and lay-out for the coming editions of the Newsletter. The editorial board plans to publish at least two Newsletters per year.

Finally the Board of the Ingeokring has decided to use the Newsletter as a medium to inform non-members about Engineering Geology in the Netherlands. For this purpose copies will be sent to libraries, to institutions of research and education and to enterprises or companies working in the field of Engineering Geology.

We wish you much pleasure with the "metamorphosed" Newsletter.

The Editors and the Board of the Ingeokring

The Wijkertunnel shell layer; evidence for a tsunami or a storm surge deposit?[1]

M.H. den Hartog, Section Engineering Geology, Faculty of Mining and Petroleum Engineering of the TU Delft, The Netherlands (January 1995).

A thin shell layer was found in the Netherlands during the building of the Wijkertunnel. The layer is a mixture of marine shells and salt-brackish water shells. At several locations old borehole logs show a similar layer. The date of the deposition of the layer is similar to the deposition time of the grey, micaceous, silty fine sand layer found in Scotland. There are two possible explanations for the type of event that deposited the shell layer: a storm surge or a tsunami wave. The fine sand layer found in Scotland is believed to be deposited by a tsunami wave, which was generated by the second Storegga submarine slide ±7000 years BP.

INTRODUCTION

This paper was written for a literature study, in the fourth year program of engineering geology, at the department of Mining and Petroleum engineering of the Technical University in Delft, the Netherlands.

During the building of the Wijkertunnel a shell layer was found in the building pit. This very heterogeneous layer was deposited by a high energy and low frequency event. There is still a lot of discussion about the type of event which deposited the layer. Some argue it was deposited during a storm, others think a tsunami is a better explanation for the layer. In Scotland the same type of discussion took place. There a grey, micaceous, silty fine sand layer was found. B.A. Haggart (1988) argued that the apparent confinement of the 7000 year old sand layer of eastern Scotland was better explained by a storm-surge than by the tsunami hypothesis, whereas Dawson et al. (1988) claimed that the great extent of the layer in its areas of occurrence favours the tsunami explanation. Nowadays it is believed that a tsunami wave is the most likely mode of deposition.

This paper describes the sand layer found in Scotland, the evidence for the tsunami wave hypothesis and the different opinions about the type of event that deposited the shell layer in the Netherlands.

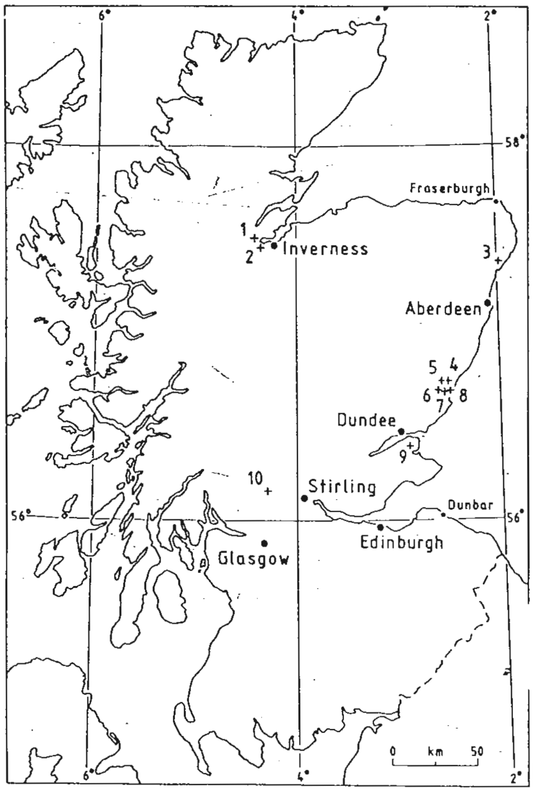

Figure 1 The numbers refer to stes where the sand layer has been investigated.

SCOTLAND

The eastern coastline of Scotland is marked by a large number of raised shoreline features formed during and following the retreat of the Late Devensian ice sheet. The area is elevated above sea level due to glacio-isostatic recovery. Amongst the most prominent features are the carselands, raised estuarine sediments of Holocene age. The sedi-

[1] This paper was awarded the "best paper" price in the TUD course "Engineerig Geology workshop" of 1994/1995.

ments of the carselands consist of a grey silty clay or clayey silt with lenses of sand, gravel and locally shells. These sediments are not uniform. The carseland clays penetrate small peat mosses inland and within these mosses form wedges of sediment. In the carseland sediments a persistent and widespread layer of grey, micaceous, silty fine sand has been identified over a large area in several hundred boreholes (fig.1). The silty fine sand layer generally shows little evidence of sorting either laterally or vertically. At most sites no sedimentary structure has been observed in this layer. The layer forms within the peat a separate wedge below the wedge of grey silty clay (fig.2).

Although not proved more than 74 cm, the layer is generally less than 15 cm in thickness. At several sites there is evidence of erosion of the underlying deposit.

The layer contains abundant diatoms (Paralia sulcata, Cocconeis scutellum, Diploneis and Hydalodiscus stellinger (Smith et al.,1985)) which are dominantly marine and marine to intertidal. There is a reduced occurrence of brackish diatoms which dominate the overlying and underlying carse clays.

Radiocarbon determinations of the peat located at either side of the layer, where the basal peat surface does not apparently show signs of erosion, range from 7140120 to 685075 yr. BP. Age differences between samples of peat taken at the same site above and below the layer are less than 300 years.

ORIGIN OF THE SAND LAYER

The landward tapering style of the sand layer implies a marine derivation, an origin supported by the diatom evidence. The stratigraphy and radiocarbon dates support the concept of a single event, whilst the pollen and radiocarbon dates indicate an event of relatively short duration. Certainly, a terrestrial origin, such as fluvial, is unlikely to have produced a single event so regionally extensive. An aeolian deposit would have been more variable in thickness. Rapid deposition is recognised by the absence of particle size gradation where the layer has been seen in section.

As Smith et al. (1985) observed, the presence of Paralia sulcata in large numbers amongst the diatom population indicates turbulent conditions during deposition.

Smith et al. (1985) considered that a storm surge may have been responsible for the layer, but raised doubts about this origin in view of the uniqueness of the deposit.

Storm surges are generally agents of erosion with the net movement of sediment seaward and deposition of coarse material within fine seafloor sediments. This is due to return currents which

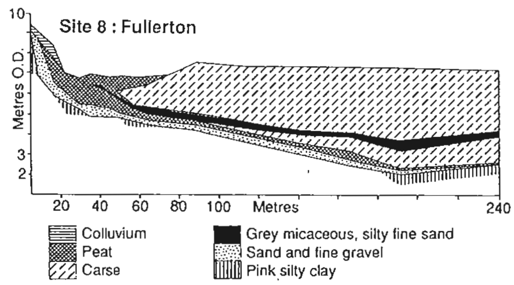

Figure 2 Section through the deposits at Fullerton.

tend to create storm deposits in shallow water areas with the movement of littoral material out to sea. In view of the doubts about a storm surge origin, Dawson et al. (1988) considered that the layer had been the product of a tsunami. Although tsunamis are generally viewed as destructive events, they have been known to deposit on land thin veneers of marine material, predominantly fine sand, derived from the local offshore environment (Wright and Mella, 1963). This is due to the translatory nature of a tsunami wave having net sediment transport landwards.

The sand layer in eastern Scotland has many of the characteristics of a tsunami deposit. Its extensive nature is similar to tsunami deposits. The lack of sorting in exposures of the layer can also be explained by tsunami waves, because due to the few waves involved there is little opportunity for sorting of the sediment carried ashore. A tsunami wave will often disturb the water column to a considerable depth, eroding sediment from the seabed at depths greater than a severe storm wave ; hence the transport of marine diatoms landward.

Dawson, Long and Smith (1988) believe that the fine sand deposit could have been laid down by a high magnitude tsunami caused by the Second Storegga Slide.

The Storegga Slide occurred on the Norwegian Continental Shelf edge at 63N 5E, 750 km north-east of Fraserburgh (fig.3). It is one of the largest submarine slides recorded in the world. This slide has been shown to comprise three events (Jansen et al., 1987). The first and largest slide of which involving 3880 km^3 of material occurred before 30.000 years BP. A second slide occurred between 8.000 and 6.000 years BP whilst the third and smallest event probably occurred soon after the second slide. The combined volume of the second and third slides totals 1700 km^3. The second slide

Figure 3 Location of Storegga slide.

covered a depth interval of 3500 m and had a total length of at least 800 km. Earthquakes possibly together with gas released from decomposition of gas hydrates are considered to be the most likely triggering mechanisms.

Computations of wave amplification effects reveal run-up heights for the Second Storegga Slide between 3 and 5 m in exposed areas along the eastern coast of Greenland, Iceland and Scotland and the western coast of Norway (1992).

An earthquake which initiated a submarine landslide and a tsunami wave occurred at Grand Banks, Newfoundland in 1929. The scale of this event (magnitude 7.2, volume of landslide 760 km^3, maximum wave height 12 m) is comparable to that at Storegga.

The Grand Banks earthquake and subsequent slide caused a tsunami which was extremely variable in its effects on the local coastlines. The nearby Sable Island experienced no tsunami, and Johnstone (1930) suggested that this was due to the island being protected by sand banks. The wave is recorded as having reached a maximum of more than 30 m high at Burin (Gregory, 1929) although Johnstone (1930) gave a value of only 12.2 m. The enormous increase in wave height within this area is thought to have been due to resonance in the V-shaped Burin inlet. It is interesting to compare this dramatic increase with the fact that the greatest height above the contemporary high water mark for the tsunami deposit in eastern Scotland occurs in the gullies around the Montrose Basin. Similar comparisons can be made when looking at the apparently strong directional component to the size and velocity of the tsunami wave of both the Grand Banks and Storegga events (if no evidence can be found in Scandinavia). In both events the direction of tsunami propagation was at right angles to the orientation of the slide.

NETHERLANDS

During the building of the "Wijkertunnel", a tunnel below the "Noordzeekanaal", the two building pits were a good opportunity to study the condition of the soils and the local geological evolution of the last 10.000 years. The geology of the pits can be seen in figure 4. The northern building pit was investigated by the 'Rijks Geologische Dienst' in Haarlem.
The basis of the two building pits is the 'dekzanden' (fig.4) at approximately 17 m below NAP. On top of the sand layer the basal peat is found. These peats were developed about 8000 years before present and are found in the building pits as a hard, compressed black peat about 20 cm in thickness with good preserved tree stumps and branches in it.

Thousand years later, approximately 7000 years before present, the west part of the Netherlands was characterised by an extensive lagoon complex that covered the basal peats. In this environment brackish clays (named : Klei van Velsen) were deposited. The following layer found in the northern building pit, has locally a very remarkable, almost 50 cm thick, shellrich layer at the base. Parts of the 'Klei van Velsen', the basal peats and even the Pleistocene sands are locally eroded. On top of this shellrich layer a layer was deposited with alternating sand- and clay layers from a few millimetres to a few centimetres.

N.W. Willemse (Rijks Geologische Dienst, 1994) : The shell layer consists of a graded bed of mainly autochthonous shells which lie at a depth of ± 15.80 m NAP erosively on top of the 'Klei van Velsen' (eastern side) and basal peat (western side). The shell-material consists mainly of Peringia ulvae (80%), Cerastoderma edule, Macoma balthica, Mytilus, Ostrea, Scrobicularia plana and Littorina. Doublets have been found of juvenile Cerastoderma edule and Macoma balthica which indicate an originally subtidal flat fauna of these shell debris. Lithologically it is a very heterogeneous layer of coarse shell-halfs and shell-remains in a matrix of Peringia ulvae, sand and mud (fig.5). In this layer,

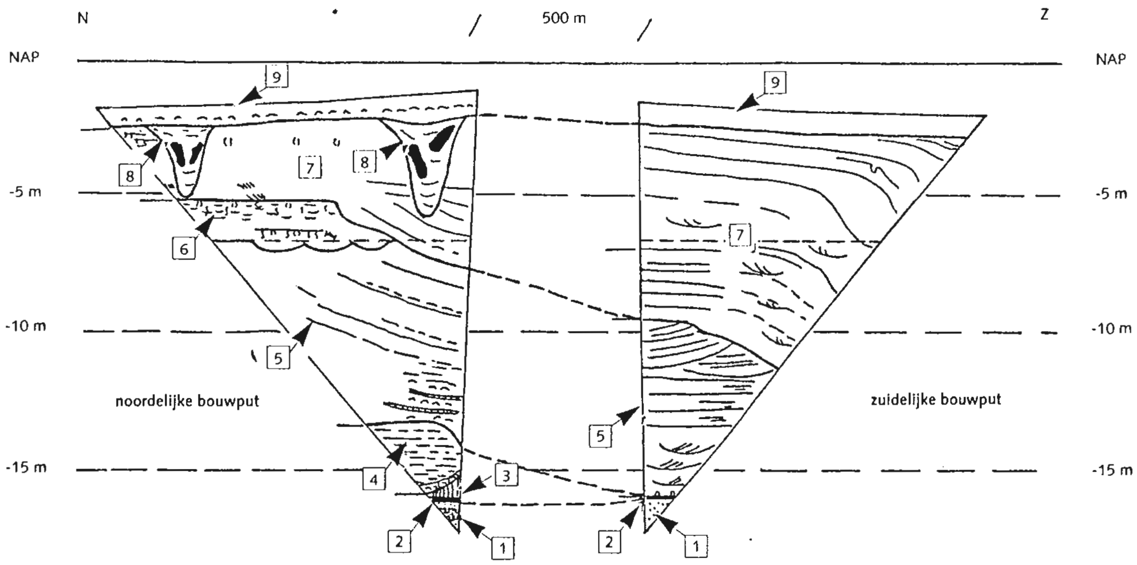

Figure 4 Geological section of the two building pits.

in the building pit, vertically as well as laterally, a gradation is visible. At the east side, the layer consists of a massive graded shell-bed with a thickness of 0.70 m. The layer consists of, in north-east direction dipping sets (± 10 cm) of shell-half's mainly piled up backwards in a finer matrix of Peringia ulvae which at the top of each set is graded in a layer with relatively more Peringia. At the eastside within this bed also enclosed parallel laminated sands with an equal set-thickness are found. More to the west the shellbed is alternated with an in thickness increasing silty/(fine) sandy clay layer which is slightly laminated. Here the shellbed lies unconformably on the basal peat.

