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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 improving 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, WP 6.1 or in Word 6 or 7, 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.

From the chairman of the Ingeokring

Dear members,

It is quite some time ago that I wrote an introduction for the News Letter. Since that last time I completed my PhD Thesis. The researchwork for it was satisfying, however, it took much my time. The thesis is based on data gathered by students of TU Delft and ITC during their regular engineering geological fieldwork. Using this opportunity I thank all those who have helped and provided the data for my research.

Although my research is rounded off, TU Delft and ITC still do the engineering geological fieldwork in Spain. In fact this introduction is written in Spain. Today was the first day that the students are alone in the field, trying to become engineering geologists. The ongoing of the fieldwork with about 20 students from TU and 11 from ITC shows that the education of engineering geology in Delft is in good shape whatever rumours you may have heard. It is not prudent to comment on these rumours, but the Board of the Ingeokring is aware of what happens in Delft and will keep in close contact with those involved.

The discussion about the position of engineering geology as applied science and as profession in industry started in 1995 and culminated with the presentations and discussions during our annual meeting last year. Based on these discussions, the board has drafted a position statement on engineering geology in the Netherlands. It will be sent to you in due time and will be presented to the annual meeting on 23 April 1997.

Last year many members of the Ingeokring were present at the annual meeting and I hope that this year even more will attend. Apart from the presentation of the position paper on engineering geology, also two presentations will be given, both related to tunneling. They should be interesting to many engineering geologists in the Netherlands.

From a warm and sunny Spain, I send you my regards and hope to see many of you on 23 April.

Robert Hack.

The potential use of fuzzy set theory in engineering geology

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This paper presents a brief introduction to fuzzy set theory. It covers fundamental aspects such as: what is fuzzy set theory and fuzzy logic, operations on fuzzy sets, membership functions, linguistic modifiers, inference mechanisms, fuzzification, defuzzification methods and so forth. Furthermore, a practical application is given of how fuzzy set theory can assist Engineering Geologists to cope with non-probabilistic uncertainties in a flexible, transparent and consistent framework. Finally, selected references are listed, including books, papers, FTP sites on Internet and useful software available on the market.

INTRODUCTION

Problems in which Engineering Geologists are involved are often typically imprecise, vague and uncertain. This applies for example to rock slope stability assessment, rock mass classification systems, tunnel stability and support, engineering geological mapping, etc., that is, they carry a certain degree of fuzziness in the description of their nature. Several factors contribute to the fuzziness:

- in most cases the amount of data necessary to describe an engineering geological problem is limited or unreliable;
- the inherent variability and non-linearity of geological processes and ground behaviour. Consequently the input-output relationship of the variables cannot be explained by means of traditional statistical methods, i.e. Multilinear Regression Analysis, Correlation Analysis, etc;
- theoretical knowledge based on small scale laboratory experiments;
- there are different opinions among the experts concerning the exact or close solution of a particular problem.

Moreover, in many engineering projects the same concept or property is allowed to have a different degree of imprecision (fuzziness) in different geological scenarios. For example, the proposition 'a rock with a high permeability' is not exactly the same when it is used for the design criteria of a small dam (i.e. 20 m height) as when it is used for the design criteria of a large dam (i.e. 120 m height). This indicates that, the degree of fuzziness can be considered as an intrinsic part of the phenomenon itself. This fuzziness can be captured or handled by making fuzzy logic models.

WHAT IS A FUZZY LOGIC MODEL?

A fuzzy logic model describe the system by means of *if-then* rules with vague predicates (fuzzy sets). The *if* part of the rule is called the premise and the *then* part the consequent. These rules define the influence of the input variables on the system's output. They are combined in the rule base of the model, which takes the place of the usual set of equations used to characterise a system.

An important concept in a fuzzy logic model is a fuzzy proposition. Fuzzy propositions represent

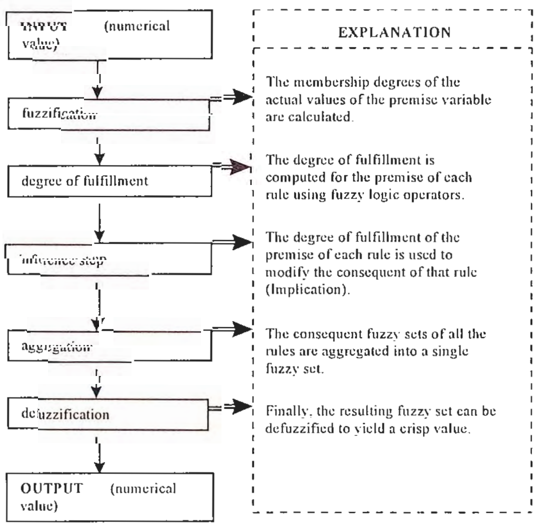


***Figure 1** A general overview of a fuzzy reasoning mechanism in a fuzzy logic model*

statements like 'the strength of the rock is *high*', 'the slope is *more or less* stable' and so forth, where *high*, *more or less* are linguistic labels, defined by fuzzy sets.

Fuzzy propositions connect variables with linguistic labels defined for those variables. They can be combined by means of the intersection, union and complement operations
The output of a fuzzy model can be represented as a linguistic variable (Mamdani-method) or as a function of the premise variables (Sugeno-method) (Jager, 1995; Babuška, 1996).

Basically, the reasoning mechanism -inference- of a fuzzy logic model proceeds in five stages (in Babuska, 1995) (Figure 1):

WHEN FUZZY LOGIC IS NEEDED?

Briefly, there are two important aspects to consider to judge whether fuzzy logic is a good approach to a problem:

- numerical data is available: In a fuzzy system the variables are fuzzified, based on numeric value and membership functions.
- fuzzy logic is best used when there is no specific hard break or sharp definition in the data and the underlying uncertainty is non-probabilistic in nature.

SOME HISTORY OF FUZZY SET THEORY

The first publication about fuzzy set theory dates back to 1965. It was published by Lotfi Zadeh at University of California, Berkeley. In 1970 Ebrahim Mamdani at Queen Mary College in London, applied fuzzy logic for the first time to control a steam generator that was impossible to get under control with traditional methods. Later at the University of Aachen, Germany, Hans Zimmermann applied fuzzy logic to Decision Support Systems.

In the 1980's Japanese companies started to use fuzzy logic in control engineering. For example, in 1983 Fuji Electric employed fuzzy logic to control a water treatment plant. In 1987 Hitachi used fuzzy logic in a subway system. These applications influenced the Japanese industry considerably and today fuzzy logic is used in many other disciplines such as intelligent control of devices, machines and data processing. Recently, Mitsubishi company announced the world's first car where all control systems are based on fuzzy logic (Von Altrock, 1997).

Only five years ago, major European companies have started to introduce fuzzy logic in their applications. Since then more than 200 fuzzy logic applications have been launched onto the market. Some of them are in home appliances; others in automotive processes. The industrial automation includes chemical and biological process control, machinery equipment control, and intelligent sensors.

Due to the increasing commercial success of these applications, fuzzy logic is today considered a "standard" design technique and has gained broad acceptance in the engineering community. This has been possible because of the development of excellent fuzzy logic software and expert systems, which support all development stages of a fuzzy logic design, implementation and portability.

In geology, particularly in rock engineering, fuzzy set theory has gained broad interest in the last few years. Fuzzy logic has successfully been applied on underground openings for the prediction of rock burst, on grouting control processes (Zettlers, A.H. et al. 1996), engineering geological mapping (Orlič, B. et al. 1994), on Decision Support Systems, Expert Systems, etc., (Feng, et.al. 1997).

BASIC CONCEPTS OF FUZZY SET THEORY

This section presents basic concepts of fuzzy set theory. Its aim is not to be complete, but to provide the parts of fuzzy set theory necessary to understand the remainder of this paper. As classical set theory serves as the basis for classical logic, fuzzy set theory serves as the basis for fuzzy logic. This means that theoretic operations in fuzzy sets are a base for logical operations.

What are fuzzy sets?

Zadeh (1965) introduced fuzzy sets. Contrary to classical set theory, a fuzzy set consists of objects and their respective grades of membership in the set. The membership function $\mu_A(x)$ is a mapping from the universe X into the unit interval [0,1].

$$\mu_A(x): X \rightarrow [0,1] \qquad (1)$$

If the value of the membership function equals one, x belongs completely to the fuzzy set. If the value of the membership function equals zero, x does not belong to the set and if the membership degree is between 0 and 1, x is a partial member of the fuzzy set. Example 1 illustrates the differences between classical set and fuzzy set theory.

Example 1: Assume the following proposition 'the strength of the rock is *high*'. By using the classical set theory the set *high* can be defined as follow: A = { UCS | UCS ≥ 100}, where UCS represents the unconfined compressive strength of the rock. In this case, the conclusion is either *high* strength rock or not (1 or 0) (Figure 2). It is clear that in certain cases for UCS = 20 MPa, the strength of the rock is definitely not high whereas for UCS = 150 MPa the strength of the rock is definitely *high*. However, the problem arises for UCS values of about 90 MPa. This type of uncertainty (non-probabilistic in nature) can be handled by using fuzzy set theory. For example assume now that the classical set *high* is modified to a fuzzy set and is represented with a predefined membership function as indicated in Figure 2. So, for UCS values of about 90 MPa, the strength of the rock is *high* with a degree of fulfilment of 0.9. The sharp definition of a set *high* has been modified to a continuous function that allows incorporation of expert knowledge in the definition of the term *high*.

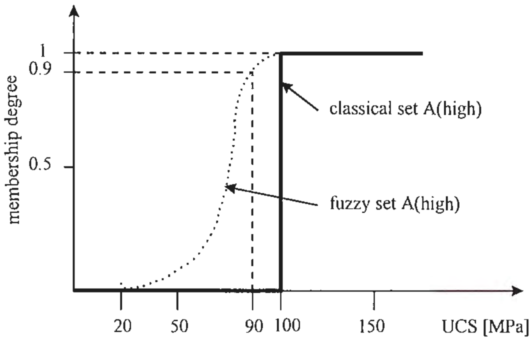


Figure 2 *Classical set and fuzzy set of high rock strength.*

Membership functions

The concept of membership functions is the cornerstone of fuzzy set theory. Memberships functions are used to represent fuzzy sets. A fuzzy set can be represented in a continuous domain and in a discrete domain. In continuous domains, fuzzy sets are defined analytically by their membership functions. Examples of continuous membership functions (bell-shaped) are: trapezoidal membership functions and piece-wise exponential membership functions (in Babuška, 1996):

- *Trapezoidal* membership function:

$$\mu(x;a,b,c,d) = \max\left(0, \min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right)\right) \quad (2)$$

where a,b,c, and d are coordinates of the trapezoid apexes. When b=c, a triangular membership function is obtained (Figure 3).

- *Piece-wise exponential* membership function:

$$\mu(x;c_l,c_r,w_l,w_r) = \begin{cases} \exp\left(-\left(\dfrac{x-c_l}{2w_l}\right)^2\right), & if\, x<c_l \\ \exp\left(-\left(\dfrac{x-c_r}{2w_r}\right)^2\right), & if\, x>c_r \\ 1 & otherwise \end{cases} \quad (3)$$

where c_l and c_r are the left and right shoulder and w_l and w_r are the left and right width. When $c_l = c_r$ and $w_l = w_r$, the Gaussian membership function is obtained (Figure 3).

In discrete domains $X = \{x_i \mid i = 1,2,\ldots,n\}$, a fuzzy set A may be defined by a list of ordered pairs: membership degree/set element:

$$A = \{\mu_A(x_1)/x_1, \mu_A(x_2)/x_2, \ldots, \mu_A(x_n)/x_n\}, \quad (4)$$

or in the form of two related vectors:

$$x = [x_1, x_2, \ldots, x_n]^T, \mu = [\mu_A(x_1), \mu_A(x_2), \ldots, \mu_A(x_n)]^T \quad (5)$$

In practice, however, the membership function is chosen somewhat arbitrarily. Its position, core, and support (Figure 4) depends on the particular application. Figure 3 shows some commonly used types of membership functions. It should be appreciated, however, that up to now, their meaning in nature and how membership functions are derived is not yet explicitly clear. Typically, it is a compromise between the available data, the expert knowledge and the context.