There is still a lot of discussion about the way the shell layer was deposited. The layer was laid down during a high energetic and low frequency event. But was the shell layer deposited during a big storm or by a tsunami wave?

N.W. Willemse (1994) draws the (careful) conclusion that the shellbed in the Wijkertunnelpit is deposited in a lagoonal subsystem with a strong marine influence in association with supratidal saltmarshes.

Both for intertidal and supratidal accumulations an erosion/deposition mechanism is assumed in a shallow marine environment in connection with high energy and low frequency events, such as storm surges.

"The shell layer lies in between the lagoonal 'Velsenklei' and a more tidal-dominated deposit above it. The strongly bioturbated bed which is found as topfacies of the shell layer and which is associated with the shell layer is most likely intertidal (tidal flat). The gradation in the layer and the facies-association (parallel lamination, laminated clay), the fact that it is about an isolated deposit which lies unconformably on a lagoonal deposit and the dating of the shell layer at 6730±40 (^{14}C) years BP in relation to MSL, makes it, with the supposed sedimentary environment, acceptable that it is a inter/supratidal skeletal bank. A single trace oxidation within the shellbed which is observed sporadically could support this hypothesis, however it is unclear if it is not an artefact. The set structure in the massive bed which shows a north-east set direction and the intercalation of clays and fine sand layers seawards of the bank are for such a facies indicative sedimentological structures."

Th. de Groot (Rijks Geologische Dienst) thinks a tsunami wave is the most likely depositional medium.

The deposit is probably more extensive than thought when the layer was found. Several borehole logs in Noord-Holland and Zeeland show a similar shell layer. The layer is very heterogeneous and is a mixture of marine shells and salt/brackish-water shells. Some tree trunks were found which were rooted in the Pleistocene sand, but are broken off at the contact between the 'Velsenklei' and the shell layer. The event had to be strong and large enough to bring shells from a few kilometres from the coast onto land, and to erode locally the 'Velsenklei' and the basal peat.

Figure 5 Profile sketch of the shell layer by N.Willemse.

The dating of the layer is more or less the same as the fine sand layer found in Scotland, ± 7000 years BP. This might be an indication that the tsunami generated by the Second Storegga Slide has also deposited this shell layer. But a lot more research needs to be carried out before more founded conclusions can be drawn.

The shell layer found in the Netherlands might support the tsunami hypothesis in Scotland and maybe investigations in adjacent areas (for example Norway) can show similar layers which never attracted special attention before.

CONCLUSIONS

There is still a lot of discussion about the mode of deposition of the shell layer. The shell layer was deposited by a high energy and low frequency event at more or less the same time the sand layer in Scotland was deposited, ± 7000 years BP. The sand layer in Scotland is believed to be deposited by a tsunami wave generated by the Second Storegga Slide. The uniqueness of the layer within the Holocene record mitigates against a storm surge origin. However a tsunami origin explains the transportation of marine sediments onto land and the regional presence of the layer with its highest contemporary altitudes occurring in narrow inlets. Still a lot of research needs to be carried out, but comparison of the shell layer with the sand layer in Scotland and with historical tsunami deposits found in other countries, might aid the determination of the type of event that took place ±7000 years ago.

ACKNOWLEDGEMENT

I would like to thank Th.A.M. de Groot, N.W.Willemse and D.Beets of the 'Rijks Geologische Dienst' who supported me in this literature study. The source of all the information about the shell layer found at the Wijkertunnel location is the 'Rijks Geologische Dienst' in Haarlem.

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Book review

Support of underground excavations in hard rock

E. Hoek, P.K. Kaiser & W.F. Bawden (1995), Balkema, Rotterdam. pp. 215. Price: Hfl 100,70 (hardbound), Hfl 47,70 (paperback)

To my pleasant surprise a new book in the style of the classic work of Hoek & Brown (1980) "Underground excavations in rock" has appeared on the market. This book is the result of a four year research programme for the Canadian mining industry and was carried out under the supervision of the authors, all professors of rock mechanics at Canadian universities. The book bears the imprint of the first author, E. Hoek, who is a master in presenting the subject in a concise, to the point style. The book is not boring at all and invites reading.

In fact, the book reminds strongly of the Hoek & Brown "Underground excavation" book and at first glance one might think that it is only an upgrade of the earlier work. The same approach is followed and it is interesting to compare the contents of both books. The new book, as suggested by the title, is mainly directed to the support methods, whereas the classic book also addresses subjects such as excavation methods. Although many familiar figures and tables are present, to describe the basic principles, the progress in understanding the subject over the past 15 years has led to a riper and simpler presentation of principles.

It is a pleasure to see how new research and new tools (numerical analysis methods, spreadsheet calculations) have been smoothly integrated in the basic framework of discontinuous rock mechanics that was developed in the 1970's. I noted interesting new data on rock strength (a table with m-values for different rock types that can be used in the Hoek-Brown failure criterion). A new rock mass classification, the GSI (Geological Strength Index) is developed, using the Hoek-Brown criterion to overcome limitations posed by very weak rock masses when applying the RMR (Rock Mass Rating) system of Bieniawski.

In the new book also engineering geological data evaluation, rock mass classification and shear strength of discontinuities are treated. New work on in-situ rock stress and an explanation by anisotropic elasticity theory for the high horizontal stress - vertical stress ratio *k* is discussed. Halve of the book is devoted to support problems and support systems. Support design in overstressed rock and progressive spalling in massive brittle rock have been treated in separate chapters. Rock bolts and dowels, cable reinforcement and shotcrete support are treated in detatil. At relevant places is shown how relatively simple laboratory tests, graphical methods (stereograms) or numerical analyses are used to study certain problems.

The book is an example of how the merging of geological engineering and rock mechanics can be apllied to a rock engineering application. Like the earlier mentioned book of Hoek & Brown and its companion "Rock slope engineering" by Hoek & Bray (1974,1981[3]) it will assist professional geotechnical engineers and engineering geologists.

If we consider the price of this book, there is really no excuse; every student of engineering geology or applied rock mechanics should have it.

Peter Verhoef
T.U. Delft, Mijnbouwkunde & Petroleumwinning,
Sectie Ingenieursgeologie

Chemical stabilisation of clay soils

E. Degefu, Student engineering geology, ITC Delft.

In order to improve the engineering properties of in-situ soils different stabilization methods can be applied. An overview of the methods commonly used is given with special emphasis on chemical stabilizers. Six of the methods described at the end are considered relatively recent developments in chemical stabilization.

INTRODUCTION

Because of the increasing need to utilize poor soils for foundation support and because many soils can be made into useful construction materials if properly treated, soil improvement has become a part of many present day civil engineering projects. The alteration of soil properties to meet specific engineering properties, is known as soil stabilization (Ingles and Metcalf,1972).

Almost every problem related to soil use is due to the unfavourable interactions between water and soil (Kezdi,1979). The chief properties of a soil with which the construction engineer is concerned are volume stability, strength, permeability and durability.

Many clay soils swell or shrink with change of their moisture content.If uncontrolled, this phenomenon can disrupt road surfaces and crack buildings. It is a well known fact that the bearing capacity or strength of any wet soil is low. Permeability also presents engineering problems, which are mainly associated either with pore pressure dissipation or with seepage flow. So, in order to overcome these problems, methods which can exclude water from the soil and at same time transform it into a rigid granular mass are required.

Besides the traditional ways of applying cement, lime and bitumen; other special methods of stabilization like thermal, electro-osmosis, electro hardening and chemical stabilizers are also used from time to time. In most cases the special methods are too expensive to be applied except in special situations where no cheaper alternative is available. In recent years research is specially focused on a great number of chemicals and chemical processes with the objective of using them as soil stabilizers. Some of the chemical methods that are generally accepted and those that are considered relatively new are explained in this paper. A brief overview of the other methods is also given.

COMMONLY USED STABILIZATION METHODS

Mechanical Stabilization

Strength and durability of soils can be improved by mechanical means using compaction without the addition of any foreign matter. Water is added during compaction in order to displace air and facilitate movement of fine grained particles past one another so as to achieve densification.

Cement Stabilization

Depending on the soil type 3 to 10% of cement by weight of dry soil is mixed with the soil to cause it to harden into a compact mass which will not soften in the presence of water. Cementation is based on hydration of the cement. The major hydration products are a series of calcium silicate hydrates (CSH) and hydrated lime, $Ca(OH)_2$. Reactions of the soil with cement include replacement of adsorbed cations by Ca^{++}, adsorption of $Ca(OH)_2$ by particles and cementation at interparticle contacts by the CSH gel. When clay-grade minerals are present in excess of about 30% it is more difficult to achieve economic stabilization by use of cement due to great difficulties in pulverizing and mixing (Gillott,1968).

Lime Stabilization

Lime stabilization is achieved with calcium oxide (quick lime) or calcium hydroxide (slaked or hydrated lime). The stabilization mechanism of lime is similar to that of cement. Lime acquires silica from clays or other pozzolans in the soil to form CSH gel. Cement contains silica initially. Lime reduces plasticity by replacing troublesome cations such as sodium with calcium. At the same time coagulation of particles, i.e, flocculation takes place and the coarser lime particles absorb a good deal of free water resulting in dehydration. Lime treatment of 3 to 8% by weight of dry soil are typical for improvement of plastic and expansive fine-grained soils (Mitchell,1982).

Use of cement or lime may be extended by the addition of pulverized fuel ash, PFA (Bell,1994). It is reported that mixtures of cement and PFA or lime and PFA did not give good results as when cement and lime were used on their own, however, Bell remarks that it may be worth making some sacrifices in soil improvement to obtain the saving in cost that the use of PFA brings.

Bitumen Stabilization
In bituminous stabilization, bituminous materials (in the form of hot, cutbacks and emulsions) or road tars are mixed with soil so as to water proof the particles and/or provide the additional cohesion necessary for stabilization.The amount of binder normally ranges between 4 and 7%.

SPECIAL METHODS OF STABILIZATION

Deep Stabilization
Surface stabilization of clay has been used for a long time. Deep stabilization of clay, however, was not possible until 1975 when both Swedish and Japanese Scientists independently produced equipment for deep stabilization of clay with unslaked lime (Bryhn, Loken and Aas,1983).

Columns are produced by feeding a metered quantity of stabilizer such as cement slurry or quick lime, into a soft clay mass through a rotary drill equipped with a special auger bit which advances to the desired depth and mixes the soil and admixture thoroughly during withdrawal. Admixture contents are 5 to 15 percent by dry soil weight and strength increases of 10 to 20 times the untreated value are typical (Mitchell,1981).

The use of lime-fly ash slurry injection technique, for deep in situ stabilization of fine grained soils has also advanced significantly (Joshi, Natt and Wright,1981).

Many researchers have also observed that, when waste gypsum is added to unslaked lime a new binding agent called gypsumlime is formed, which improves the strength development of clays in deep stabilization (Kujala and Niemen,1983).

Geotextiles
The purpose of the application of synthetic fabrics is to cut off completely the movement of water in the soil. Examples are polythene sheet and nylon thread reinforced polythene.

PHYSICAL STABILIZERS

Thermal Stabilization
Heating fine-grained soils to temperatures higher than 100°C can cause drying and strength increase while heating to temperatures in the range of 600 to 1000°C can produce significant permanent property improvements including decrease in water sensitivity, swelling, and compressibility and increase in strength (Mitchell,1982).