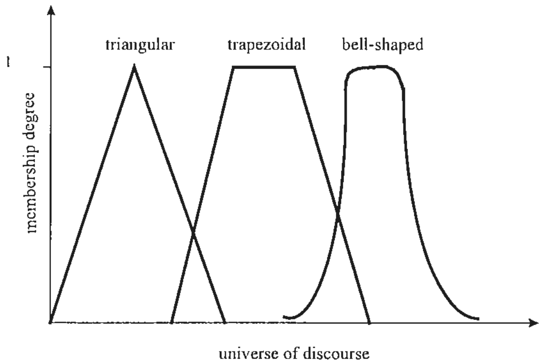


Figure 3 *Common types of membership functions.*

Properties of fuzzy sets

In this section, the most frequently used fuzzy set properties are discussed (Jager 1995) (Figure 4).

The *height* of a fuzzy set A, hgt(A) is the supremum of the membership grades of elements in A and is defined by:

$$hgt\,(A) = \sup_{x \in X} \mu_A(x) \quad (6)$$

Fuzzy sets with a height equal to 1 are called normal. Fuzzy sets called subnormal are characterized by hgt(A) < 1.

The *core* of a fuzzy set, also referred to as *kernel* or nucleus, is a crisp subset of X:

$$core(A) = \{x \in X \mid \mu_A(x) = 1\} \quad (7)$$

The *support* of a fuzzy set A is the crisp subset of X whose elements all have non-zero membership grades:

$$\sup p\,(A) = \left\{ x \middle| \mu_A(x) > 0 \right\} \qquad (8)$$

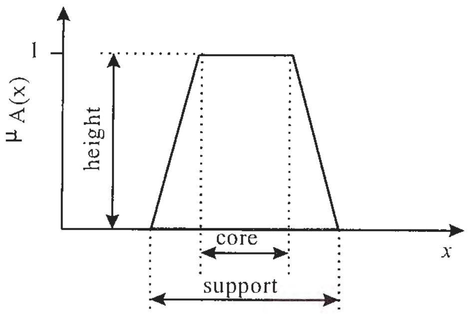


Figure 4 *Principal Fuzzy set properties.*

Operations on fuzzy sets

Many operations on fuzzy sets and on fuzzy relations have been defined in the literature. The most common operations on fuzzy sets are: *intersection*, *union* and *complement*. It should be appreciated that fuzzy relations operations are beyond the scope of this paper. Interested readers are referred to Jager (1995):

Intersection of fuzzy sets: Let A and B be two fuzzy sets in *X*. The intersection of A and B is a fuzzy set C, denoted C= A∩B (Figure 5), such that each x ∈ *X*: This corresponds to the minimum operator.

$$\mu_C(x) = \min[\mu_A(x), \mu_B(x)] \qquad (9)$$

The minimum operator is also denoted by '∧',

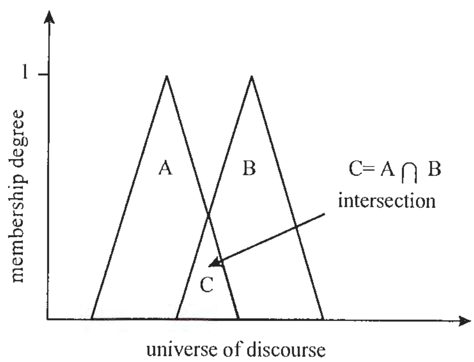


Figure 5 *Intersection of two fuzzy sets.*

Union of fuzzy sets: Let A and B be two fuzzy sets in *X*. The union of A and B is a fuzzy set C, denoted C=A∪B, (Figure 6) such that each x ∈ *X* This corresponds to the maximum operator.

$$\mu_C(x) = \max\left[\mu_A(x), \mu_B(x)\right] \qquad (10)$$

The maximum operator is also denoted by '∨'.

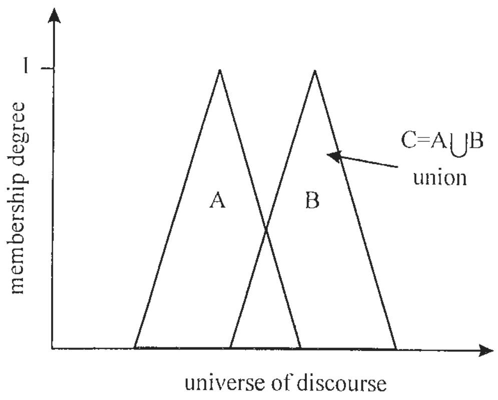


Figure 6 *Union between two fuzzy sets.*

Complement of a fuzzy set: Let A be a fuzzy set in *X*. The complement of A is a fuzzy set denoted Ā, such that for each x ∈ *X* :

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \qquad (11)$$

What are linguistic modifiers?

Linguistic modifiers, also known as hedges are used to modify the meaning of a fuzzy set. Two basic approaches to the implementation of linguistic modifiers can be distinguished: powered hedges and shifted hedges (Zimmermann, 1991; Lakoff, 1973). The powered hedges that operate on grades of membership can be expressed as:

$$m_p(A) = \int_X m_A^p(x) / x \qquad (12)$$

where m_p is the linguistic modifier and p is a parameter specific to certain linguistic modifiers; p ∈ [0,1]. For example, p=2 for *very*, ½ for *more or less*, etc. Figure 7 shows an example for the linguistic modifier *very* (p=2) and more or less (p=0.5).

Example 2: Suppose that we have defined the term *permeable* rock with a trapezoidal membership function as indicated in Figure 7. However, we can modify its meaning to *very permeable* (p=2) or *more or less permeable* (p=0.5) by using the powered hedge operations. This fuzzy operation allows to deal with imprecise data and to incorporate it into a geological model in a consistent and flexible way following the natural language.

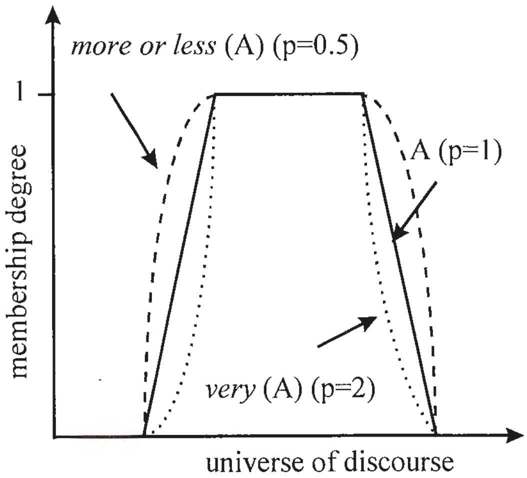


Figure 7 *Fuzzy set A permeable (solid line), fuzzy set very permeable (A)=A^2 (dotted line), and more or less permeable A=$A^{0.5}$ (dashed line) using powered hedge operations.*

Fuzzy inference mechanism

The inference mechanism of fuzzy logic reasoning is based on the compositional rule of inference proposed by Zadeh (1973). By means of this mechanism an output fuzzy set is obtained given the rules and the input variables. Let's assume that a fuzzy rule: **If** *x* is A **then** *y* is B, is represented by a fuzzy relation *R*: (*X* x *Y*) which is computed by:

$$\mu_R(x,y) = I(\mu_A(x), \mu_B(y)), \quad (13)$$

where the operator I can be either a fuzzy implication or a conjunction operator (a *t*-norm).

Examples of fuzzy implications are the Lukasiewicz's implication:

$$I(\mu_A(x), \mu_B(y)) = \min(1, 1 - \mu_A(x) + \mu_B(y)) \quad (14)$$

or the Kleene Diene implication:

$$I(\mu_A(x), \mu_B(y)) = \max(1 - \mu_A(x) + \mu_B(y)), \quad (15)$$

Examples of *t*-norms are the minimum, often called the Mamdani 'implication' and the product, which is also called the Larsen 'implication':

$$I(\mu_A(x), \mu_B(y)) = \mu_A(x).\mu_B(y) \quad (16)$$

More details about fuzzy implications and related operators can be found elsewhere. (Zimmermann, 1991; Jager, 1995).

Common fuzzy inference methods

Two common inference methods are used in practice (Jager 1995): the *Max-min* method and the *Max-prod* method.

The *Max-min* method was introduced by Assilian and Mandani (1974). When this method is applied the *min* operator is used for the conjunction of the rule and for the implication function and a *max* operator is used for the aggregation of the fuzzy sets. In this case the application of the compositional rule of inference (Zadeh 1973) results in:

$$\mu_{B'}(y) = \max \min(\beta_k, \mu_{B_k}(y)) \quad (17)$$

where,

$$\beta_k = \min \alpha_{i,k} \quad (18)$$

$$\alpha_{i,k} = \sup \min\left(\mu_{A'_i}(x_i), \mu_{A_{i,k}}(x_i)\right) \quad (19)$$

In the *Max-prod* method, also called *max-dot* method, the inference method is characterized by sacaling the consequent B_k of a fuzzy rule r_k with the degree of membership β_k of that rule, then the results B_k are aggregated by means of a max operator to obtain the fuzzy output (in Jager 1995).

$$\mu_{B'}(y) = \max \beta_k * \mu_{B_k}(y) \quad (20)$$

where (*) represents multiplication. The implication represented by the product operator (*) is known as Larsen's implication (Larsen, 1980 in Jager 1995).

Defuzzification methods

Defuzzification is the final phase of a fuzzy logic approach. Defuzzification means translate a linguistic proposition (fuzzy output) into a crisp value (a single numerical value). Several defuzzification methods have been defined (Zadeh 1965). The most common defuzzification methods are: the Center of Gravity (CoG) and the Mean of Maxima (MoM).

The **CoG** method also called the centre of area in the case of 1-dimensional fuzzy set, is the same method used to calculate the centre of gravity of a mass. The difference is that the (point) masses are replaced by the membership value. It should be appreciated that the method is not limited to 1-dimensional fuzzy set. The centre of area defuzzification method is defined by:

$$cog(B') = \frac{\int_y \mu_{B'}(y) y dy}{\int_y \mu_{B'}(y) dy} \quad (21)$$

where: B' is the output fuzzy set and $\mu_{B'}$ is the membership function

The **MoM** method computes the output of the system only for the fuzzy set with the highest resulting degree of validity; if the maximum is not unique, like for example when trapezoidal membership function is used (Figure 3 and 7), then the output will be the mean of the maximizing interval.

$$mom(B') = icog(B', hgt(B')) \quad (22)$$

Example 3: Assume that you need to assess the slope stability of a dam. Assume further that there is very little geotechnical information available, so you developed a fuzzy logic model to accomplish this task. As a result you obtained that the slope is *more or less* stable (fuzzy output). However, the designer needs to know exactly whether the angle of the slope should be modified or not and to what extent. This can be solved by using some of the defuzzification methods (i.e. CoG or MoM) described above. In this way, it is possible to translate the fuzzy output result *more or less* stable to a numerical value (crisp value), i.e. Factor of Safety (FoS) = 1.2

GUIDELINE TO DEVELOP A FUZZY LOGIC MODEL

There are, basically, six fundamental stages in the construction of fuzzy models (Figure 8). To illustrate these steps a practical application is presented.