Electro-osmosis and electro hardening
In electro-osmosis, the passage of electric current through a clayey soil causes the movement of water and the exchangeable ions associated with the clay minerals towards the cathode. This can produce an irreversible change leading to stabilization of the soil.

If a corrodible electrode is used such that electrolytic attack on the anode provides a continuing supply of some cation such as aluminium, which displaces en route cations of less valence from the clay soil, then a possibility of a true soil stabilization known as electro hardening takes place (Ingles and Metcalf,1972).

Chemical Stabilizers
The chemical stabilizers are divided into two groups, the inorganic and organic stabilizers. The actions of organic and inorganic stabilizers are generally quite different. The organics are characterized by a rapid strength gain and constant properties with time (Mitchell,1981). Examples of organic materials that have been proposed for use as admixtures are acrylamides, resins, polyurethanes, polyesters and asphalt. Besides lime and portland cement, other examples of inorganic stabilizers are phosphates, sodium chloride, calcium sulphate (gypsum) and caustic soda (sodium hydroxide).

CHEMICAL SOIL STABILIZATION

The important mechanisms of chemical stabilization are given below (Kezdi,1979).

- The soil is treated with a chemical compound having a stronger bond to the surface of the soil particles than that of water, whereby water sensitivity is eliminated. The additive displaces the water molecules from the grain surface thus making the soil non-wetting.
- The soil is treated by non-hydrated positive charge ions attracted to surfaces of a generally negative charge, and substituting other ions. Through such a transformation the sensitivity of the soil to water will decrease.
- The soil is treated with large molecule type ionic compounds. These macromolecule chains connect the soil particles with electrostatic and polar forces whereby aggregates are produced. The soil becomes porous, but remains water-impermeable and structurally stable.

- The interaction between water and soil can be modified by separating the polyvalent cations (Mg, Ca) bound to the surface of the soil particles through the addition of certain chemicals. Thereby, in the presence of free water the soil can be readily compacted and made water-impermeable.

In the various stabilization processes one or more of the following chemical reactions occur:

Ion exchange

Many clay properties depend on the type of the cations adsorbed over the surface of the soil particles, thus a change in the adsorption complex will be associated with the same in the soil characteristics.

Precipitation

During the chemical reactions new, water-insoluble substances can be created which will then be separated or precipitated from the original solution. Some are suitable as stabilizers.

Polymerization

In the course of the reaction certain heavy-weight large-size molecules are produced from some simple organic compounds. This process is known as polymerization.

Oxidation

In certain stabilization processes it is believed that the stabilizer is produced through oxidation.

Some Examples of Inorganic Chemical Stabilizers

Acid, neutral and alkaline type of inorganic stabilizers may be distinguished (Ingles and Metcalf, 1972). The first and last owe their effects primarily to an actual attack on the soil components (usually the clay minerals), with subsequent precipitation of new and insoluble minerals which bind the soil together. Neutral stabilizers act chiefly to alter physical properties of the soil, such as density.

Phosphoric acid

If phosphoric acid (H_3PO_4) is added to a soil containing clay minerals, the reaction forms aluminium metaphosphate ($Al_2(OH)H_3PO_4.XH_2O$) which is hard, water insoluble and capable of exerting a stabilizing effect.

Calcium Salts [sulphate (gypsum) or chloride]

When calcium salts are dissolved in the pore water of the soil they supply cations which are capable of participating in the following reactions (Kezdi, 1979).

- Exchange with ions already present in the soil
- Adsorption over the surface of the particles
- Supply of ions connecting the soil particles
- Ion concentration increases, whereby the inter granular electric repulsion will be reduced.

Usually, more than one of these reactions take place simultaneously. Their essential common feature is aggregation or coagulation action whereby they increase the electric force of attraction between the adjacent fine soil particles.

Some Examples of Organic Chemical Stabilizers

Polymers

Polymers are chain-type large molecules produced by linkage from simple (monomer-class) organic compounds by a process called polymerization. Polymer stabilizers fall into three groups, cationic, anionic and non-ionic.

The cationic polymers carry positively charged substituent groups which form a strong electrostatic bond with the negatively charged surface of the clay minerals and fine silica sand. This flocculates and structures the soil, giving increased resistance to shear forces (Ingles and Metcalf, 1972). Typical cationic polymers which have been tried for soil stabilization are the polyacrylamides (PAA), cetyl trimethyl ammonium bromide (CTAB) and such trade products as Armeen, Arquad, etc.

Of the anionic stabilizers, sulphonates and lignosulphonates are typical. The materials serve mainly as compaction aids.

Non-ionic stabilizers owe their effects to strong hydroxyl bonds formed between -OH groups on the polymer chain and surface oxygen of the clay minerals. Examples are polyvinyl alcohol (PVA) and Carboxymethyl cellulose (CMC). It is reported to be particularly effective as a coagulant.

Resins

Resins are used mainly for rendering the fine grained soils waterproof. The resin encloses the soil particles with a thin water repellent film, thereby preventing the reduction of cohesion. Vinsol is one brand used for a long time.

Aniline Furfural

Aniline is a primary aromatic amine and furfural is a primary aldehyde. The two additives react and produce a resin and/or a polymer which exerts its effect by reducing water permeability, bringing about strong bonds, and, thereby, increasing strength.

Calcium Acrylate

Calcium acrylate is an organic salt produced by the combination of calcium carbonate and acrylic acid. If it is added to a soil, polymerization takes place and, as a result, the soil particles become enclosed by strong and flexible polymer chains. After polymerization, soil strength is greatly increased.

Lignins

One of the lignines produced from the cellulose-plant wastes of the timber processing industries is called CaO lignine (alkaline calcium salt of the lignine sulpho-acids). It is claimed that lignine would form a gel type skeleton which is practically water-insoluble and capable of forming strong bonds with soil particles. It will increase cohesion and workability, and decrease permeability.

RRP (Reynolds Road Packer 233)

This is a strong acidic material which alters effectively, through ion exchange, the water absorption capacity of fine soil particles. The RRP does not produce binding forces between particles but helps to compact the soil easily (Kezdi, 1979).

Another similar chemical is CBV (Chemische Bodenverbesserug). An increase in CBR value from 4.4 to 27.7% is reported for samples treated with CBV (Gaspar,1981).

RECENT DEVELOPMENTS IN CHEMICAL STABILIZATION

Stabilization of Sensitive Clays Using $Al(OH)_{2.5}Cl_{0.5}$

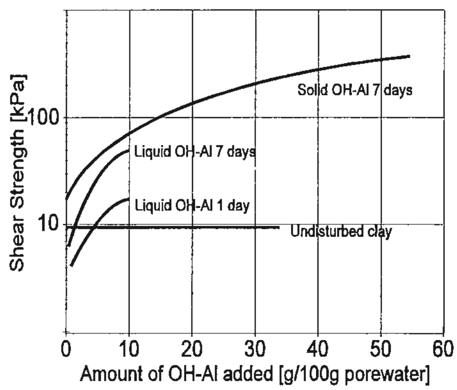

Figure 1 Shear strength in stabilized clay measured by fallcone test as a function of added OH-Al.

In 1980, a project was started at the Norwegian Geotechnical Institute on quick clay stabilization using polymeric aluminium hydroxide, including $Al(OH)_{2.5}Cl_{0.5}$ (denoted OH-OL or hydroxyl aluminium). It was already known that polymeric OH-Al reacts like an ideally shaped and charged cation in the exchange process, releasing Ca^{++}, Mg^{++}, K^{+} and Na^{+}. The project consisted of laboratory experiments as well as full-scale, in situ testing using OH-Al alone or together with KCl or K_2SO_4 (Bryhn, Loken and Reed, 1985). Lime stabilized clay was used as a comparison. The rate of soil improvement was determined as the rate of increased shear strength (Tbl 1 & Fig 1).

Table I Experimental Series and Chemicals Used.

	OH-Al	OH-Al + KCl	OH-Al + K_2SO_4	OH-Al + $CaCO_3$	OH-Al + CMC	OH-Al + $CaSO_4$	OH-Al + miscellaneous*	CaO	CaO + KCl	CaO + $CaSO_4$	CaO + miscellaneous**
Preliminary laboratory experiments	x										
Preliminary diffusion experiments	x	x						x	x		
Deep stabilization at Emmerstad:											
Section 1	x							x			
Section 2	x	x	x								
Section 3 and 4	x	x	x					x			
Laboratory stabilization:											
Emmerstad	x	x	x	x	x	x	x	x		x	x
Ellingsrud	x	x	x	x	x		x	x	x		
Honefoss	x	x	x	x	x	x	x	x	x	x	
Torrekula	x	x	x	x	x	x		x		x	
St. Leon	x	x	x	x	x	x		x		x	
Drammen	x	x	x	x	x	x		x		x	

* OH-Al + NH_4Cl, NH_4NO_3, $(NH_4)SO_4$, $FeSO_4$, bentonite,Iron Powder
** CaO + bentonite, silica dust
Norwegian quick clays from Ellingsrund, Emmerstad and Hanefos, and one quick clay from Torrekulla, Sweden were used. In addition a medium salt marine clay from St. Leon in St. Lawrence valley Canada, and a salt marine clay from Drammen, Norway, were tested.

As reported by Bryhn et al, columns of stabilized clay with different chemical-clay ratio, were prepared in the field using a deep stabilization equipment. Direct shear, unconfined compression, and bending tests were performed in the field on full diameter columns. In addition, unconfined compression tests on small pieces of the columns were made in the laboratory. The clay adjacent to the columns was also tested both mechanically and chemically.

Based on the test results, the authors reached the following conclusions:

- Stabilization of sensitive clays with polymeric hydroxy-aluminium seems very promising. OH-Al with necessary additives can stabilize all types of clay. The result is depending only on the amount used. Additives like $CaCO_3$, CMC (Carbo xymethyl Cellulose) and K_2SO_4 are very useful in increasing the stabilizing effect of OH-Al.

- Field stabilized columns showed a much lower shear strength than that indicated by the laboratory experiments. This is believed to be due to the installation equipment which gave incomplete mixing.
- Stabilization of the clay adjacent to treated columns appears promising. Diffusion of ions either added or resulting from ion exchange, produced increased remoulded shear strengths of the clay.
- CaO is very effective in silty clays but has little or no effect in clays with high water content and in salty clays.
- The optimum engineering choice of chemicals for stabilization, considering both the strength of the column and the effect in the surrounding clay, appears to be OH-Al for short term stabilization (e.g temporary excavations) and OH-Al+ K_2SO_4 for long-term improvement, such as permanent fillings (Bryhn, Loken and Reed, 1985).

Stabilization by Multivalent Cations

Trivalent cations of Fe^{3+}, and Al^{3+} are found to be a method of improving the engineering properties of soft clays (Matsuo and Kamon, 1981). The clay soil used by the investigation of Matsuo and Kamon is a very soft marine clay.

The soil was air dried and powdered in order to gain good mixed soil samples with various amounts of the additives. The additives are a polyaluminium chloride (PAC) for Al^{3+} and iron powders for Fe^{3+}.

The PAC acts as the aggregating agent of the clay particles due to the cation exchange effect. The Al^{3+} aggregates are formed by the physical adsorption of aluminium oxides. The iron powders, which are oxidized in the soils, change to the trivalent cation, and cement and bind inter-clay particles and intra-aggregates due to the physical adsorption. The micro structure models of the aggregates is shown below (Fig 2).

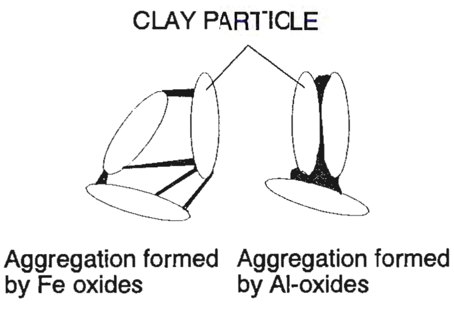

Figure 2 Microstructure Models of Aggregates.

It was shown that shearing strength (qu) sharply increases with the amount of added multivalent cations (Fig 3), and the length of curing time. Because of the importance of the co-reaction of the PAC and the oxidizing iron powders the method is recommended for shallow soil stabilization.

The Consolid System

According to the company brochure (Consolid AG, Switzerland), three products, which are normally used in combination, are developed for use as soil stabilizers in pavements. They are named CONSOLID 444, CONSERVEX and SOLIDRY. Consolid 444 is applied to a total layer thickness of 150 to 300 mm. and Conservex or Solidry only additionally in the top 50 to 100mm.

Consolid 444 reduces the surface tension of the water around the soil particles allowing the surfaces of the particles to stick to each other. This causes an agglomeration of fines. Consolid 444 is not a binding compound but improves soil characteristics through the waterproofing effect. Conservex is a bituminous product which adheres to the soil particles and blocks capillaries. Solidry uses cement and lime as extender and its effects are similar to Conservex. Consolid 444 and Conservex are shown to be best for dry silty/sandy soil while Consolid 444 and Solidry are recommended for wet clayey/silty soil.