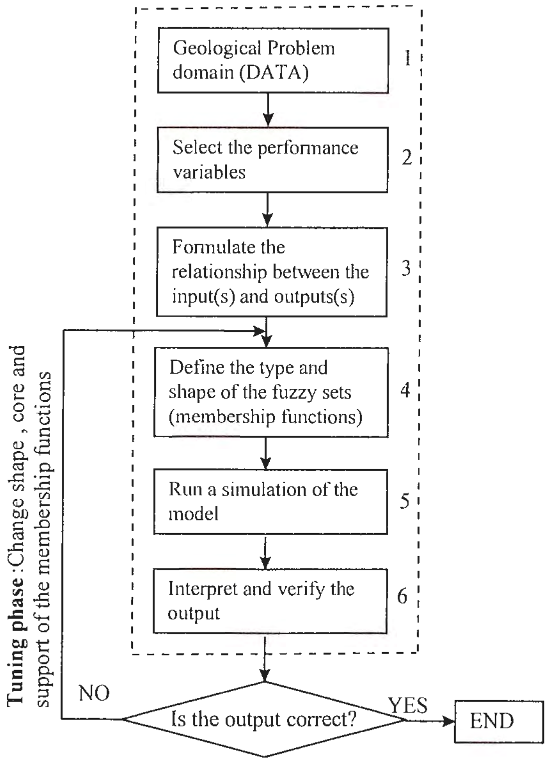


Figure 8 *Basic fundamental stages in a construction of a fuzzy logic model*

APPLICATION

This section describes the development of a 'prototype' linguistic fuzzy model to predict the specific wear of the cutting tools of rock cutting trenchers. The application presented here is a shortened version of a paper by Alvarez Grima, M & P.N.W. Verhoef (1997). Interested readers in this subject are also referred to (Hartog den, et al. 1997; Alvarez Grima et al. 1996).

Selection of model variables

The selection of the variables included in the model is based primarily on previous work done in the laboratory (Deketh, 1995; Verhoef, 1997) and the monitoring of the performance in terms of wear rate of the T-850 trencher (Vermeer Manufactory Company, Pella, Iowa, USA) in different geological settings (17 trenching projects), Deketh et al. 1996. From the many different factors that possibly influence the wear rate of the cutting tools, the experts have selected the followings:

Initial input variables
- rock strength (MPa)
- rock dimensions: refers to the hard rock body in the trench (m^2)
- grain size (mm)
- volume % of abrasive minerals (%)

Intermediate variables
- feed: refers to the penetration depth of each individual bit into the rock at each passing/traverse (rev/min)
- adjusted wear capacity of the rock: refers to the likeliness of high temperature generated (adhesive wear of the bits)

Output variable
- the specific wear, weight loss per m^3 of excavated rock (g/m^3)

Knowledge based structure

For the sake of simplicity the knowledge domain has been divided into several smaller sub-bases. This decomposition follows from the structure of the knowledge domain. The result is a three-level hierarchical knowledge base and is depicted in Figure 9. Note, however, that two intermediate variables (the feed and adjusted wear capacity of the rock) have been defined.

Knowledge representation: rule base formulation

The model has been formulated in the form of *if-then* rules. Several types of knowledge representation have been proposed in the literature (Mylopoulus et al. 1984 in Jager 1995). In the

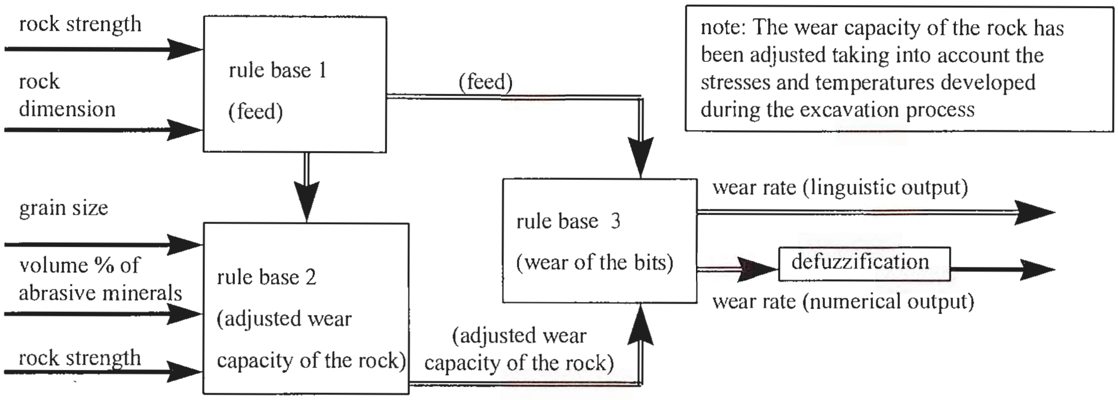


Figure 9 *Knowledge bases for predicting the specific wear. Solid lines represent numerical variables and double lines represent fuzzy variables.*

model the procedural knowledge representation has been used in combination with the local inference method (Jager, 1995). Using local inference, the inference of a rule base is broken down to inference of individual fuzzy rules and the results aggregated afterwards (Figure 12). Each rule in the model consists of two parts, the *if part* with a single or multiple premises and the *then part* with a single consequent. Example of some rules in the model are:

- **If** Grain size is *fine* **and** Vol. % abras. Min is *absent* **and** Rock strength is *low* **Then** Wear capacity of the rock is *very low*
- **If** Wear capacity of the rock is *very low* **and** the Feed is *low* **Then** Wear of the bits is *low*

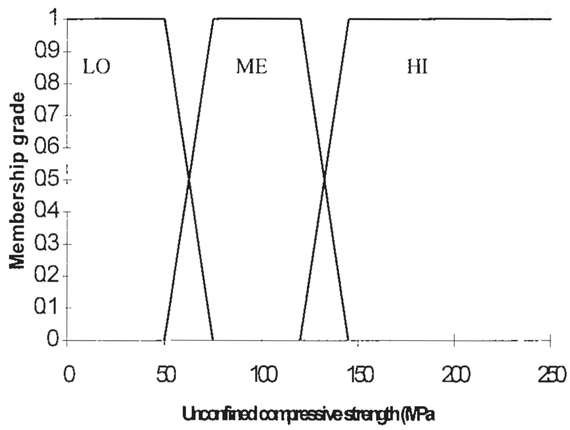


Figure 10 *Example of trapezoidal membership function for the rock strength (UCS) (input variable in the model). LO=low, ME=medium and HI=high.*

Type of variables used in the model

Two types of variables have been used in the model, crisp numerical variables and fuzzy variables. The numerical variables are defined by the corresponding membership function (fuzzy set) in the numerical domain X, $X \subset \mathbb{R}$. Example of crisp variables in the model are: the rock strength, the rock dimension, grain size, volume percentage of abrasive minerals (inputs), the specific wear (output). The fuzzy variables are defined in the set of reference linguistic terms. Example of fuzzy variables in the model are: the feed and the adjusted wear capacity of the rock.

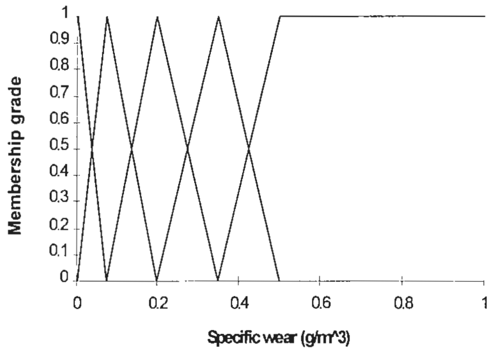


Figure 11 *Example of triangular membership function for the specific wear (output variable in the model). VL=very low, LO=low, ME=medium, HI=high and VH=very high.*

Membership functions used in the mode

Defining the type and shape of membership functions is undoubtedly the most critical stage of building a fuzzy logic model. As mentioned early, it is very subjective and context-dependent. In the model, a trapezoidal membership function was used for the input variables (Figure 10) and triangular membership functions for the output (Figure 11).

Fuzzy reasoning mechanism

The fuzzy reasoning mechanism in the model proceeds in five basic steps (Figure 12): fuzzification, degree of fulfillment, inference, aggregation and defuzzification (Jager, 1995; Babuska, 1995). The degree of fulfillment step is implemented by means of the minimum operator as

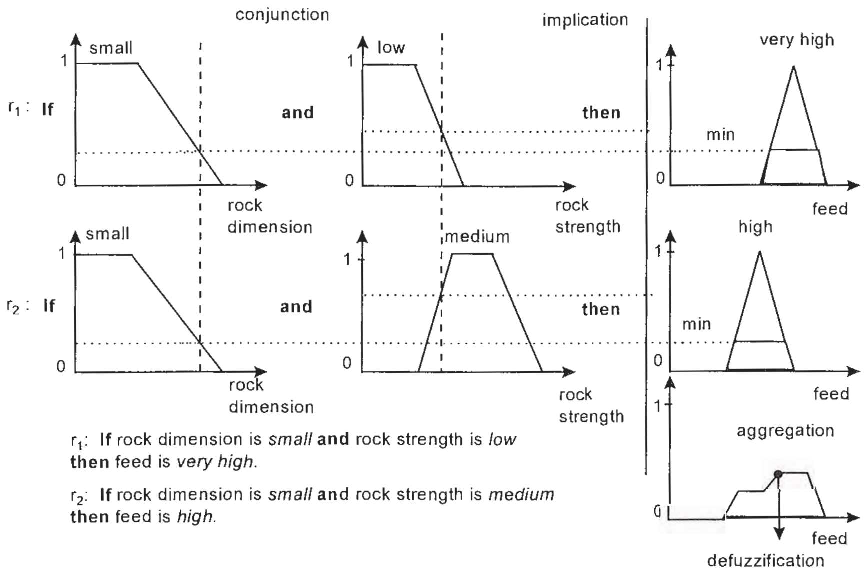


Figure 12 Schematic representation of the fuzzy logic reasoning mechanism with two rules. The fuzzy output is the aggregation (max) of the two clipped fuzzy sets. The outputs are obtained after defuzzification by using the fuzzy weighted mean method.

proposed by Mamdani (1974). The aggregation step is implemented by means of the maximum operator. The output of the fuzzy model is defuzzified by means of the fuzzy mean (weighted mean) method.

Results of the model

In order to verify the developed fuzzy wear model two types of validation have been applied: a qualitative validation based on expert knowledge and a quantitative validation based on numerical data. The qualitative validation aimed to check the

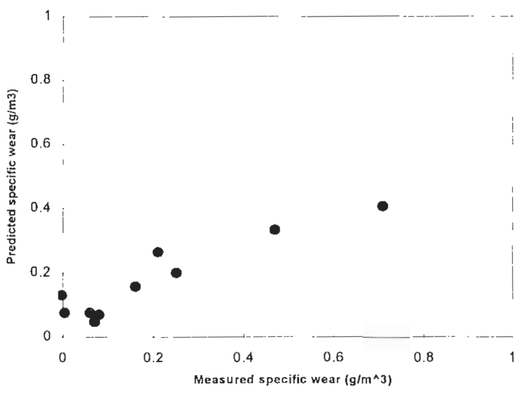


Figure 13 Numerical performance of the specific wear model.

overall correctness of the knowledge base with respect to the background expertise gained in the field. For that purpose artificial data-bases were used. Figure 13 depicts the predicted numerical performance versus the measured one. In general, the predicted numerical performance of the specific wear correlate reasonably well with the measured performance data. Most of the data points lie close to the one-to-one line, which represents the ideal prediction of the model. The significance of the model is expressed by using the standard error of the regression line between the predicted and the measured data: the standard error for the specific wear is 0.06 which represents 8.45 % of the maximum specific wear found in the data.

SOURCES OF INFORMATION

Some sources of information about fuzzy set theory and fuzzy logic are listed below.

Non-mathematical books

Kosko, B. 1993. *Fuzzy Thinking: The New Science of Fuzzy Logic.* Warner, 1993

McNeill. D and P. Freiberger. 1992. *The Discovery of a Revolutionary Computer Technology.*

McNeill D and E.Thro. 1994. *Fuzzy Logic: A practical approach.* Academic Press, Boston, MA.

Cox, E. 1994. *The Fuzzy System Handbook: A Practitioner's Guide to Building Using and Maintaining Fuzzy Systems.* Academic Press, Boston, MA.