For soils treated with the consolid system large increase in dry density, CBR and UCS as well as reduced plasticity and swell are reported. The company claims that the Consolid system improves soaked CBR values by at least 3 - 5 times.

Stabilization with Iron Oxide and Sodium Silicate Solution

The process involves heating a fine grained soil to a temperature high enough to destroy its water sensitivity, adding finely divided iron oxide, and introducing a sodium silicate solution (Mitchell, 1982 coating Ingles and Lim, 1980). After compaction the mixture is said to set into a hard, durable material.

Stabilization of Dispersive Clay Using Calcium Rich Salts

It has been found that if water with a high concentration of calcium is allowed to seep slowly through a clay with a high concentration of sodium (dispersive soil) ion exchange in the soil can take place: sodium ions are replaced by calcium ions and the soil flocculates i.e. becomes non-dispersive (Wagener, Harmse, Stone and Ellis, 1981). The method was used to repair a reservoir which failed due to dispersive piping through the embankment and basin floor. The calcium rich salt chosen for

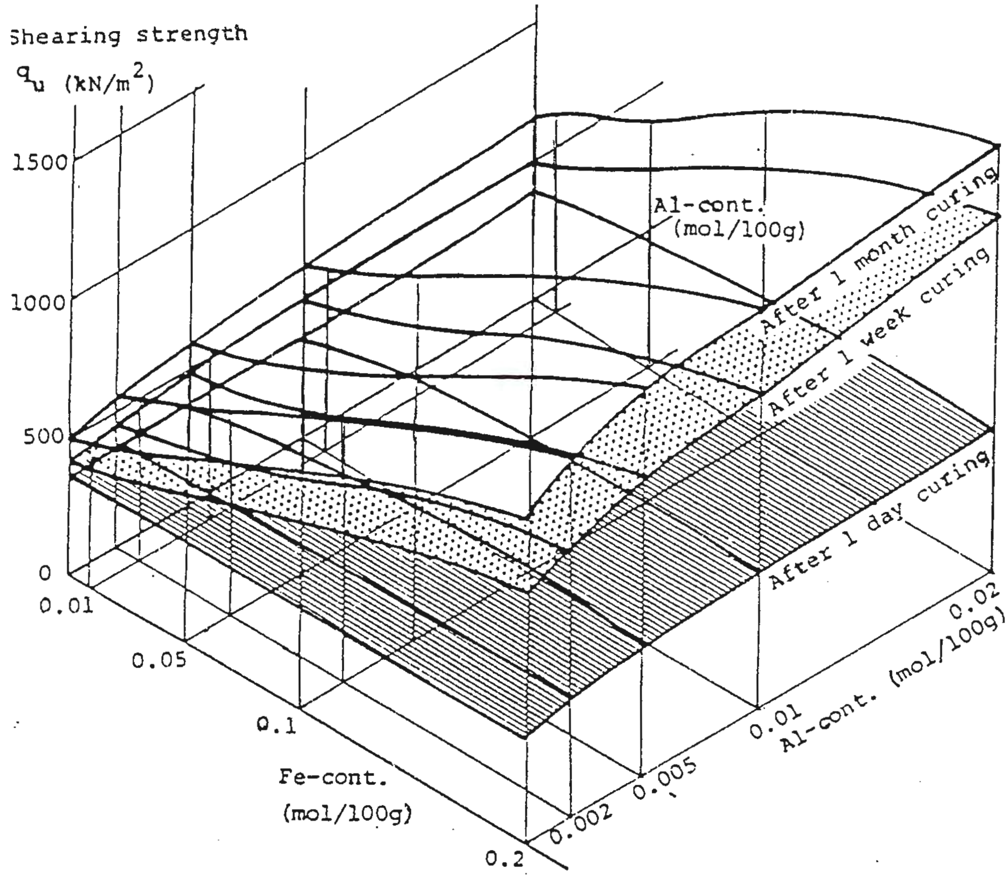

Figure 3 q_u versus cation content.

the above case was gypsum ($CaSO_4.2H_2O$). The gypsum was applied to the basin floor, the breached embankment, the riprap on the upstream face and a certain amount was also added to the reservoir water. Because of the measures applied, failure did not re-occur and seepage from the reservoir reduced with time.

Stabilization of Clay Soils by Applying Melment, Plastiment A 40 and Mowiton M 370.

It is reported that addition of either Melment or Plastiment A 40 to clayey soils mixed with cement resulted in a remarkable increase in strength (Chandra, 1987). Soils mixed with lime and treated with Mowiton M 370 are also reported to have shown a high increase in strength.

Melment is a melamine formaldehyde based admixture while Plastiment A 40 is a product of AB Svenska SIKA. Mowiton M 370 is a chemical supplied by Perstorp, Sweden.

The investigation was carried out in order to utilize clayey soils as building materials by improving their durability. In connection with the same investigation it was also reported that the water absorption of all the specimens was significantly reduced by brushing with a solution made of 40% butylstearate and 60% vanolene.

CONCLUSIONS

Even though research is in progress on chemicals and chemical processes with the objective of using them as stabilizers only a few of such methods are generally accepted. There is still much research, experimentation, practical observation and experience needed before the mass introduction of these methods is possible. Excellent laboratory test results may be achieved but researchers say that, often, these can not be reproduced on site, or else they proved to be prohibitively expensive.

According to the investigations made by Dr. Gaspar of the Hungarian Road Research Institute, (as quoted by Kezdi, 1979), chemical treatment of soils can be beneficial if the following requirements are met:

- The application of a small amount of chemical should be sufficient to cause a major drop of the liquid limit;
- Due to the treatment, the maximum dry density and the optimum moisture content should be increased;
- CBR values of treated samples, compacted at optimum moisture content and exposed to capillary action for four days should be minimum 15 to 20 per cent, and the accompanying swelling should not be more than 2 to 3 mm;
- PH value should not be greater than 7.5.

It must be emphasized that many soil stabilizers are patented products developed individually or by particular industries, and that their composition and/or mode of action is not always known clearly, even to the vendor (Ingles and Metcalf, 1972). Ingles and Metcalf further say that fair comment on such stabilizers can only be made after careful field trials.

Use of such materials should, therefore, be approached with caution, accepting their use only on an experimental basis, without reliance on previously reported trials unless made under full scientific control.

Attempts have been made to systematize data regarding soil stabilization. A paper about systematization of data is presented in the 8th European Conference on Soil (Andrei and Manea, 1983).

Using data systematization a computer programme is written which stores information, classifies soils and predicts the most suitable technique to stabilize a given soil. The authors have reported that a good agreement is shown between stabilization techniques applied in practice and those predicted by the computer programme.

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Book review

Wear of rock cutting tools, Laboratory experiments on the abrasivity of rock.

H.J.R.Deketh (1995), A.A. Balkema/Rotterdam. pp. 144. Price: Hfl 120.00 (hardcover).

A new book titled "Wear of rock cutting tools" (Laboratory experiments on the abrasivity of rock) written by Jan Reinout Deketh has appeared on the market. This book is the result of four years of investigations (Ph.D research program) carried out at Delft University of Technology, Section of Engineering Geology. The research has been sponsored by the Technology Foundation of The Netherlands (STW).

Wear of rock cutting tools is a system dependent process, in which many variables are involved. The wear problem is often easy to understand, for example when observing worn chisels, bits, pick points or any other cutting tools, after the end of the cutting operation of excavation machinery. But to predict the wear (important cost factor) in practice is quite complex.

The new book of Jan Reinout Deketh faces a real practical problem in the trenching and dredging industry, which is treated with an innovative and original approach based upon an experimental laboratory procedure. It was a pleasure for me to read the contents of the book before its publication.

The back-bone of this book consists of a wear mode hypothesis which is supported by results of the special developed *Scraping Test*. The book emphasizes, that the possible wear mechanism at the wear-flat of rock cutting tools is mainly due to sliding motion, in which *abrasion and adhesion* are predominant. Wear of rock cutting tools can also be caused by impact motion.

It is clearly presented how the mechanical-physical properties and the mineralogical composition of the "intact material" (artificial and natural materials) influence the wear process of the rock cutting tools. The author emphasizes, that the unconfined compressive strength, the E-modulus, the brazilian tensile strength, the point load strength, the dry density, the grain size, the grain shape and the volume percentage of abrasive minerals are the principal variables governing the wear process.

Other variables like: the cutting velocities, rock relief strength, hardness of the mineral grains, chisel material (steel) used, chisel shape, the effect of spacing on chisel interaction are also treated.

Almost all research related with a new topic ends with the classical *more research should be done*. Of course more studies should be done on this subject but the conclusions and recommendations given in this book represent a big step forward in the understanding of the wear process. To some extent, this book can be used as a guideline for the engineering geologist, mining engineer, civil engineer or other specialist involved in mechanical rock cutting, and why not by students.

Mario Alvarez Grima, T.U. Delft, Mijnbouwkunde & Petroleumwinning, Sectie Ingenieursgeologie

In Focus: Mario Alvarez Grima

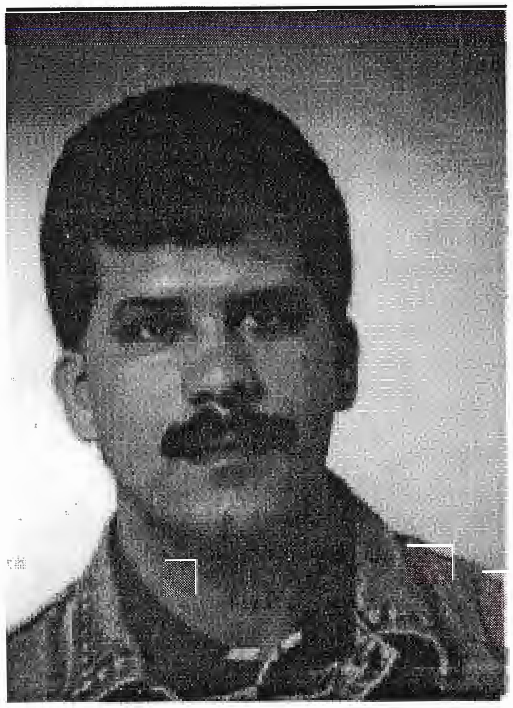
A.B. de Jong en I.M. Hergarden

The International Institute for Aerospace Survey and Earth Science (ITC) in Delft is one of the institutes in the Netherlands which can offer a postgraduate course to engineers from foreign countries. Mario Alvarez Grima (31) from Cuba is one of the students who participated in the Engineering Geology course in 1991.

"The Dutch embassy in Cuba arranges the participation in the ITC courses. If you want to apply for the course, you have to be working for a company which will pay your salary even if you are in the Netherlands. Actually this is some kind of fellowship. The ITC in the Netherlands makes the selection between all applicants."

Before Mario Alvarez Grima came to the Netherlands he was working as a hydrogeologist. Together with a team from Czechoslovakia and a team from the (former) Sovjet Union, Hungary and Bulgaria he was concerned with big projects related to dam constructions, site investigations and tunnelling. The dam projects varied between rather small dams of about 10 meters high and large ones of 170 meters high. The dams were all made of local materials with a clay core. "In this project you can really apply all your engineering geological knowledge because everything is included in the project." Most dams were build for irrigation purposes, other purposes are watersupply, to be able to control the flow of the river and the generation of electricity. "My task in the projects was mainly to try to avoid leakage through the body of the dam and through the foundation. This could very often be solved by grouting or improvement of the foundation." The places where new dams had to be constructed were not easy to build on because the easiest places had already been used. Left were places with very much loose sediments which had to be either removed (the fines) or grouted (coarser material). Another problem often encountered at the sites was the occurrence of karst features in the limestone (the majority of dams has problems with the karst).

"In 1991 I studied for one year in the Netherlands (the postgraduate course) and after that I went back to Cuba. In 1993 I applied for the Msc course at ITC. During this course I was working with Robert Hack from ITC in rock mechanics. We investigated the influence of roughness and shear strength. I finished this course and applied for a job at the university of technology in Delft. The position I got is for 2 years. The project I am working on is partly funded by the Dutch government and it involves an investigation of the behaviour of a machine which makes trenches in rocks. This method has to be used when blasting of the rocks is impossible to do, e.g. posible damage of existing foundations of buildings. At this moment we are mostly doing in-situ measurements. My task in this project is to measure the performance of the machine in-situ and to continue to do some laboratory tests."



Mario Alvarez Grima MSc.

What will happen after these 2 years is not yet clear to Mario Alvarez Grima. He would like to continu to do research. "I like to combine the theoretical knowledge with the practical experience. Sometimes you need the both qualities in one person and I try to have both components at least parallel to each other."