Specialized journals

International Journal of fuzzy Sets and systems
IEEE Transactions of Fuzzy Systems
International Journal of Approximate Reasoning
International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems

FTP sites on Internet

A number of anonymous FTP sites are accessible via Internet among them:

Osfold Regional College Fuzzy Logic Anonymous FTP Repository: ftp. Dhhalden.no:/pub/fuzzy/

Tim Butler's Fuzzy Logic Anonymous FTP Repository and Email server: ntia.its.bldrdoc.gov:/pub/fuzzy or rnalib@its.bldrdoc.gov

Togai InfraLogic Fuzzy Logic Email Server: To receive instructions of how to access the server, send a message containing a single word **help,** with no subject to fuzzy-server@til.com

Useful Software

EXSYS *Professional* (Expert System Development Software): www.nm.org/~exsys

MATLAB: Fuzzy tool: www.mathworks.com/products/fuzzytbx.shtml

*fuzzy*TECH: Fuzzy tool: http://www.fuzzytech.com

FuzzyClips: ai.iit.nrc.ca/fuzzy/fuzzy.html

REFERENCES

Alvarez Grima, M., M.H. den Hartog, H.J.R. Deketh, P.N.W. Verhoef and R. Babuška. (1996). Uncertainty handling of mechanical excavation processes with fuzzy logic. *Proc. 3rd Int. Workshop on Informatics and Geosciences.*, Havana, Cuba.

Alvarez Grima, M. & P.N.W. Verhoef. (1997). Forecasting of rock trencher performance using a fuzzy logic approach. To appear in NYRock'97. 36 th US Rock Mechanics Symposium 29 June-2July, 1997, Columbia University, New York, USA.

Babuška, R. (1995). Fuzzy logic in modeling and control. *Proceedings Symposium Computational Intelligence*, May 10, 1995, Delft, the Netherlands.

Babuška, R. (1996). *Fuzzy Modeling and Identification*. PhD dissertation, Delft University of Technology, Delft, the Netherlands. ISBN 90-9010153-5.

Cox, E. 1994. *The fuzzy systems handbook: A practitioner's guide to building, using, and maintaining fuzzy systems*. Academic Press, Boston, MA.

Deketh, H. J. R.. (1995). *Wear of rock cutting tools. Laboratory experiments on the abrasivity of rock*. Balkema Publishers, Rotterdam, ISBN 90 5410 620 4.

Deketh, H.J.R., M. Giezen, M. Alvarez Grima, and M.H. den Hartog. (1996). Performance of rock cutting trenchers at different sites. *Proceedings of the 2nd North American Rock Mechanics Symposium, Montreal Canada*. (NARMS) pp. 669-675.

Feng X,T, K. Katsuyama, Y.Wang and Y. Lin. (1997). Technical Note: A New Direction-Intelligent Rock Mechanics and Rock Engineering. *Int. J. Rock Mech. Min. Sci.* Vol. 34. No. 1, pp. 135-141.

Hartog den, M.H., R. Babuška, H.J.R. Deketh, M. Alvarez Grima, P.N.W. Verhoef, and H.B.Verbruggen. (1996). Knowledge-based fuzzy model for performance prediction of a rock cutting trencher. To appear in *IJAR Journal of Approximate Reasoning* Autumn 1997.

Jager, R. (1995). *Fuzzy logic in Control*. PhD dissertation, Delft University of Technology, Delft, the Netherlands. ISBN 90-9008318-9.

Lakoff, G. (1973). Hedges: a study in meaning criteria and the logic of fuzzy concepts. *Journal of Philosophical Logic* 2, 458-508.

Mamdani, E.H. (1974). Applications of fuzzy algorithm for control of simple dynamic plant. *Proceedings IEE*, number 121, pp. 1585-1588.

Orlič. B and D. Sunarič. (1994). Assessment of engineering geological suitability for urban planning by fuzzy logic. 7th International IAEG Congress, Balkema, Rotterdam,
ISBN 9054105038, pp. 2329-2335.

Verhoef, P.N.W. (1997). *Wear of Rock Cutting Tools, implications for the site investigation of rock dredging* projects (in preparation).

Von Altrock, C. (1997). *Fuzzy Logic and NeuroFuzzy Applications in Business and finance*. Prentice Hall PTR.

Zadeh, L. A. (1977). Fuzzy Set as a Basis of a Theory of Possibility. *Memorandum* M77/12, Electronics Research Laboratory, University of California, Berkley; Fuzzy Sets and Systems, North-Holland Publishing Company, vol. 1, no. 1, 1977, pp.3-28.

Zadeh, L.A. (1965). Fuzzy Sets. IEEE Information and Control, Vol. 8: 338-353.

Zimmermann, H. J. (1991). *Fuzzy set theory and its applications*, (2nd ed.). Dordrecht: Kluwer Academic Publ.

Notations

A, B	fuzzy sets
K	number of rules in a rule base
β	degree of fulfilment of a rule
$\mu, \mu(.)$	membership degree, membership function
$\mathbb{R}$	set of real numbers
$\wedge$	intersection, logical AND, minimum
$\vee$	Union, logical OR, maximum
$\cup$	fuzzy set intersection (conjunction)
$\cap$	fuzzy set union (disjunction)
I	implication or conjunction operator

Interpretation of the monitored behaviour of a large powerhouse using back analysis techniques

Luis Ribeiro e Sousa, LNEC, Lisbon, Portugal

Below Follows short resume of the conference done by L. Ribeiro e Sousa during his stay in Delft.

For the interpretation of the observed behaviour of underground structures in rock formations, computational methods have been largely used due to their potentialities. However, in spite of the sophisticated techniques used, the observed behaviour of the structures usually differs from the one expected from computational models. This discrepancy is mainly due to the numerous uncertainties associated with the mechanical characterisation of rock masses and the quantification of the in-situ state of stress installed in rock masses.

The characterisation of the rock masses that involve these structures is carried out during the design and construction stages. Detailed geologic and geomechanic studies are conducted for identification of the rock formations and for the characterisation f their properties. The parameters obtained are re-evaluated during construction by taking into account the results obtained from monitoring. In this sense, numerical techniques for back analysis have been developed. These techniques make possible the identification of the characteristics of both the rock mass and the most relevant actions, namely those resulting from the relief of the in situ state of stress. Furthermore, they also make it possible to assess the suitability of the project and the construction procedure.

It was the aim of the conference to illustrate the potentiality of back analysis techniques in geotechnical practice, especially in underground structures, for the interpretation of the monitored behaviour. A general methodology for the solution of back analysis or inverse problems was presented, particularly focused on identification of parameters. In general, this identification consists of quantification of parameters of the numerical model used for the analysis of the problem under study that can be best adjusted to the measurements carried out. Special mention was made of the direct formulation. The methodology was applied to underground structures. A back analysis algorithm using models solved by the finite element method was developed. The corresponding computational system allows to consider the sequence of excavation and provision of supports followed in underground hydroelectric powerhouses and to the measurements carried out in terms of differences of displacements.

Finally the numerical computational system was applied to the Alto Lindoso underground powerhouse in Portugal. A brief description was made of the hydroelectric scheme and of the monitoring pan implemented. A comparison between observed and predicted values from numerical solutions during construction was performed in order to permit the safety evaluation of underground structures at this stage. Results obtained with back analysis models for the identification of the deformability of the rock mass and of the in situ state of stress by taking into account the data previously collected from tests performed were presented.

In focus: Anwar Farouk El-Kadi

E.J. Schoute & A.R. Zimnik

Anwar Farouk El-Kadi (33) is at present a student at ITC in Delft, where he attends the MSc course in Engineering Geology. After working for several years in Egypt he decided to apply for a fellowship in The Netherlands. This year he is doing his M.Sc. and will hopefully graduate in July 1997. He is married and has a daughter.

Anwar was born on the 30th of January 1964 in Aachen Germany, where his father was doing his PhD on Civil Engineering. After 4 years he went with his mother and sister to Egypt, where he initially attended a German girlschool.

After finishing primary school he went to the Deutsche Evangelische Oberschule. Afterwards he went to the Ain-Shams University in Cairo to study Civil Engineering, where he graduated after 5 years in 1989. The same year he was employed by his father's company 'Nile Engineering Consulting'. One year later he became a project manager in this company.

In his first job he worked as a site engineer on a silo project. Two silo's had to be built to the south and north of Egypt. "The reason I got this big responsibility on my first job was a result of doing much practical works during the summer holidays." During one of his projects he was working together with a Dutch company. On a visit at the Dutch embassy he was told about the possibility of obtaining a fellowship in the Netherlands. He wanted to study more because he thought there was a hiat in his education. "As a civil engineer you have a lack of knowledge about rock behavior in certain problems. "As I went through the list of possible educations, I found Engineering Geology to be the most suitable type of education to satisfy my needs."

The major difference between studying in Egypt and in the Netherlands, is the way of studying. In Egypt one has to learn a thick book fully by heart, in the Netherlands the educational system forces you to do a lot more reading by yourself. Because of this you get a better view of handling a specific problem in practice.

Also, the practical part in education is missing in Egypt. There is no fieldwork during the education, whereas in The Netherlands you first receive the theoretical part of a certain topic and after that a practical part (if the possibility is there). Although he is very satisfied with the education he got at ITC, Farouk believes that certain aspects could still be improved in the Engineering Geology M.Sc. course as he has followed it: "What should be more emphasized in the course in the Netherlands, is foundation engineering. More knowledge about this will give a better fitting site investigation in most projects".

Anwar Farouk El-Kadi

Next year he wants to go back in practice in Egypt. "I want to be closer to the market because otherwise they start forgetting you". Other future plans are involve possibly doing a Ph.D. and the installment of an Engineering Geological department in his father's company. His interests are going out to applying geophysical methods in certain projects.

About living in Holland, he stated that there are of course a lot of differences. The most strange thing he came across, is that you're never asked to identify yourself on the streets: "You can walk around for twenty years without having a permit".

A study of the variation in properties of crushed rock aggregate

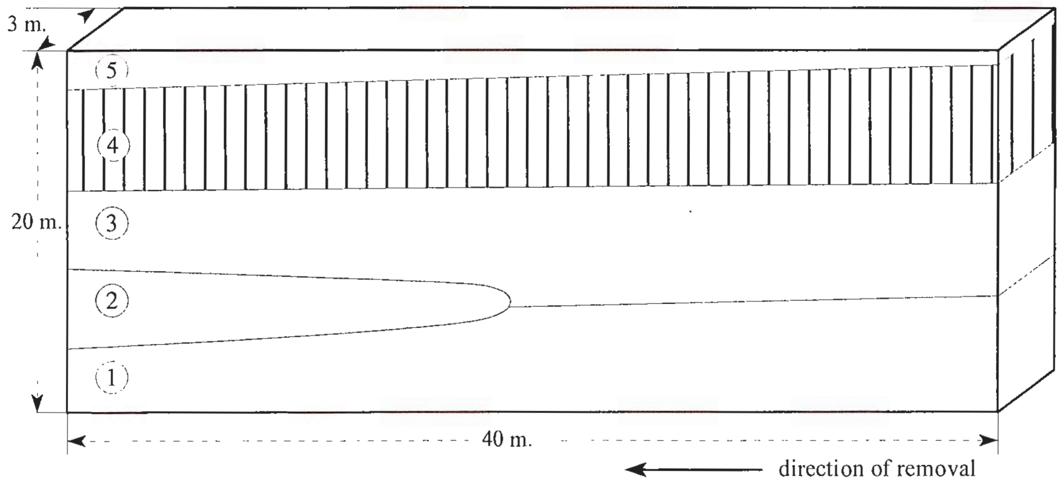
Ir. J.K. Haasnoot, Section Engineering Geology, Faculty Applied Earth Sciences, Delft University of Technology, P.O. Box 5028, 2600 GA Delft, the Netherlands

To engineering geologists it is well-known that rock is a heterogeneous material. However, technicians often regard rock, especially coming from crushed rock quarries, as a homogeneous material. The heterogeneity can have its consequences on the behaviour of the construction the rock is applied in. It is therefore important to know the quality and the variation in quality of the aggregate. These two aspects can already be established in the quarry. The advantage is that in the quarry the rock is present in ordered zones which can relatively easy be investigated and quantified. This paper is based on the thesis "A study of the Variation in Properties of Crushed Rock Aggregate" (Haasnoot, 1995), awarded with the Netherlands Students Award for Engineering Geology 94/95.

INTRODUCTION

To engineering geologists it is well-known that rock is a heterogeneous material. However, technicians often regard rock, especially if from crushed rock quarries, as a homogeneous material. The heterogeneity can have its consequences on the behaviour of the construction the rock is applied in. This article discusses the heterogeneity of crushed rock aggregate and shows that this is related to the occurrence of the rock in the quarry. The article is based on M.Sc. research (Haasnoot, 1995) performed at the Section Engineering Geology, faculty of Mining and Petroleum Engineering, Delft University of Technology.

The aim of this research is to establish the relation between the quality of rock as it is in the quarry and the quality of the crushed rock aggregate product. Attention has been paid to the method of quarry investigation and which techniques can be best applied. During the research, performed in a sandstone quarry in Belgium, a volume of rock has been followed from its place in-situ in the quarry face until processing to rock aggregate. It also comprised which type of techniques can be used in variation investigation



Quantification per zone

The relative quantity of a geotechnical class per zone is given

	very/extreme strong	strong	moderate strong
zone 1	65		35
zone 2			100
zone 3	97		3
zone 4	97		3
zone 5		90	10

Quantification of the total face

The relative quantity of a geotechnical class over the toatl of the face is given

geotechnical class	relative quantity
very/extreme strong	67.4
strong	15.0
moderate strong	17.6

***Figure 1** Schematic view of the quarry face*

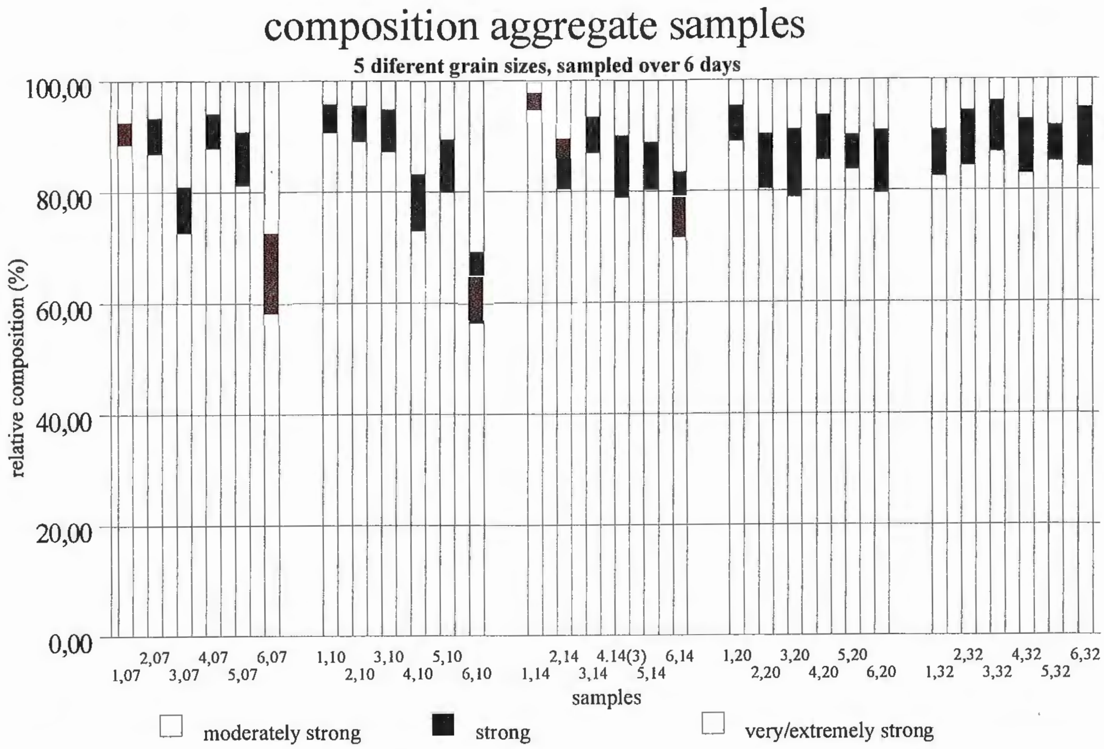


Figure 2 *Graphical presentation of the geotechnical composition of the aggregate samples. See table 1 for remarks on the sample numbering.*

as{private well as testing of aggregate both in the field as in the laboratory. For a complete overview of the research is referred to Haasnoot (1995). This article highlights the petrographical part of the study.

FIELD INVESTIGATIONS

The field investigations showed that two apparatus are particularly suitable for quarry investigation: the equotip hardness tester and the point load tester. Both tests are used to determine the strength of rock and are correlated to the unconfined compressive strength test (UCS). The main advantage of both tests is their ability to be used in the field. It is also possible to take many measurements within a relatively short time span. This is an important option when the variation is to be established.

Equotip hardness tester

The equotip hardness tester is originally developed for the metal industry. It is a convenient electronic

Sample No	very/extremely strong (weight %)	strong (weight %)	moderately strong (weight %)	Sample No	very/extremely strong (weight %)	strong (weight %)	moderately strong (weight %)
1.07	88.64	3.94	7.43	4.14	78.85	11.11	10.04
2.07	86.90	6.31	6.78	5.14	80.26	8.45	11.29
3.07	72.62	8.33	19.06	6.14	71.91	11.54	16.55
4.07	87.84	6.17	5.98	1.20	88.97	6.32	4.71
5.07	81.21	9.53	9.26	2.20	80.41	9.82	9.77
6.07	58.34	14.30	27.37	3.20	78.84	12.19	8.97
1.10	90.68	5.05	4.27	4.20	85.53	8.03	6.44
2.10	89.03	6.36	4.61	5.20	83.84	6.17	9.99
3.10	87.18	7.53	5.29	6.20	79.56	11.28	9.16
4.10	72.95	10.18	16.87	1.32	82.50	8.39	9.11
5.10	79.89	9.47	10.64	2.32	84.41	9.93	5.66
6.10	56.37	12.65	30.97	3.32	86.86	9.20	3.94
1.14	95.08	2.91	2.01	4.32	82.96	9.73	7.31
2.14	80.49	9.24	10.28	5.32	85.13	6.46	8.41
3.14	86.91	6.45	6.64	6.32	84.16	10.62	5.22

remark: The sample numbers consist of two numbers separated by a point. The number before the point indicates the day of sampling (day 1 to 6). The number after the point indicates the upper limit of the grain size class. Hence, sample 5.14 is the sample taken on day 5 of the 10/14 mm grain size class.

Table 1 *geotechnical classification of the aggregate samples.*

devise that is used to determine the hardness of metals.

A special test tip is shot by means of a spring from a fixed distance on the test surface from which it rebounds. The impact and rebound speed are electronically processed to the so-called equotip hardness value, which can be read on a electronic display. Depending on the purpose of the test and the situation, different tips can be used. Research by Verwaal & Mulder (1993) showed that this device also can be used to determine the strength of rock. It is particularly useful in the field when the rock mass is highly fractured and sampling is difficult. In general the equotip hardness tester could be regarded as an electronic Schmidt Hammer, with the remark that the impact energy of the equotip is considerably lower than that of the latter.

Point load tester

The point load tester is used to determine the strength of rock pieces. The apparatus consists in principle of two conical points which are moved together by hydraulic pressure. The force that is required for the rock to fail is a measure for the strength of the rock. Although mainly cylindrical samples are used, the test standards also allow the testing of irregularly shaped samples.

QUARRY INVESTIGATIONS

The investigation in the quarry comprised of a petrographic classification and quantification of a quarry face. This face is subsequently blasted and processed to crushed rock aggregate. These results are compared with the tests on the aggregate product.

Quarry face investigation

The classification is based on petrography. Petrography determines in this case the mechanical properties of the rock, which permits to consider it as a geotechnical classification. After determination of the classes, the strength is determined with the equotip hardness tester.

The face of interest measured 40 meter in length and 20 meter in height, approximately. On this face the petrography and strength of the rock is determined using different methods (amongst others along regularly spaced lines). Although the applied methods did not allow measurements higher than 4 to 5 metre, it was possible, after blasting, to classify material coming from above this height.

Also stereographic photographs are used to quantify the observed classes. In principle this quantification of the different rock types on the face is based on a two-dimensional surface. However, the distribution is considered to be equal in depth as the blasted slab is only 3 meter thick and the thereby exposed surface appeared to be equal to the original surface (figure 1).

Results quarry investigation

The quarry face can be divided in five geological zones. The face consists of river deposits, something which is clear by the lenticular shape of the fine material (zone 2) in a matrix of coarser material (other zones). Although five geological zones exists, the geotechnical classification can give an other view of the face.

Research showed that the five zones consist of three different rock types (classes) with different mechanical behaviour:

classification	petrography	strength (equotip)
very/extreme strong	sandstone and conglomerate	590-1000
strong	sandstone with high clay content	475-590
moderate strong	shale and siltstone	305-475

The nomenclature of the different classes (left column) is related to the strength of the rock. This is based on the nomenclature defined by the Geological Society engineering Group (1977) and determined with the equotip hardness tester.

Figure 1 indicates the composition of each zone and the composition of the total face. This is determined using the stereographic photographs and the extensive at the face.

In figure 1 is also the direction of removal indicated. This is the direction in which the blasted material is transported to the crushing installations. It is vital to know this direction to be able to interpret the relation between the material in-situ and the aggregate product. As the composition in horizontal direction changes it can be expected that the end-product changes in time.

AGGREGATE PRODUCT RESEARCH

This part of the research discusses the composition of the aggregate product and its variation in composition. This is done in context with the research results in the quarry to enable a comparison between the results of both parts.

The quarry produces the fractions : 0/3, 3/7, 7/10, 10/14, 14/20 and 20/32 mm. The crushing process involves in principle three phases. Depending on the initial grain size and the desired end-fraction it is possible that the rock does not encounter all phases. Different rock types enter the crushing process, these flow at a different speed through this process. This makes it likely that the produced fractions are not of the same composition. To what extent this can be observed in the results depends on the efficiency and control of the crushing process.

Aggregate research

To apply statistically based procedures as proposed by Gy (1979), it is, amongst others, necessary to know the composition of the aggregate in advance. As this is not the case and due to some other disadvantages of this procedure, alternative procedures are applied as they are described in the different national and international standards (for an overview: CUR, 1993). Pieters (1992) advises in situations where little is know on the composition of the aggregate to use the ASTM D 75-87 (1984) standard or the method given by Smith & Collis (1993). An important difference between this two methods is the number of increments that have to be taken to acquire a bulk sample. Smith & Collis (1993) advise eight increments opposed to the three increments recommended by ASTM (1984). Monjoie et.al. (1984) describe a method used in Belgium for the petrographic quality control of aggregates, illustrated with an example of shale and sandstone in the grain size classes 2 to 40 mm. They conclude the ASTM procedure is very reliable and easy to execute.

Aggregate research results

Considering the recommendations of Monjoie et.al. (1984) and a number of practical reasons (Haasnoot, 1995) the sampling of the crushing process is done according to the ASTM D 75-87 standard. Except for the fraction 0/3 mm, all fractions are sampled for six days, taking one bulk sample a day.