Recently published papers

Most members of the Ingeokring are working in the field of Engineering Geology and related fields of expertise. By virtue of the interdisciplinary character of Engineering Geology the topics of work and study of the members of the Ingeokring range widely, and as a result their work is published in journals and proceedings of different nature. Because of this, not all publications come to the attention of the different members. To ease the access to the publications of different Ingeokring members, the authors of recently published papers are given the opportunity to present a short abstract (15 lines) of their publication, in the Newsletter. In addition the authors should give a name and address, to which persons that are interested can respond to for more information.

Geomechanical analysis of small earthquakes at the eleveld gas reservoir
(Eurock '94)

A distinct relationship exists between the production of natural gas and small earthquakes near the reservoir. Simple models show that the sensitivity for fault activation sue to differential compaction evidently depends on the fault-reservoir geometry. A very sensitive geometry, leading to several small earthquakes, is found in the Eleveld gasfield. The observed magnitudes correlate well with the estimates from a more complex model. In this specific geological setting residual tectonic stresses are assumed to be negligible. For the coming decades, pressure depletion is expected to amount to only a fraction of the pressure depletion up to now. Therefore the potential magnitudes of possible future earthquakes in this area are expected to become only marginally higher.

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Wear of rock cutting tools
Laboratory experiments on the abrasivity of rock
(ISBN 90 5410 620 4)

The consumption of chisels, pick points or any other cutting tools on rock excavation machinery forms an important cost factor in the total excavation process. The prediction of this consumption before a project starts is a very difficult undertaking. Essential to improve methods of estimation is a better understanding of the wear mechanisms that take place.
This book provides for a better insight in the wear processes which take place during the cutting of rock with steel cutting tools. Rock cutting experiments in different rock types are described, that led to a new approach to the estimation of rock cutting tool wear.
Together with the other book "Site Investigation for Rock Dredging" (to be published in 1996) in the series "Wear of Rock Cutting Tools" this book is essential for any engineering geologist, mining engineer and civil engineer working in the field of mechanical excavation of rock.

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publisher: A.A.Balkema Publishers, P.O.Box 1675, 3000 BR Rotterdam, Netherlands (Fax 31.10.4135947)

Rock characterisation for dredging purposes
(Terra et Aqua nr.55)

The step from soil to rock dredging, undertaken by dredging contractors a few decades ago, has been one which has led the dredging people slowly from the realm of soils to that of solid rock. The transition has not been without surprises. Even today contractors are confronted with unexpected problems when dealing with rock. Since the machinery is able to cope with increasingly stronger rocks, the type of information needed increasingly differs from that traditionally used when dredging soils.

This paper intends to review the basic information needed when working on a site where rock is involved. It is based on state-of-the-art engineering geology practice. Particular attention is given to abrasivity of rock and the amount of wear to be expected from some rock types.

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The potential use of geotechnical information systems in the planning of tunnels for Amsterdam
(Tunnels and Underground Space Technology Vol.9, No.2)

The use of engineering geological information systems consisting of geotechnical information obtained from site investigations and ground water levels forms a powerful new dimension in planning of tunnels with respect to anticipating hazards and design problems. A pilot study was initiated in 1986 to produce an engineering geological information system for a 4-km^2 area of the west-central district of Amsterdam.
The information system contained cone penetration profile data, as well as information on boreholes and groundwater levels. The system has been shown to work using standard data base and mapping programmes to produce thematic maps which can be used in tunnel planning and design. Reference is made to the proposed north-south underground light-railway line for Amsterdam to provide planning examples for which such an information system would be of relevance. The fact that these two projects ran concurrently but covered different areas of Amsterdam only emphasizes the need for tunnel planners and engineering geologists to become more aware of each others' needs. Use of information systems in tunnel planning has been successfully undertaken for the recent aquaduct tunnels of London.

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Earthquake-hazard mapping with questionnaires in the Roermond area (Netherlands)
(Proc. 7th Int.I.A.E.G.Congress)

Early morning of Monday, 13th April 1992 an earthquake of magnitude 5.8 occurred on the Peelrand fault in the eastern Netherlands near the city of Roermond. A questionnaire was distributed in the town of Herkenbosch (near) Roermond to determine local variations in intensity using classification systems such as the MMS, JMA, MSK-64 and the Eurocode-MSK-(EMS) scales. About 75% of the households responded to the questionnaire. The moderate intensity of the earthquake combined with the high integrity of construction does not allow for high resolution using the existing scaling systems. The questionnaire is reviewed with respect to questionnaires used elsewhere for this purpose. The paper discusses the compromises made in such questionnaires to ensure questions are reasonably understood, avoids tedium, are compiled to obtain maximum data for the circumstances of the earthquake, take into account the geographical extent of the survey area and that they remain comparable to similar studies carried out elsewhere. Initial correlations are presented with building type and with the foundation-soil profiles. The information compiled from the survey, the geology and the building types, the classification, the correlations and the areal distribution of both classified and correlated information is being combined to form part of the Seismic Engineering Information System (SEIS) being developed at Delft.

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Applications of satellite remote sensing and gis, to the inventory and analysis of geological hazards: A review of the results of an unesco sponsored project of international cooperation"
(International forum "Natural Hazards Mapping" Tsukuba (Tokyo) Japan, June 1993)

The organizational background, the objectives and the main phases of execution of an international research project on mountain hazard mapping using GIS are described. Airborne and satellite remote sensing techniques, such as photography, imaging radar and multispectral scanning provide spatially

distributed electromagnetic reflection data from the earth's surface. In a process of digital image processing, these data can be geo-referenced and be made ready for the production of imagery for visual interpretation and for introduction into a Geographical Information System.
A GIS makes it possible to combine data about the geology, terrain form and a number of other terrain characteristics, as derived from maps, field surveys and from remote sensing in an analysis to determine the influence of these various terrain factors on the likelihood of occurrence of a number of different slope instability processes.
The authors discuss the possibilities and limitations of scale and resolution of remote sensing imagery, when it is used for slope instability hazard analysis. Key factors are the size of the slope instability phenomena and the various scales at which hazard maps should be prepared for regional, local and site planning purposes.
Conclusions are presented about the applicability of available types of airborne and satellite remote sensing imagery and desirable developments for the future are indicated.

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Mountain hazard mapping in the andean environment: An international project to integrate remote sensing and GIS for hazard mapping (International Forum "Natural Hazards Mapping" Tsukuba (Tokyo) Japan, June, 1993)

The organizational background, the objectives and the main phases of execution of an international research project on mountain hazard mapping using GIS are described.

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Satellite remote sensing and GIS for landslide hazard zonation
(Int. Symposium "Operationalization of Remote Sensing", Enschede The Netherlands, April 1993)

The authors discuss the possibilities and limitations of scale and resolution of remote sensing imagery, when it is used for slope instability hazard analysis. Key factors are the size of the slope instability phenomena and the various scales at which hazard maps should be prepared for regional, local and site planning purposes.

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Mountain hazard mapping making use of remote sensing and geographic information systems (Proceedings "25th Int'l Symposium on RS and Global Environmental Change, Graz, Austria, April 1993. Volume 1, pp. I-54-I-65)

The application of remote sensing images to slope instability hazard mapping is evaluated, as well for direct mapping, as for indirect mapping methodologies, where small scale data are useful for the spatial evaluation of possible parameters controlling the slope instability. The combined use of different types and scales of remote sensing data is facilitated by the application of Geographic Information Systems (GIS). These systems are particularly important in the analysis of the instability processes in relation to the large amount of factors, which may be involved in the occurrence of the process. To enable an acceptable cost/benefit ratio, a methodology is given for the hazard zoning at three different scales, maintaining a reasonable level of objectivity and reproducibility, also at the smaller scales.

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Application of satellite remote sensing for natural disaster reduction in developing countries (IDNDR, World Conference on Natural Disasters Reduction, Yokohama, Japan, May 1994)

The paper describes the integrated application of Remote Sensing (RS) and Geo Information Systems (GIS) in the process of monitoring and hazard assessment of natural disasters.
After a short introduction on the methodology of hazard assessment emphasis is given to the unique role which satellite Remote Sensing can play in this context.
An evaluation is made of the applicability of different types of RS-imagery, considering their spatial, spectral and temporal resolution. The capabilities of the use of RS-data in GIS for data integration and analysis of hazard occurrence specifically for conditions in developing countries are highlighted.

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Methodological aspects in hazard zoning with a special reference to the application of remote sensing: Experiences of a research project on mountain hazard zoning in the Andean Cordillera in Colombia (Workshop on Remote Sensing applied to Geological Hazard Mapping Programme on Geological Applications of RS, GARS, UNESCO, February 1994)

A high demand exists for natural hazard and risk mapping. A comparison of recent examples of disasters is showing the effectiveness of a proper hazard mitigation. For hazard zonation, risk assessment and the planning of relief operations, the use of remote sensing is playing an important role. An effective application requires an integrated system, using and combining data derived from several sources, varying in sensor type, scale and time.
The paper presents the results of a mountain hazard research project in Colombia. The unique role of remote sensing is highlighted and an evaluation is given of the applicability of different remote sensing data, considering spatial, spectral and temporal resolution. An overview of a methodology for slope instability hazard mapping is presented for three scales of analysis.

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GISSIZ: Training package for the use of geographical information systems in slope instability zonation (10th Thematic Conference Geologic Remote Sensing, San Antonio, Texas, May 1994)

Within the framework of two international research projects a training package has been developed, allowing earth-scientists to gain experiences with GIS and landslide hazard zonation. It consists of the following item:
* A **textbook** on the theoretical aspects of the use of GIS in slope instability zonation, in which an overview is given of useful conventional techniques and how they have to be adapted for the application of GIS. Procedures for data collection, data entry, data base design and data analysis are extensively treated. Results of various methods of analysis are described and compared using a basic data set from the Chinchina-Manizales area (central Colombia). An evaluation of potential error sources is given as well as recommendations for the most useful techniques at different scales of analysis.
* An **exercise manual**, containing GIS exercises at four different scales (national, regional, medium and large scale), made on different levels of complexity.
* A set of 10 diskettes, containing a **training data** set of the study area, required to carry out the exercises, a **tutorial version of a PC-based geographic information system** (ILWIS), and a **demo** diskette, which can also be used outside of GISSIZ on any MSDOS computer with a colour screen (also normal VGA).

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Slope instability of remote sensing and GIS in recognition, analysis and zonation
(The Royal Society, London, March 1994)

Slope instability processes are the product of local geomorphological, hydrological and geological conditions, the modifications of these conditions induced by geodynamic processes and human activity, the vegetation and landuse practices and the frequency and intensity of precipitation and seismicity.
The paper describes the integrated use of remote sensing and GIS in the process of recognizing slope movements and in the analysis and zonation of landslide hazard. After a short introduction on some methodological aspects of slope instability hazard mapping, emphasis is given to the unique role of remote sensing in the hazard mapping. An evaluation is made of the applicability of different remote sensing data, considering spatial, spectral and temporal resolution. The capabilities of GIS in the data integration and the analysis of terrain variables in relation to slope instability are highlighted. A methodology for different scales of analysis is given. Some observations are made on aspects of objectivity and accuracy in landslide hazard assessment. Finally a training package for the use of GIS in slope instability zonation (GISSIZ) is presented.

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An engineering geological GIS data base for mountainous terrain
(7th Congress of the IAEG, Lisboa, Portugal, September 1994)

Within the framework of two international research projects a method was designed for the application of geographic information systems in the construction of an engineering geological data base at a scale of 1:10,000. The method was applied to a mountainous area: the city of Manizales, in central Colombia. The major problem encountered in heterogeneous, mountainous, areas is the extrapolation of point information which allowed, in combination with boreholes and outcrop data, to model the layer sequences spatially. Different maps were made for the spatial distribution of each material type. The depth of these materials was obtained by modelling materials thicknesses as a function of other parameters. The resulting Engineering Geological data base was used as the main input in hydrological models and slope stability calculations.

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Geotechnical classification of peats and organic soils

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Peats and organic soils possess engineering properties which significantly differ from those of mineral soils. Consequently, routine investigation and design methods may be inappropriate and results in error. The paper aims to provide information on the typical behaviour of peats and organic soils. It is shown that many aspects of engineering behaviour of these materials are related to their mode of formation. An outline is given of the development of Dutch peats and organic soils. A classification system is presented which reflects properties such as compressibility and strength anisotropy. An outline of test procedures is included.

INTRODUCTION

In many parts of the western, central and northern Netherlands peat and organic soils make up a substantial part of the soft Holocene deposits, posing various problems for construction such as high compressibility and low strength. Some of the most densely populated areas of the Netherlands are also the areas where peat and organic soils are predominant in the upper part of the subsoil. Infrastructural works suffer from the poor subsoil conditions, both during construction and lifetime. Problems during construction are related to excessive deformations and marginal stability of embankments; post-construction problems are presented by high maintenance costs owing to creep and a high sensitivity of the construction to additional loading. Also, in the less densely populated polder areas continuous lowering of the ground water table causes land subsidence, driven by oxidation of organic components of the soil.

The severity of the problems associated with the use of peat and organic soils is not reflected in the amount of attention generally paid to the selection of investigation and design methods appropriate for these soils. In daily practice, peat and organic soils are supposed to behave in the same way an anorganic clay soil would, with extreme values for compressibility and strength parameters. Participants of the 1993 Delft International Peat Workshop [Edil e.a. 1994] appeared to be divided over the question whether entirely new and different investigation and design methods should be adopted for peats and organic soils. However, there was consensus over the fact that investigation and design for constructions on peats and organic soils should take into account at least the following aspects:

- *high variability of all properties on all scales*
  Conventional testing and sampling densities, empirically developed for anorganic soils, may well prove to be too low for organic deposits
- *presence of constituents with dimensions compatible to those of conventional in situ testing equipment and samples*
  The random occurrence of wood remains or reed stems will strongly influence the results of in situ tests, causing a strongly erratic pattern of in situ parameters, e.g. vane shear strength. Wood or reed stems in laboratory samples may invalidate the results of routine tests, e.g. oedometer or permeability.
- *sensitivity to sample disturbance*
  Because of their high compressibility, peat and organic soils are very sensitive to forces exerted by a sampling device. Moreover, fibrous peats will be subject to stresses caused by the samplers edge cutting through the fibre components. Sample disturbance induced by small diameter samplers (i.e. less then 70 mm ID) has a significant effect on engineering properties [Helenelund 1980, Carlsten 1993].
- *extreme compressibility*
  The typical low initial effective stresses in peats and their high compressibility may lead to a gross overestimation of deformations caused by even relatively small loads, when using the conventional Terzaghi settlement formula with stress-independent compression constants.
- *anisotropy*
  Peats and organic soils exhibit a strong anisotropy in many properties. As a result of anisotropy in the strength parameters, the routine practice of deriving strength parameters from triaxial compression tests alone will overestimate the average resistance along a potential failure surface.

- *susceptibility to oxidation*
  Peat and organic soils are susceptible to oxidation, the rate of oxidation being greatly increased by the availability of oxygen. Water table drawdown will cause rapid decomposition of the material newly exposed to the air, leading to a reduction in strength and potential loss of its constructive function.

In 1987, the Dutch Technical Advisory Committee on Flood Defences (Technische Adviescommissie Waterkeringen, TAW) has initiated a research program in order to bridge the gap between operational knowledge of anorganic clays and that of peats and organic soils. This paper presents some of the results of the program, which will be more elaborately described in a Technical Report 'Geotechnical classification of peats and organic soils' to be issued this year by TAW [TAW 1995]. The purpose of this paper is to familiarize the reader with concepts and terms related to the behaviour of peats and organic soils, since these are the basis of methods for investigation and design to be presented in future TAW reports or guidelines.

The results given in this paper represent only a small part of the total research program, which encompassed variability [Sikder 1994], sample disturbance, stability analysis [Edil e.a. 1994], compressibility [den Haan 1992], constitutive modelling [Sellmeijer 1994], the development of artificial peat [Termaat e.a. 1994]. Other useful information may be found in the comprehensive text by [Hobbs 1986], the general report of the 1988 Tallinn Conference [Carlsten 1988], and many papers presented at the 1993 Delft International Peat Workshop [Edil e.a. 1994].

CLASSIFICATION OF PEATS AND ORGANIC SOILS

In general, a geotechnical classification system will aim to:

- impose uniformity in nomenclature
- provide a basis for zonation of a peat deposit, distinguishing more or less homogeneous units with respect to geotechnical properties
- delineate classes representing a specific behaviour, to be described by specific constitutive models, parameters and tests
- allow the development of correlations between simple classification parameters and engineering parameters

Many classification systems have been put forward [Landva 1983] but only a few can be said to fulfil the requirements given above for a geotechnical classification system. The essence of an appropriate classification system is a thorough knowledge of the engineering behaviour in given conditions. Properties governing the engineering behaviour should then be reflected in the choice of the classification parameters.

The existing Dutch standard NEN 5104 [NNI 1989] for classification of soil only serves the first purpose, i.e. uniformity in nomenclature. 'Peat', according to the Dutch standard NEN 5104 [NNI 1989], is soil containing more than 15 to 30 % organic matter, the percentage depending on the nature of the anorganic constituents. 'Organic soils' are not explicitly defined by NEN 5104. In this paper, the NEN 5104 medium and strongly humose soils with organic contents between 2.5 and 30 % will be considered 'organic soils'.

A classification according to NEN 5104, and consequently the terms 'peat' or 'organic soil', is a poor indication of the engineering behaviour of a material. For this reason, an additional system for classification has been developed. A first version of this system has been presented in [Venmans e.a. 1990] and [CUR 1992]. Since that time the system has been validated using data from different sites in the Netherlands. The final version described in the following contains some minor modifications and simplifications as compared to the earlier system.

Before embarking on a description of the classification system, the two subsequent chapters will contain a brief description of development and morphology of peats and organic soils in the Netherlands, and a brief introduction to the engineering behaviour of peats and organic soils in one-dimensional compression and slope stability problems.

DEVELOPMENT AND OCCURRENCE IN THE NETHERLANDS

Development

The following is a summary of the excellent text by Hobbs [Hobbs 1986] on this subject.

Peat is an accumulation of partially decomposed vegetation. If the vegetation accumulates in waterlogged anaerobic conditions, complete decomposition is prevented and a series of complex and chemical and biological changes may interact to produce humus and thereafter peat. Any system of plants, water and underlying peat, irrespective of origin, nature, stage of development or size may be conveniently termed as a *mire*. Mires may form and peats may accumulate wherever the conditions are suitable, irrespective of altitude or longitude; they tend to be most common in regions with a comparatively cold and wet climate.

Climate and topography primarily determine the conditions for accumulation of peat. There should be a superfluity of water throughout the year and the landform should be such that a sufficient amount of water is retained to support vegetation and to provide a permanent reservoir to preserve the remains of this vegetation, i.e. the peat. Waterlogged depressions, lake shores and river banks with low energy water flow provide suitable refuse for peat accumulation.

Even under seemingly stable climatic conditions mires are not static; whereby plant communities alter their habitats, that change also follows in the mire development. The complete development is a very slow process in human terms. For example the change from open reedswamp to raised bog occurs through thousands of years. The low period of growth and development of mires can be divided into three stages, each stage with its peculiar plant communities producing their characteristic peat with distinctive geotechnical properties. These stages which are determined by the hydrological state of the mire are described below.

Rheotrophic stage

In this stage the mire develops in mobile water in lakes, basins and valleys under the control of the water level, nutrients supplied by stream flow, runoff and percolating groundwater (figure 1a/b). Generally the nutrient supply is rich, and is further enriched by washed-in sediments; such conditions are known as *eutrophic*. The landscape after completion of this stage is marsh like and is commonly referred to as fen and the peats as fen peat (Dutch: *'laagveen'*). Typical species associated with the early stages of basin filling are bulrush, water lilies and reed. Predominant species in the later stages are sedge, willow, alder, birch and oak. These mires are generally underlain by very soft organic muds (*gyttja*) which can cause severe engineering problems. Behind natural levees along rivers forests may develop in eutrophic conditions. Regular flooding of the levees provides an abundant amount of nutrients, at the same time depositing mineral matter.

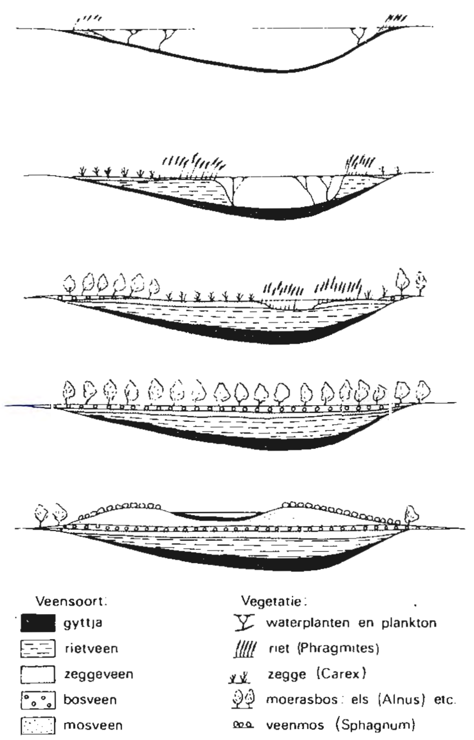

Figure 1 Different stages in peat formation [Pannekoek 1973].

In this stage the organic content is still relatively low, varying between 10 and 80 %. Somewhere in this range lies the transition form an 'organic soil' to a true 'peat'. The organic content increases with the height of the peat above the substrate. Void ratios and water contents are high; the water content at the beginning of the stage is typically 100 %; with increasing peat thickness, the water content increases to values in the order of 500 %.

Transition stage

In this stage the mire is in the process of changing from the rheotrophic to ombrotrophic stage because of upward growth. The mires in this stage depend to an increasing extent on precipitation for their growth, and receive nutrient form groundwater to a decreasing extent by virtue of fluctuations in water level. The margins of the mire may continue to receive groundwater (figure 1c/d). The nutrient conditions are *mesotrophic*, which is an intermediate condition between eutrophic and oligotrophic. Typical species are pine, birch and spaghna (mosses).

The organic content of the peats developed in this stage is relatively high, varying between 80 and 95 %. Void ratios and water contents are high; typical values of the water content are between 500 and 1000 %.

Ombrotrophic stage

This is the morphological stage in which the mire has grown beyond the maximum physical limits of the groundwater and is solely dependent on direct precipitation for its water and nutrient supply (figure 1e). The peat deposit itself acts as a reservoir to hold water above the groundwater level. The nutrient conditions are deficient or *oligotrophic* as precipitation contains only minute quantities of nutrients. The peats are acidic in character and are referred to as raised bog peats (Dutch: '*hoogveen*'). Ombrotrophic mires need not necessarily be preceded by transitional mires, but under favourable climatic and topographical conditions they can form directly on the land surface. Typical species are spaghnum, cotton grass and heather.

The organic content of peats in this stage is very high, often exceeding 98 %. Void ratios and water contents are extremely high, with typical values for the water content between 1000 and 2000 %.

Humification

At least three processes are involved in the humification process, i.e. the change of state from fresh plant tissue to peat:

i loss of organic matter as gas or by solution and by removal by small invertebrates
ii loss of physical structure
iii change of chemical state, including those changes brought about by micro-organisms.

Soil microflora, bacteria and fungi obtain their energy and nutrients by breaking down the plant organic matter. Earthworms enhance the breakdown of cellular structure of plant remains in non-acidic soils and make it suitable for further decomposition by bacteria and fungi. As these organisms require oxygen, they are aerobic in character. Immersion in water reduces the oxygen supply abruptly in comparison with exposure to open atmosphere, thereby reducing the activity of aerobic microflora. By immersion the activity of anaerobic species with different and less rapid metabolic activity is increased. Due to this reduction in total activity, partially decayed vegetable material can accumulate as peat. The end products of aerobic humification are carbon dioxide and water. In anaerobic conditions methane and hydrogen sulphide may be formed. Methane is explosive when mixed with oxygen, which implies a hazard for site investigations or constructions in peat. Also, gas-driven water wells have been reported following extraction of site investigation equipment.

The intensity of the humification process is neither uniform nor general throughout the peat, because certain parts are more resistant to decomposition than other parts and also certain plants are more resistant than others. In relatively undecomposed state, there are little or no granular-looking materials in peat. Leafs, roots, stems and fibres are the main constituents, which are light in colour. In the completely decomposed state there are little or no fibres and the peat is dark in colour. The physical and engineering properties of peat are closely related to its state, more precisely to the average state of humification.

Formation of Dutch peats and organic soils

At the end of the last glaciation during the Early Holocene, the restoration of the sealevel started and the North Sea again became a sea. At the end of the Boreal period (8500 years BP) the coastline of the North Sea approached its present location. Due to this transgression, the groundwater table in areas behind the coastal barrier rose and a wide strip of land behind the barrier was drowned. Initially reed peats formed on Pleistocene deposits in open fresh and brackish water marshes under eutrophic conditions. Following the accumulation of peat, conditions became less eutrophic, leading to the formation of mesotrophic wood peats and heather peats. Locally moss peats developed in oligotrophic conditions. Approximately 7500 years BP peat formation came to an end because of a renewed transgression. During the entire Atlantic period the sealevel was rising rapidly, which resulted in a thick sequence of lagoonal and tidal flat deposits, the Calais deposits. The peat between the Pleistocene layers and the Calais deposits is commonly known as the Basal Peat. Its present thickness is generally less than 0.5 m, which is 15 to 25 % of its original thickness due to compaction by the overlying deposits. During the Calais transgression the backswamp moved upward over the gentle slope to the east. Here, fluviatile sediments are

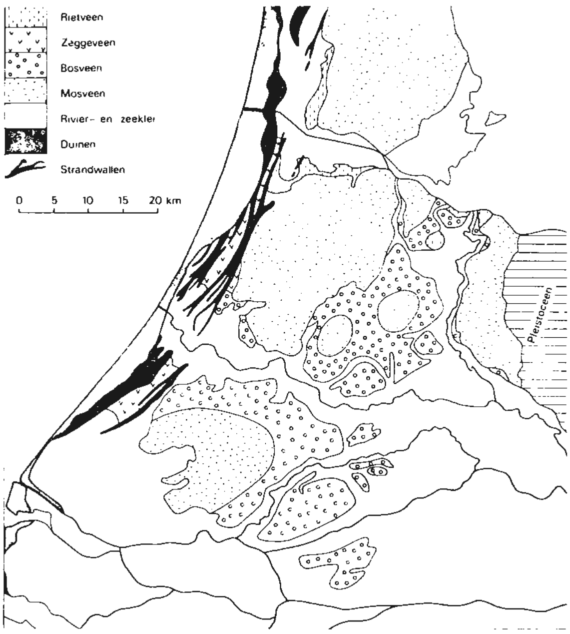

Figure 2 Distribution of superficial peats in the western Netherlands, 1200 AD [Pannekoek 1973].

found intercalated in the peat, which are known as the Gorkum deposits. Sedimentation of the Gorkum deposits was directly influenced by relative sealevel movements, but marine and brackish water sediments themselves are absent.