To determine the petrographic composition of the sample the procedure described in ASTM C295 is applied (see also Dolar-Mantuani, 1983). Similar to the classification in the quarry, the classification of the aggregate product is based on petrography, and on properties such as colour, shape and texture of the grains. A strength indication is obtained using the point load tester. This also shows that the strength of aggregate grains clearly depends on petrography. The three in the quarry observed classes are for aggregate described in table 2.

classification	petrography	strength (MPa)
very/extreme strong	fine to coarse sandstone and conglomerate, light grey to grey, very angular to angular, granular texture	> 6
strong	shaly, silty sandstone and sandy siltstone, grey, sub-angular, smooth to granular texture	3 - 6
moderate strong	shale and siltstone, dark grey, sub-rounded smooth texture	0.75 - 3

Table 2 *Aggregate classification factors.*

The results of the geotechnical classification of the aggregate samples is given in table 3, and graphically illustrated in figure 2. The results show that the composition of the coarser fraction (14/20, 20/32 mm.) fluctuates less than that of the finer fractions (3/7, 7/10, 10/14 mm.). It is also seen that the variations are most explicit in the "very/extreme strong" and the "moderate strong" classes, the composition of "strong" class is more constant. Over the six days of sampling a decrease in the very/extreme strong class can be observed and an increase in the weaker material.

COMPARISON QUARRY - AGGREGATE

The source of the investigated aggregate is the described quarry face. This offers the opportunity to compare the geotechnical composition of source and product, and interpret the similarities and differences. The transport of rock from the quarry to the crushing installations started halfway the first day of sampling (day 1). Halfway day 4 the total face is transported to the crushing facility.
Some assumptions are made to enable the comparison:

- The samples that are taken on a day are representative for the whole day. This assumption is based on a study where several samples are taken on the same day.
- The composition of the non-sampled fraction 0/3 mm. is estimated to be 50% "strong" and 50% "moderate strong". This assumption is based on observations in the quarry.
- The time that the rock stays in the crushing process is considered to be one working day (10 hours).

Table 3 summarises the results of the geotechnical composition comparison study. The composition of the aggregate product is determined using the composition results of table 1 and the quarries production data (Haasnoot, 1995).

geotechnical class the quarry	rel. % aggregate		rel. % in product
very/extreme strong	67.4	72.5	
strong	15.0	13.9	
moderate strong	17.6	13.6	

Table 3 *Geotechnical comparison.*

Table 3 shows that the composition of the aggregate product resembles the composition of the material in-situ. Some increase of the very/extreme strong class after crushing can be observed. The reason for this is that the weaker material is partly sieved out before the start of the crushing process and does not appear in the end product.

Considering the direction of excavation of the quarry face, an increase in weak material is to be expected (zone 2 in figure 1 is classified as "moderate strong"). This trend is visible in the aggregate product results. The aggregate composition results show an increase in "moderate strong" material.

The reason for a relative constant percentage of "strong" material can also be related to the quarry face. Zone 5 in the quarry face is the only zone contributing to the "strong" class. The thickness of zone 5 slowly increases in the direction of excavation. This slow increase is also visible in the aggregate composition results.

CONCLUDING REMARKS

Although engineers often consider crushed rock aggregate to be a homogeneous material, it often is not the case. The inhomogeneity does not only exist between two different quarries, but can also occur within one quarry. The quality of the aggregate product could be influenced when variation in rock properties exists within a quarry. The properties of the aggregate could change during exploitation.

The advantage of study in a quarry is that the different rock types are neatly ordered in layers or zones. This makes classification and quantification for professionals with a geological background relatively easy.

Considering the many applications of crushed rock aggregate and the higher criteria they have to fulfil, it is important to understand how the composition of the aggregate relates to source of the rock (the quarry).

The clear relationship between the composition of rock in the quarry and the composition of aggregate implies regular evaluation of the expected petrographic changes of variation of the quarries product. This so-called "proof of origin" should be assessed by a qualified and independent organisation.

ACKNOWLEDGEMENTS

I would like to thank the Ingeokring for awarding me the Netherlands Student Award for Engineering Geology 94/95. I also want to thank my thesis supervisor Ir. A.R.G. van de Wall for his co-operation and advise during my research project.

REFERENCES

ASTM Designation C 295 - 79, 1979, Standard Practice for Petrographic Examination of Aggregates for Concrete. Annual Book of ASTM Standards (1982), Part 14: Concrete and Mineral Aggregates. 218-227.

ASTM Designation D 75 - 87, 1987, Standard Practice for Sampling Aggregates. Annual Book of ASTM Standards (1988), Section 4: Construction, Volume 04.08: Soil and Rock, Building Stones; Geotextiles, 62-65.

CUR: Civieltechnisch Centrum Uitvoering Research en Regelgeving, 1993, Handleiding voor de Monsterneming van Loskorrelige Materialen. CUR-rapport 93-4.

Dolar-Mantuani L., 1983, Handbook of Concrete Aggregates. A Petrographic and Technological Evaluation. *Noyes Publications, Park Ridge, New Jersey*. 345pp.

Geological Society Engineering Group Working Party Report, 1977, The description of rock masses for engineering purposes. Q. J. of Eng. Geology, 10, 355-388.

Gy P.M., 1979, Sampling of Particulate Materials, Theory and Practice. *Elsevier Scientific Publishing Company*, Developments in Geomaterials 4.

Haasnoot J.K., 1995, A study of the Variation in Properties of Crushed Rock Aggregate. Memoirs of the Centre of Engineering Geology in The Netherlands No 124.

ISRM - Commission on testing Methods, Working Group on the Revision of the Point Load Test Method, 1985, Suggested Method for Determining Point Load Strength. Int. Journal Rock Mech. Min. Sci., Volume 22 No 2, p 51-60.

Monjoie A., Schroeder C., Zeimet M.J., 1984, Petrographic Studies in Relation with Quality Control of Aggregates. Bulletin of the international association of Engineering Geology, No 29, p 407-409.

Pieters W.E., 1992, Petrographic examination, Memoirs of the Centre of Engineering Geology in The Netherlands No. 102.

Smith M.R. & Collis L. (ed.), 1993, Aggregates: sand, gravel and crushed rock aggregates for construction purposes (2nd edition). Geological Society Engineering Geology Special Publication No 9. *The Geological Society*. 339pp.

Verwaal W. and Mulder A., 1993, Estimating Rock Strength with the Equotip Strength Test. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol 30, No 6, pp 659-662.

"$100,000,000 was the damage: whither research in the 1992 Roermond Earthquake?"

P.M. Maurenbrecher and A. den Outer, Delft University of technology, Faculty of Applied Earth Sciences, Delft.

Originally the above damage for the talk was advertised in guilders but Berz (1994) puts the figure in terms of *f* 170 m. If Germany is included the total comes to DM 250 million. Less than one percent of that amount would be needed to carry out a Ph.D. research project of 4 years to make an inventory of the actual damage so that architects and structural engineers in the Netherlands can know what aspects of their buildings are vulnerable to earthquake loading damage.

The cost of such research is minuscule not only in terms of percentage or as a research project in itself. The reason for this is that the information exists on paper: in the vaults of the Municipality of Roermond consisting of about twenty to thirty large lever-arch files. These files contain forms filled in by surveyors to estimate damage to houses so as to decide which households would be eligible for repair grants from the "Rampen Fonds" (Disaster Fund) set up by the government following the earthquake. The difference in damage exceeding *f* 5000 would qualify for grants.

WHERE ARE THE PRIORITIES FOR RESEARCH ON THE ROERMOND EARTHQUAKE?

Initially in 1992 with this unique event fresh in everyone's mind and having received considerable publicity on television, radio and the press there were many potential researchers keen to get on the earthquake/seismology bandwagon. Evidence for this is the special volume giving papers presented at a symposium held nine months after the earthquake in Veldhoven. A total of 40 papers were published subsequently in a special issue of "Geologie en Mijnbouw," Vol 73, Nos. 2-4 1994/1995. Most of the papers were seismological in content and only a dozen papers were concerned with damage to structures. The only paper by a structural engineer (Bouwkamp, 1994) is not from the Netherlands but from Germany. He did view a number of damaged buildings, which he describes in his paper, and then, gave a general presentation on the causes of damage to buildings in terms of their design and construction under earthquake loading. Quite rightly he states "*Based on geological site conditions, zoning provisions are absolutely essential. The observed slope failures of the Maas embankments as well as the observed soil liquefaction in the flat lands along the Maas river, clearly illustrate the danger of building along or near the Maas, or for that matter in the flat lands along any major river in western Europe (e.g. Rhine), where such river passes through a seismic zone.*"

RESEARCH DESPITE LACK OF FUNDS: WHAT IS POSSIBLE?

This research has been pursued by the Engineering Geology Group at the Faculty of Applied Earth Sciences, TU Delft.

The research is financed by the "primary money stream," a lump sum given by the Ministry of Science and Education to allow for basis research financing. The sum is distributed to researchers in Delft in proportion to the number of publications they produce. The sum is normally insufficient to

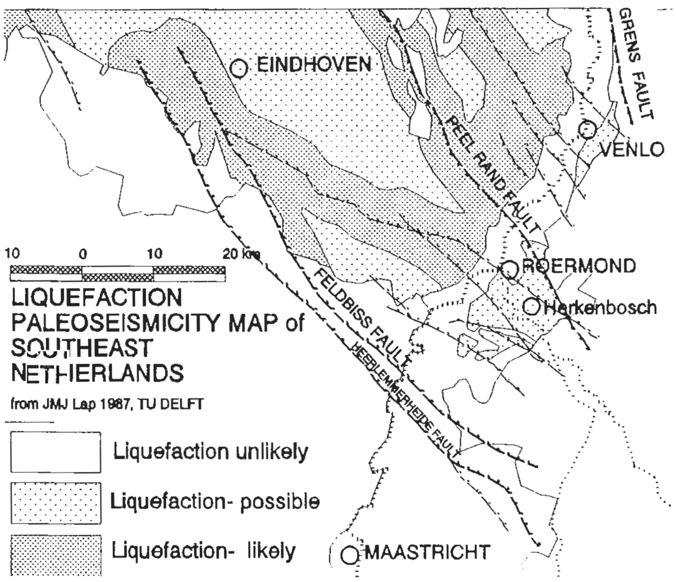
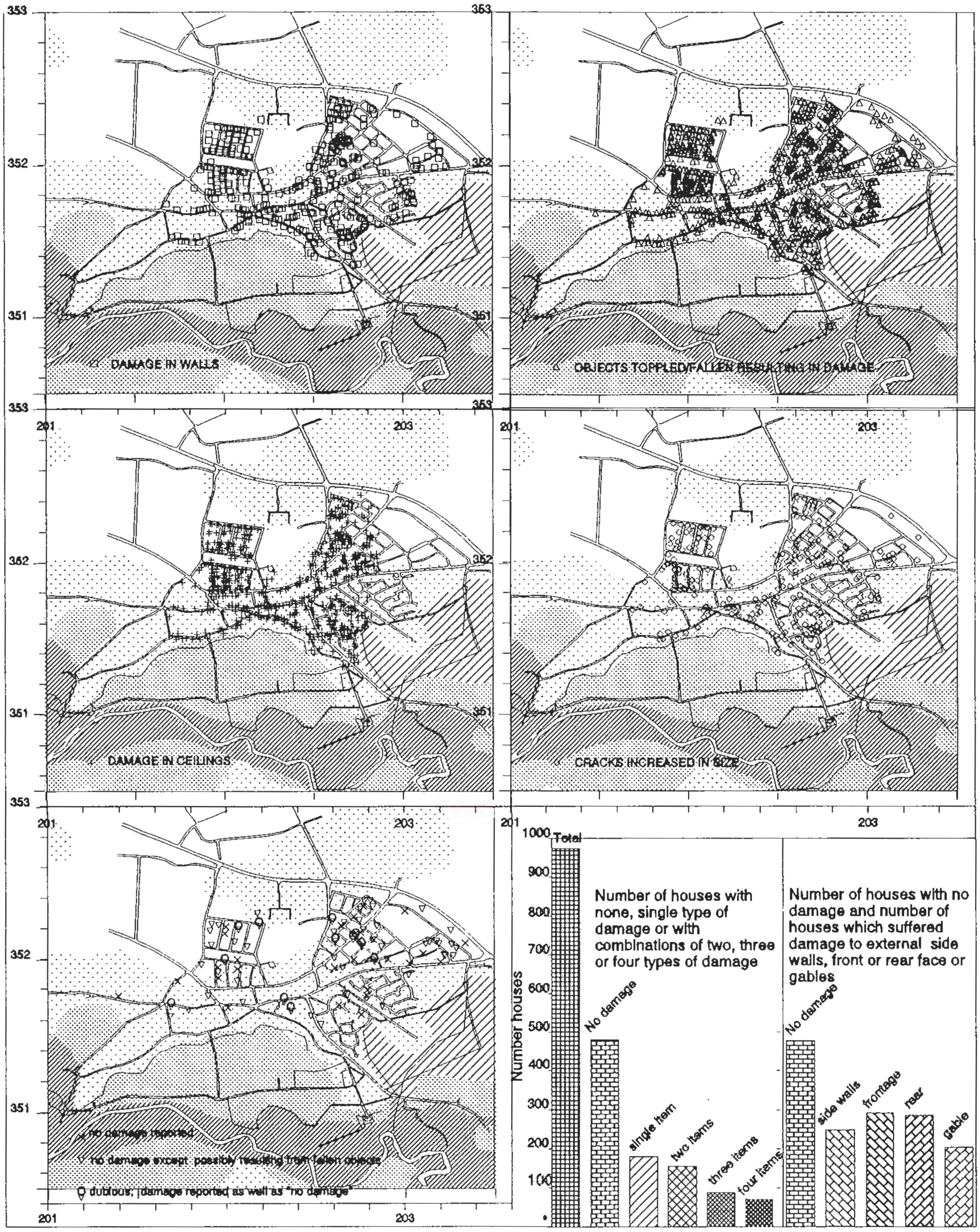