During the late-Atlantic and early Subboreal the rate of sealevel rise diminished and marine sedimentation practically came to an end. Approximately 3800 years BP a new phase of peat formation set in. Reed peat developed on top of the Calais deposits behind the coastal barrier. After the formation of reed peat, the further development of vegetation was strongly dependent on water and nutrient supply, which varied both laterally and vertically (figure 2).

Along the rivers Lek, Waal, Maas, Oude Rijn and Hollandse IJssel extensive marsh forests developed between the natural levees. Elder, willows and oak were the predominant species. The peat resulting from this vegetation generally is strongly humified because of exposure to oxygen during periods of low river discharge. Also, the peat is rich in mineral matter deposited when the river flooded the areas behind the natural levees. In brackish conditions directly behind the coastal barrier reed formation continued, e.g. in Noord-Holland.

Further from the rivers, without the abundant supply of nutrients, mesotrophic sedge peat began to develop. In the most remote areas this mesotrophic peat was again overgrown by oligotrophic peat, in which moss, heather and cotton grass were the predominant species. In this stage of peat formation the vegetation was almost

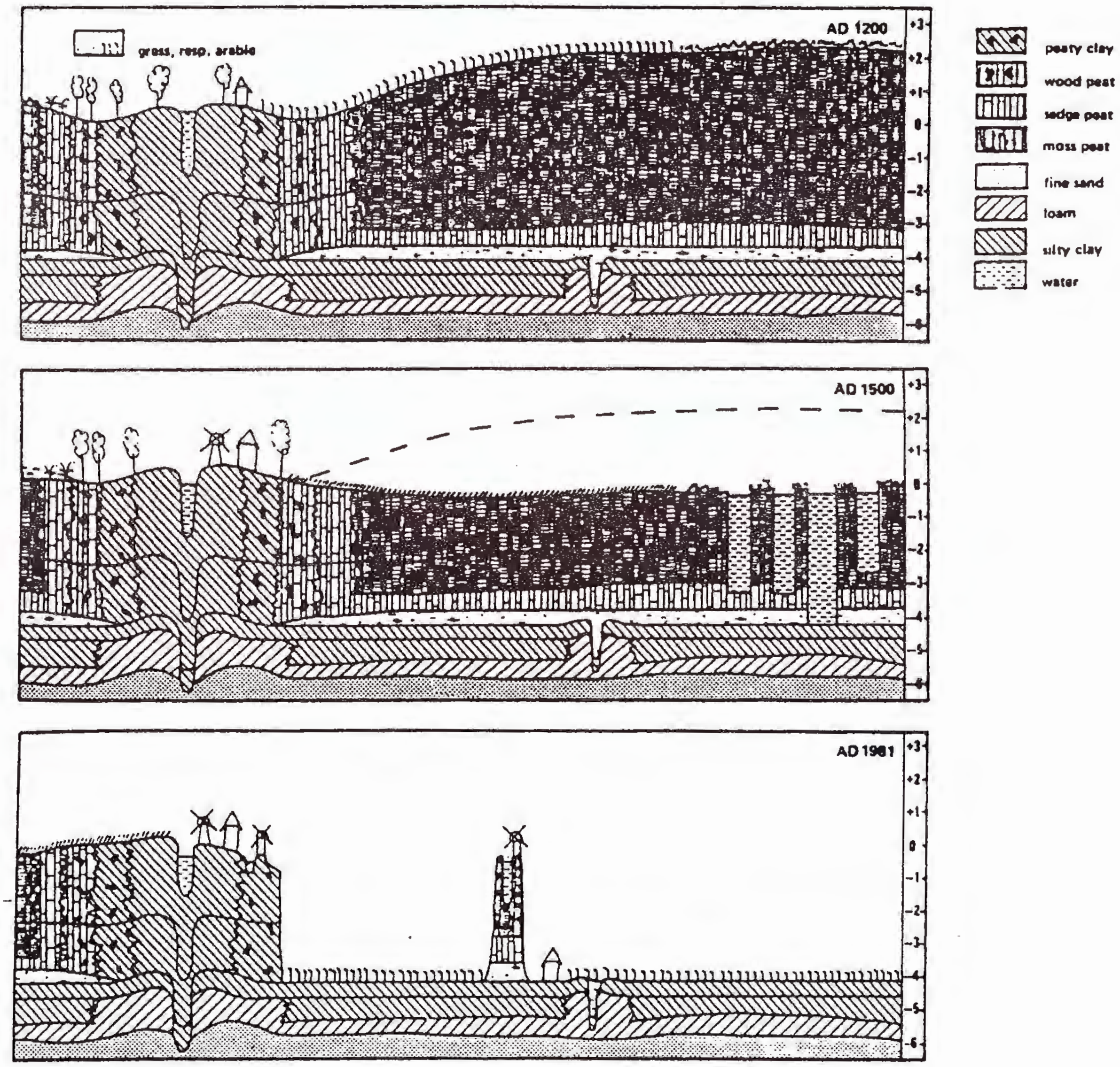

Figure 3 Typical cross-sections through a peat deposit [de Bakker 1988].

Table I Final thickness as a percentage of original layer thickness for different types of peats and organic soils, at an ultimate effective stress of 100 kPa

stage		organic content [%]	water content [%]	final thickness / initial thickness [%]
rheotrophic	early	20	100	80
	late	70	500	55
mesotrophic		90	800	45
oligotrophic		98	1500	27

independent on groundwater and large raised bogs could grow above the average groundwater table (figure 3a). Around 1200 AD several oligotrophic mires existed in Holland and Utrecht: the area of the present Vechtlakes, the area west of Gouda and some smaller areas north of the Oude Rijn. Similar oligotrophic peats could be found in Friesland, Overijssel and the western part of Brabant.

These peat deposits formed after the Calais transgression are commonly referred to as Holland Peat. Since about 3500 years BP, part of the Holland peat was eroded by the Duinkerke transgressions. These transgressive phases had most effect in places where the coastal barrier was weak, such as in river outlets (Maas, Oude Rijn, IJ), or where the coastal barrier was partly missing, such as in Zeeland and the northern part of the Netherlands. The Duinkerke deposits and their fluviatile equivalent, the Tiel deposits, only incidentally reach thicknesses exceeding 2 m. Further erosion of the Holland Peat was caused by wave action along the shores of lake Flevo and smaller inland lakes. Once eroded, the peat decomposed rapidly in the biologically active water of the lakes.

A schematic cross-section through a river and a raised bog is given in figure 3a. This cross-section might be found in the central Holland peat area around 1200 AD. The vertical succession reflects the general geological development of the area, with Holland Peat overlying the Calais deposits. The lateral succession in figure 3a reveals the influence of hydrological conditions: natural levees (sandy/silty clays) - organic clay - wood peat - sedge peat - moss peat.

The peat deposits in the Netherlands reached their maximum extent around 1200 AD (figure 2). Since that time the central Holland-Utrecht peat deposits have been excavated to serve as domestic fuel (figure 3b). The low mineral content of the oligotrophic deposits made these peats very suitable as compared to the sedge and wood peats which contained a significant amount of mineral matter. Most of the oligotrophic peats in Zuid-Holland and Utrecht have been excavated. At present, these peats can only be found in small polder embankments left over after exploitation (figure 3c).

At the same time artificial dewatering of the peat areas was undertaken to create arable land. Initially dewatering was powered by gravity, later by windmills, steam, oil and electricity (figure 3b). Dewatering a living mire will stop peat formation and induce a cyclic process of oxidation of exposed material and compaction of deeper layers, in turn followed by further dewatering. Certain areas in Zuid-Holland and Utrecht are known to have subsided as much as 2 m since the beginning of artificial drainage.

Although the discussion given above has focused on peat formation, it will be clear that the development of organic soils is closely related to peat formation. The majority of organic soils in the Netherlands are backswamp sediments, deposited between the natural levees of rivers. Frequently these organic clays may are found to laterally interfinger with wood peats; also, thin peat layers are common in these deposits.

Available maps

Several types of maps are available which provide useful information regarding occurrence and nature of peats and organic soils.

i *geomorphological maps* (available at a 1:50,000 scale) contain information on landforms, (historical) land use, drainage and relief. These features can be expected to reflect subsoil conditions, although some experience will be required for a correct interpretation. For example, former natural drainage channels in peat deposits can be detected by their slight elevation. Al-

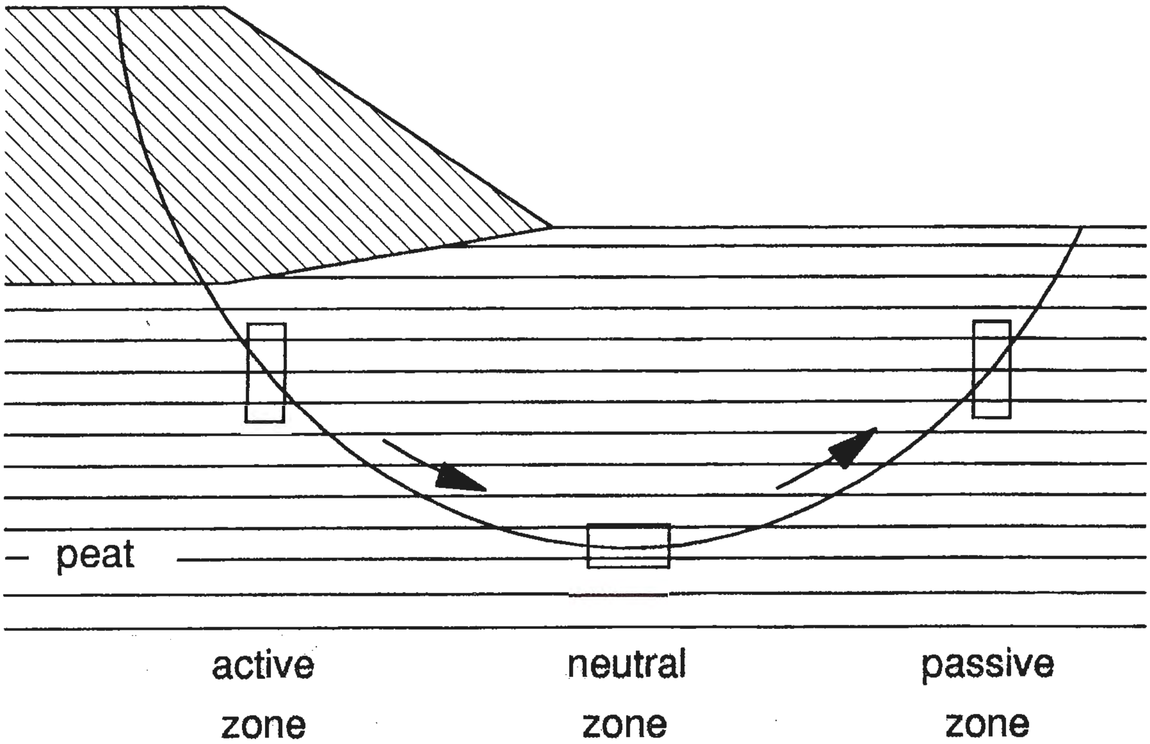

Figure 4 Loading conditions along a potential failure surface.

though these channels originally were the lowest part of the area, differential compaction of the levees and channel infill as compared to the surrounding peat has caused an 'inversion' of the relief.

ii *soil survey or pedological maps* (available at a 1:50,000 scale) have been compiled for agricultural purposes and provide information on the upper 120 cm of the subsoil. The mapping units represent soil composition, geological origin and soil formation processes. Also groundwater tables are given relative to the surface. Because the top 120 cm of a deposit has been subject to many changes since its formation, it will not be identical to deeper strata. However, soil survey maps usually reflect the general underlying Holocene deposits. The description which accompanies the maps gives a further explanation about the development of the Holocene layers. Often, cross-sections are given covering the entire Holocene deposits.

iii *geological maps* (available at a 1:50,000 scale) contain information on both the shallow and the deeper subsoil. In soft soil areas, the main map shows the nature of the holocene deposits. In addition cross-sections through the Holocene deposits is given, in which different peat types are indicated. Also, isopach maps of lithostratigraphical units and contour maps of the top of the Pleistocene deposits are included. The accompanying description contains further details on the general development of the area.

iv *engineering geological maps* (various scales) give specific engineering information, based on a geotechnical zonation of the relevant part of the subsoil and quantitative geotechnical data. Typical engineering geological maps of peat areas may show settlement caused by land reclamation or subsidence induced by dewatering.