***Figure 1** Liquefaction Zoning Map of the South of the Netherlands by Lap (1987)*



from Geology Map HerkenboschNetherlands Geological Survey map 58 IV Roermond 1933

HOLOCENE				PLEISTOCENE
Aeolian sand often dune complex. Grading fine little medium or coarse.	Fluvial clay; fine sandy clay or clayey fine sand, thicknesses exceed 0.5 m.	Marsh peats forming over fluvial sands & lower terraces; peat formation interrupted due to drainage or exploitation. Organic sand with peat crusts	Fluvial sand; predominant-ly fine sands sometimes slightly clay-ey or with small clay lenses	Lower terraces of Maas and Roer rivers. Horizontal layers fine sands could have coarser grading and contain gravel bank deposits

***Figure 2** Distribution of Damage Superposed on geological Map 58 IV Roermond 1993.*

finance research projects such as the for the Roermond Earthquake. As long as expensive fieldwork site investigation methods and laboratory

testing is avoided costs can be met in this way.

This has, up to now, been possible as the research for the zoning maps required assembling existing ground data.

An early example of a zoning map is that produced by Lap (1987) and shown in Figure 1 as an English version of that given in the Prepal publication (1994). Lap's map has been produced on a relative macro-scale.

Presented as poster at Veldhoven and later published in "Soil Dynamics and Earthquake Engineering VII", a paper by ourselves and De Vries (1995) attempted to correlate damage to the geology (Figure 2). The correlation was not really possible as the geological "resolution" was to coarse- based on a map of 1933. The recorded damage seemed to be fairly evenly spread. What the survey did highlight, however, was that some houses of the same design as their neighbours, were not damaged. We reassessed the data and produced maps (Den Outer & Maurenbrecher, 1994) showing the distribution of degree of damage using the MSK, MMS, & JMS classification (Figure 3). Though this procedure is not considered very scientific by seismologists (they use the MSK, MMS & JMS system to plot the regional attenuation of earthquake intensity). Anomalies remained in that why were some houses of the same design and construction, more badly damaged than their neighbours?

The stage has now been reached that further investigation is needed to fill in the gaps of knowledge. Ard den Outer who has been the "brain" behind most of the research in the last three years outlined briefly some of the research that has been done, mainly by students as their final year M.Sc. project.

One gap in information was geology. A map has been produced by De Vries (1996) based on predominantly information from the RGD and site investigation companies' archives. The earlier geology map superimposed on the damage survey maps in Figure 2 should, ideally, be replaced by the up-dated map.

Another project carried out by Manzano, (1996) focused on the liquefaction phenomena that occurred during the Roermond earthquake, sand-vents just outside the municipality of Herkenbosch. Back calculation of liquefaction potential, using a method based on Cone Penetration Testing developed by Olsen (1988) showed that at least 0.29g (= 2.8 m/s^2) of ground acceleration was needed to cause the sand-vents; much higher than originally assessed by the seismologists. Although these results have to be investigated for the sensitivity for those geotechnical parameters that had to be estimated, it has become clear that to predict proper ground accelerations in an area, geotechnical investigations, in addition to traditional seismological methods, are essential.

A numerical study of the ground response, using the program SHAKE91 (Schnabel et al, 1972), during the Roermond earthquake by Van Daalen (1996) showed that only the upper 30 to 40 ft have a significant influence on the decrease in damping in the ground and the related "amplification effect." Any local variations of the macro-seismic intensity

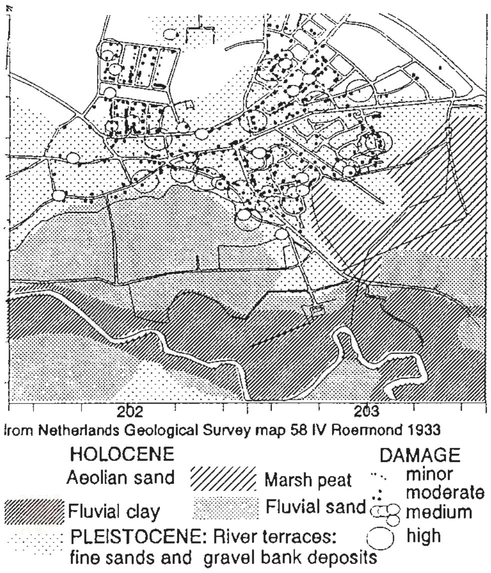


***Figure 3** Simplified Detailed MMS-Intensity Assessment for the Herkenbosch Area.*

are therefore thought to origin in this range of depths, while more regional variations are probably resulting from changes in total thickness of the overburden or due to a particularly unfavourable location relative to the tectonic structure.

The most recent study by Spruit (1997) is still carried out at this moment and investigates the local soil type and thickness variation by an Electro-Magnetic (EM) survey. This results have to be compared with the information on soil variation from the relative small number of borehole and penetration test locations in the area. Geostatistical analysis has to show whether the observed variation for the high resolution EM-survey can be properly described by the low resolution down-hole observations.

BUT WHAT HAS HAPPENED TO THE BAND WAGON OF 1992?

It appears to have been ditched once the Veldhoven symposium was held. Yet the date of the Veldhoven meeting was only nine months after the earthquake, hardly much time to allow for research. In truth, a submission had been made for one of the EU-theme projects. Its north-European flavour probably meant it was doomed from the start.

To try and keep an active group together proved increasingly futile from the limited resources within the Engineering geology group. Interest has been minor or non-existent from institutions who one would expect to play a leading role: VROM (Ministry of Housing, Planning and Environment), TNO-Bouw, the faculties of building sciences at TU Delft or TU Eindhoven. Similarly little interest has been shown by the structural engineering departments at Delft or Eindhoven despite some communication with student researchers. A few tentative attempts were made to interest them of the possibilities to carry out research. The reason co-operation is sought is because of that huge archive lying idle in the Roermond municipality vaults. The forms are filled in by hand in almost illegible handwriting. For some one familiar with building terminology it should be quite simple to make out the handwriting. Registration of the information in a proper data base should show where weaknesses existed in design and construction of housing and indicate, for safety, damage mitigation and insurance purposes what extra strengthening would be required in existing and future buildings.

WHAT CHANGES ARE REQUIRED TO PUT EARTHQUAKE ENGINEERING ON A PROPER FOOTING IN THE NETHERLANDS?:

CHANGE OF ATTITUDE? INTENSIVE LOBBYING? NETHERLANDS EARTHQUAKE SOCIETY?

The following programme was downloaded from the home pages of the Institution of Civil Engineers (ICE on-line: http://www.ice.org.uk/)

Evening meetings of the Society for Earthquake and Civil, Engineering Dynamics

- Introduced by Dr K Pilakoutas et al, 29 JAN 17:30 "Repair and strengthening of structures following an earthquake"
- Introduced by R Yeung et al, 26 FEB, 17:30 "Alternative methods for blast analysis on structures"
- Introduced by Dr T Blakeborough and Dr J Bommer 26 MAR, 17:30, "Field observations of earthquakes
- Introduced by Dr T Wyatt, Professor R Severn et al 23 APR, 14:00 "Passing on experience - a master class" AGM at 17:00
- Presented by Professor R Severn 21 MAY,17:00 "Structural response prediction using experimental data", Mallett Milne Lecture

Should not the Netherlands also have a Society for Earthquake and Civil Engineering Dynamics? Is the Netherlands less prone to earthquakes than the UK? I leave you to ponder these questions.

DORMANT ARCHIVE OF THE DISASTER FUND: WHAT TO DO?

One gaping void remains in the research which can easily be financed through the primary funding: compilation of the disaster fund archive. Despite Bouwkamp emphasising that zonation is important, he also makes it abundantly clear that design and construction of buildings and structures can define their susceptibility to earthquake loading.

The "damage" surveys carried out by the engineering geology group were based on a hurried and not all to comprehensive questionnaire. The disaster fund surveys go a stage further. The actual damage is recorded and the degree of damage is given in terms of the repair costs.

In most cases of damage only the repair costs will be used in the Ph.D. study by den Outer, for the correlation with geology, as specialist knowledge to make a more detailed interpretation of the damage reports is not available. Together with construction records a great wealth of information remains to be unleashed from the Municipality of Roermond and the Municipality of Roerdalen (Meelick, Herkenbosch and Vlodrop) situated to the southeast of Roermond.

Possibly Prof. David Price had the last word shortly after the Roermond earthquake: "There is sufficient (research) work for decades to come; we must ensure that we provide the data for that research".

ADDITIONAL NOTE

April 13th 1997 the 5 year seismic pause after the Roermond earthquake was remembered in the area near Herkenbosch, by a local television coverage of past experiences and recent accomplishments on "How to prepare for a future earthquake ?" It is unfortunate that the authors reluctantly had to comment that the earthquake engineering research is limited to the Engineering Geological Group Delft only.

The recurrence time of significant flooding caused by the main rivers is said to be less than 300 years, and is a thread taken seriously at this time. It should be needless to say that the Roermond earthquake could easily have caused more casualties, had it occurred at a less fortunate time, i.e. day-time. An earthquake of magnitude 5 of higher has a recurrence time of 105 years (de Crook, 1994) and no actions are initiated. It can only be hoped that the recent developments in case of induced earthquakes in the northern part of the Netherlands will result in more serious plans to prevent future damage or worse from any type of earthquake.

REFERENCES

Bouwkamp, J.G. (1994); The 1992 Roermond earthquake, the Netherlands: earthquake engineering; *Geologie en Mijnbouw*, **Vol. 73, No. 2-4**, pp. 291-298

Berz, G. (1994); Assessment of losses caused by the 1992 Roermond earthquake, the Netherlands (extended abstract); *Geologie en Mijnbouw*, **Vol. 73, No. 2-4**, pp. 281

Crook, Th. de (1994); Earthquake Hazard for Roermond, the Netherlands; *Geologie en Mijnbouw*, **Vol. 73, No. 2-4**, pp. 425-429

Daalen, P.M. van (1996); Earthquake Response Analysis of Horizontally Layered Sites with the Aid of the Program SHAKE 91; Memoirs of the Centre of Engineering Geology in the Netherlands, No. 139

Lap, J.M.J. (1988); An Evaluation of Earthquake-Induced Liquefaction Potential of the area South of Eindhoven, the Netherlands; Memoirs of the Centre of Engineering Geology in the Netherlands, No. 45

Schnabel P.B., J. Lysmer & H.B. Seed (1972); SHAKE: A Computer Program for Earthquake Response Analysis for Horizontally Layered Sites; Report No. UCB/EERC-72/12, Earthquake Engineering Research Center, University of California, Berkeley, 48 p.