Soil survey and geological maps provide practical information on the spatial distribution and nature of peats and organic soils. With this information, a preliminary site investigation can be planned and an indication may be obtained regarding the type of tests to be performed (cf. chapter 5.2). If cross-sections are available, a coarse estimate of settlement can be made based on local experience.

ENGINEERING BEHAVIOUR

Compressibility

Because of their high to extremely high void ratios and water contents, peats and organic soils are extremely compressible. Loads smaller than 100 kPa may reduce the thickness of a peat layer to less than 50 % of its original value. These extreme deformations cannot be described properly by traditional settlement formulas such as that of Terzaghi. It has been shown by den Haan [den Haan 1992] and other authors [Hobbs 1986] that the compressibility of peats and organic soils may be conveniently correlated to initial water content and organic content. In chapter 5.7.3 of [CUR 1992] the 'modified Fokkens' method is given for the calculation of one-dimensional compression from these parameters.

Since both water content and organic content of peats and organic soils are related to their mode of formation, so is their compressibility. Thus, soil survey and geological maps contain a wealth of information at almost no cost. As an indication, table 1 gives the final thickness of a deposit of the materials described in chapter 3.1, loaded to an effective stress of 100 kPa.

Strength

Fibres have a pronounced effect on the strength of peats and organic soils. Shear stresses will mobilize friction between fibres and between fibres and intermediate ('matrix') material. Depending on the direction of loading, tension forces may develop in the fibres. Thus, the fibres reinforce the soil matrix. It is assumed that a subhorizontal preferential fibre orientation exists as a result of deposition and compaction of vegetable material. This preferential direction is the main cause for a marked anisotropy in shear strength. This is best illustrated by comparison of the stress state along a potential failure surface, in which three zones can be distinguished (figure 4).

active zone

In the active zone the direction of loading is such that the fibres are extended, reinforcing the soil matrix. This type of loading is approached by triaxial (CU- or CD-) compression tests.

neutral zone

In this zone the fibres move parallel to each other and shearing resistance is controlled by the soil matrix. Some resistance may still be derived from intertwined fibres. Loading conditions in the neutral zone are most adequately reproduced in constant volume ('CU-') or CD-simple shear tests.

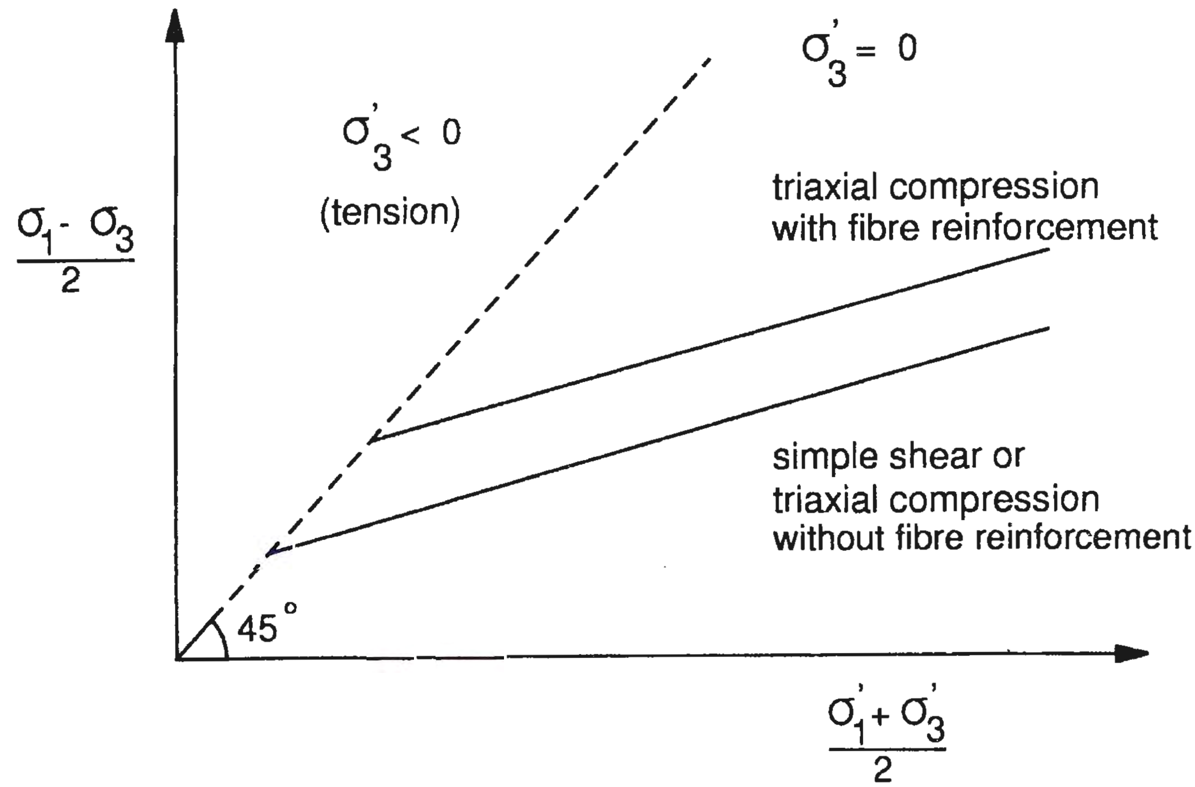

Figure 5 Triaxial compression versus simple shear
σ'_1 = major effective principal stress
σ'_3 = minor effective principal stress

passive zone
In the passive zone the fibres are compressed laterally. Although fibres may rotate and reinforce the matrix at larger strains, the shearing resistance appears to be determined by matrix strength.

Figure 5 depicts strength envelopes typically found in triaxial compression tests, both with and without fibre reinforcement, and in simple shear tests. The reinforcing effect of fibres can be described as an apparent effective cohesion. The effective friction angle of a fibre-matrix composite hardly depends on direction of loading and is equal to that of the matrix material.

Data from triaxial extension tests on natural peat are not available. Studies on fibre-reinforced sand indicate that the strength in triaxial extension is approximately equal or slightly less than the strength in simple shear.

Interaction between fibres and matrix, strength of fibres and fibre orientation determine the strength characteristics of peats and organic soils. Fibre strength is not only dependent on the type of fibre, but also on the degree of decomposition of the plant tissue. An appropriate classification system should therefore include the following information:

- amount and nature of the mineral constituents
- type of fibres: woody, stems, roots, leaves, other
- dimensions of fibres
- state of humification
- preferential fibre orientation

In a qualitative sense, strength anisotropy will be most pronounced in fibrous, lightly humified peats. A complete set of strength parameters will require a combination of triaxial compression and simple shear tests. Simple shear tests alone will give a safe, but conservative estimate of average shearing resistance along a failure surface. Triaxial compression tests alone, a routine practice in anorganic soils, will overestimate the average available shear strength. Strength anisotropy will be low in highly humified organic soils and strength parameters from triaxial compression tests can be considered representative for all parts of the failure surface.

CLASSIFICATION SYSTEM

Classification parameters

Table 2 summarizes relevant classification parameters; the choice of parameters will depend on the purpose of the classification.

Table 2 Classification parameters for various purposes

parameter	nomen-clature	zonation	selection of strength test	correlation with compressibility
main description	V	V		
type of fibres		V	(V)	
amount of fibres / leaves		V	(V)	
amount of wood		V	(V)	
von Post degree of decomposition		V	(V)	
pyrophosphate degree of decomposition			(M)	
water content			(M)	M
organic content	V	V	(M)	M
unit weight			M	M
specific gravity				(M)
shrinkage anisotropy			(M)	

V = visual observation or simple field test, recommended
M = measurement in laboratory test, recommended
(..) = optional

Table 3 Descriptive terms for amount of fibres / leaves and woody components

area percentage [%]	descriptive term
< 5	no fibres / leaves / woody components
5 - 15	little fibres / leaves / woody components
15 - 30	many fibres / leaves / woody components
≥ 30	very many fibres / leaves / woody components

The optional parameters will increase general insight in the character of the material, but cannot be considered useful in a quantitative sense according to present data.

An elaborate description of test procedures is given in the forthcoming Technical Report [TAW 1995]. In the following, an outline is given.

main description

The main description follows NEN 5104 [NNI 1989].

type of fibres

A description of the botanical composition of the plant remains is very useful for reconstruction of the formation of the peat deposit. However, a reliable determination requires a considerable amount of experience. For practical purposes, the type of fibres is best described factually. With little training stems, roots, leaves and other fibres can be recognized; a possible system is presented in [Sikder 1994].

amount of fibres / leaves / woody components

The amount of fibres, leaves and woody components can be estimated as an area percentage in a cross-section. A distinction can be made between components larger and smaller than 1 mm in length or diameter. Table 3 gives descriptive terms.

von Post degree of decomposition

The degree of humification can conveniently be estimated by the von Post test. In this test a small amount of peat is squeezed in the hand; classification follows the colour of the water squeezed out and the consistency of the retained matter. The original von Post classification comprised 10 classes. For practical purposes a number of these classes can be grouped according to table 4.

pyrophosphate degree of decomposition

Humic acids are intermediate products of peat humification processes and thus, the amount of humic acid presents is a measure of decomposition. Humic acids are dissolved in a sodium-pyrophosphate solution; the intensity of the colour of this solution is determined in a photospectrometer and expressed in a number.

water content, unit weight and specific gravity

These parameters can be determined in the same tests that are used for mineral soils.

organic content

The organic content is most conveniently calculated from the loss-on-ignition, defined as the mass loss after heating at 550 °C during 5 hours:

Table 4 Modified von Post scale

modified von Post degree of decomposition	description
H'_1	non-humified or fresh the water squeezed out is clear, colourless to light brown
H'_2	slightly humified the water squeezed out is muddy to very muddy; no solid matter is squeezed out; the residue is firm
H'_3	moderately humified the plant remains are difficult to recognize; up to two-third of the solid material is squeezed out
H'_4	strongly humified the plant remains can hardly be recognized; almost all material is squeezed out

Table 5 Recommended strength tests

zone	unit weight [kN/m³] < 11	11 - 13	≥ 13
active	CD-triaxial test (simple shear test)	CU-triaxial test (simple shear test)	CU-triaxial test
neutral and passive	simple shear test	simple shear test	CU-triaxial test

(..) = safe alternative

(organic content) = 1.04·(loss-on-ignition) - 4

In this equation organic content and loss-on-ignition are both expressed as percentages. The factor 1.04 accounts for partial disintegration of anorganic constituents.

shrinkage anisotropy

Plant remains tend to shrink most in a direction perpendicular to their long axis. Therefore, the difference between horizontal and vertical shrinkage of a regularly shaped sample of peat will give an indication of preferential fibre orientation.

Selection of a strength test

As pointed out in chapter 4.2, the selection of appropriate strength tests depends on the character of the material. Analysis of available data revealed that the selection is most conveniently based on unit weight, as stated in table 5. CD-triaxial compression tests are recommended for peat with unit weights lower than 11 kN/m^3 in the active zone because CU-triaxial tests tend to produce irreliable results.

FURTHER RESEARCH

Following the 1993 Delft Peat Workshop, contacts between research institutes have given new momentum to Technical Committee 15 'Peat and Organic Soils' of the International Society for Soil Mechanics and Foundation Engineering. Institutes from the United Kingdom, the United States, Holland, France, Poland, Sweden, Norway and Finland have decided to exchange knowledge and experiences, which should result in a state-of-the-art report in 1997.

This report will comprise:

i a recommended practice for investigation and design for peats and organic soils
ii benchmarks for validation of design methods, based on a number test sites
iii descriptions and appraisal of various constitutive models
iv benchmark laboratory tests for validation of constitutive models

This report will be the basis for further TAW technical reports and guidelines.

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The Netherlands National Group of the International Association of Engineering Geology (IAEG), the "Ingeokring" founded in 1974, is now the largest section of the KNGMG, the Royal Geological and Mining Society of the Netherlands. With more than 200 members working in different organisations, ranging from universities and research institutes to contractors, from consultancy bureaus to various governmental organisations, the Ingeokring is playing a vital role in the communication between engineering geologists in the Netherlands.