Manzano, J.A. (1996); Detailed Liquefaction Potential Analysis of the Herkenbosch Area Using the Roermond Earthquake Observations for Calibration; M.Sc. Thesis, Department of Engineering Geology, International Institute for Aerospace Survey and Earth Sciences (ITC)

Olsen, R.C. (1988); Using the CPT for Dynamic Site Response Characterisation; Proceedings of the Speciality Conference on Earthquake Engineering and Soil Dynamics II - Recent Advances in Ground-motion Evaluation, **No. 20**, pp. 374-388, American Society of Civil Engineers, New York, USA

Outer, A. den, P.M. Maurenbrecher and G.T. de Vries (1994); Earthquake-hazard mapping with questionnaires in the Roermond Area (Netherlands); 7th Int. Congress IAEG Proceedings, **Vol. 3**, pp. 2087-2094, Balkema

Vries, G.T. de (1996); Geotechnical Modelling of an Area near Herkenbosch, Limburg, based on SEIS; Seismic Engineering Information System; Memoirs of the Centre of Engineering Geology in the Netherlands, No. 115.

Boskalis werkt. Overal.

Havens en vaarwegen zijn de slagaders van vele economieën. Als toonaangevende baggeronderneming in de wereld speelt Koninklijke Boskalis Westminster een belangrijke rol bij het aanleggen en bereikbaar houden ervan. Ook het opspuiten van stranden en het winnen van land maken deel uit van het brede dienstenpakket, tot en met de complete aanleg van kunstmatige eilanden. Kust- en oeverbeschermingswerken liggen in het logische verlengde van deze baggeractiviteiten.

De omvangrijke vloot van Boskalis is veelzijdig inzetbaar. Behalve in technologie wordt ook voortdurend in hoogwaardige vakmensen geïnvesteerd. De brede know how van het bedrijf staat ten dienste van de ontwikkeling van infrastructuur, maar ook voor activiteiten op het gebied van offshore, milieu, mijnbouw en recreatie. Boskalis heeft voor elk project de juiste combinatie van specialismen in huis. Over de hele wereld.

Koninklijke
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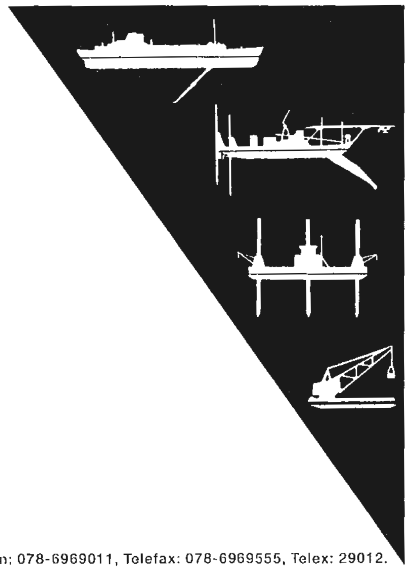

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Breiter Berg project

Ir. R. Berekelaar, Fugro Engineers B.V.

This article is a summary of the thesis called: Breiter Berg Project, Austria, by Robert Berkelaar, presently working for Fugro Engineers bv. This once-only award was presented at the 'Jaarvergadering' on may 9th, 1996 by Jan Rupke of the University of Amsterdam, Alpine Geomorphological Research Group (AGRG). The thesis was completed in spring 1994. Since already two years have gone by, some recent developments concerning the Breiter Berg Project will be included.

The Breiter Berg Project deals with an extensive study of a possibly unstable rock mass of about 200.000m^3 possibly endangering settlements in the Rhine Valley near Dornbirn, Austria. (Figure 1). The total scope of work consists of:

1. Geomorphological mapping of the potentially unstable rock mass including the direct surroundings;
2. Geomorphological mapping of the valley below the rock mass;
3. Geophysical profiling of the adjacent Rhine Valley;
4. A slope stability- and rock fall analysis;
5. Recommendations on monitoring equipment.

The part of the project performed by the author dealt with two items: the stability- and rock fall analysis. The remaining parts were covered by the AGRG, University of Amsterdam.

INTRODUCTION

The Breiter Berg has been causing problems at least since the middle ages as can be noted from historical records: *"Ein großer Felsen vom Breitenberg ober dem Satz herabfiel, der in die Ebene ein Großes Loch schlug und sich in die Erde versenkte"*. Another rock slide took place about a century later in 1760:*"1760, den 16.2, abends 8.00 uhr, stürzte beim Sturm und Regen ein noch größerer Felsen herunter, der etliche tausend Tannbäume samt Wurzeln und Erde mitbrachte...Im Rheintal meinte man, es donnere. Am anderen Morgen sah man keine Spur mehr von allem. Alles versenkte sich..."*.

The rock mass remaining at the top of the Breiter Berg, has been observed closely hereafter (Figure 2). In the late 80's local municipalities asked for a thorough investigation of the remaining rock mass because of planned expansion of the town of Dornbirn. The project, as given to the AGRG, has been one of the most recent investigations.

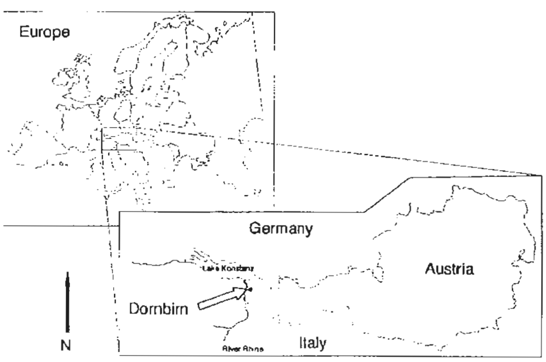

Figure 1 Location map.

The project started with field work, three weeks in autumn 1993, to map the geometry and properties of the potentially unstable rock mass, to collect samples for testing and to investigate the probable "Absturz Bahn". Laboratory tests were performed at the TU-Delft, whereafter the engineering problems were dealt with.

SLOPE STABILITY

The stability of the rock mass west of the so called Yellow Wall (release face of ancient slides, Figure 2) has been analyzed with a computer program based on Bishop's Simplified method. This method, of which the necessary input parameters result from laboratory tests, has been applied on four profiles representing the shape of the block. In the slope stability analysis attention has been given to: the variation of the angle of friction of the slip plane, the application of horizontal accelerations and the effect of partially excavating the block. Ground water models showed that ground water effects do not have a significant influence on the stability.

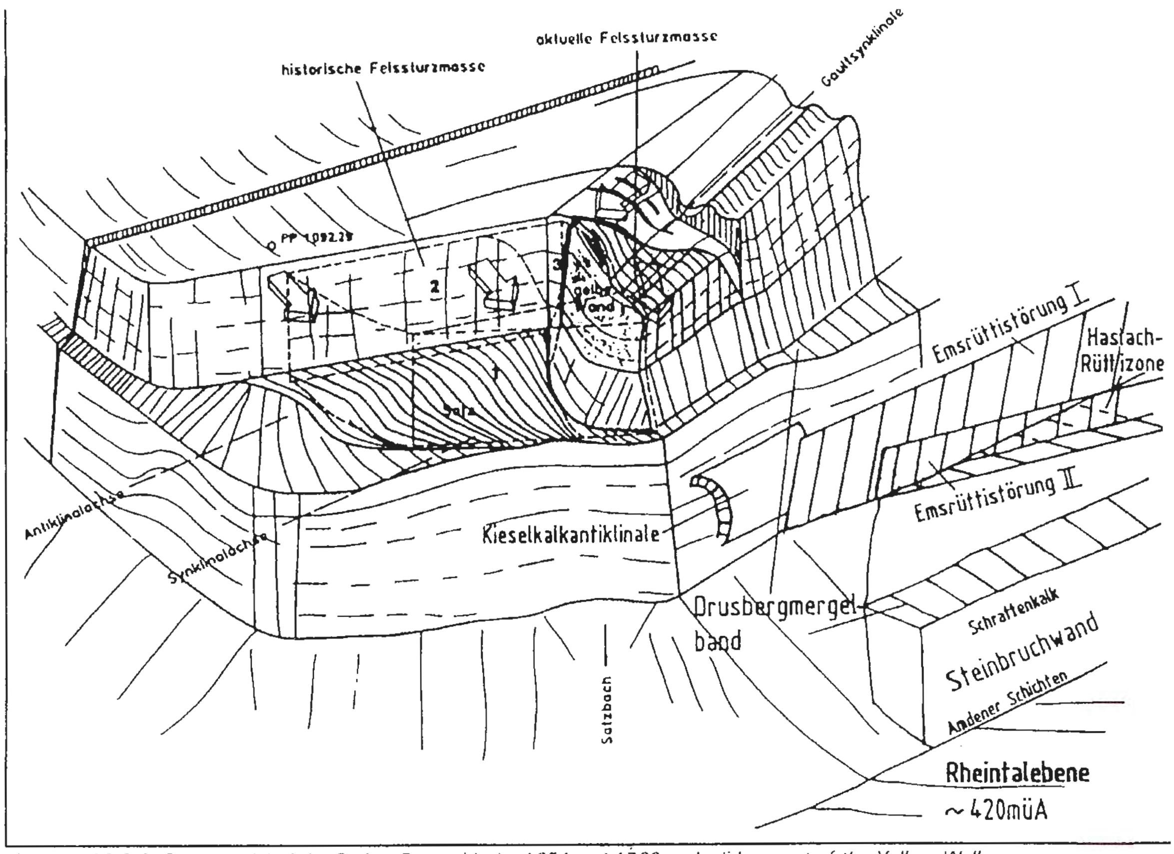

Figure 2 Block model of the Breiter Berg with the 1654 and 1760 rock slides west of the Yellow Wall (Bertle, 1992).

The results of the stability analysis show that the rock mass is stable at the present, assuming an angle of friction of 40° and no earthquakes occurring. The effect of excavating the top of the block on the stability is low, typically 50m excavation will lead to an increase in factor of safety of 11%. Total instability will probably occur in the case of an earthquake with MM-intensity of at least 7 or when the angle of friction of the slip surface decreases to a value of 34°. This could be possible as the slip surface tends to develop in the Drusberg Formation which is highly susceptible to weathering. In the case of instability, the rock mass is likely to take an anti-clockwise turn and rotate along a vertical axis towards the Satz (Figure 2).

ROCK FALL ANALYSIS

The analysis of possible instabilities has been carried out giving attention to the different behavior of rock avalanches and single blocks. All material resulting from instabilities will most likely be concentrated in the Satzbach whereafter the material will spread out on the Rhine Valley Floor. A back analysis was done on the ancient rock slides. The back analysis, done with Davies model (1982), demonstrated that a destructive zone reached up to the present soccer fields, which is in accordance with field observations and historical information. The ancient avalanche has had a destructive impact on the area up to the soccer fields where the majority of the rock mass sunk away in soft sediments. The model used for the back analysis, Davies (1982), describes the ancient rock slide impact good. Similar models, Li (1983) and Scheidegger (1973), have been used to describe the present situation.

Rock avalanches have been analyzed with the aid of the two empirical models mentioned previously, which lead to a prediction of zones of destruction, risk and safety. Both models predict roughly the same destruction zone.

Single blocks have been analyzed with aid of the computer program CRSP (Colorado Rockfall Simulation Program). This program describes the motion of a single block falling along a slope by applying equations of gravitational acceleration and conservation of energy. A range of diameters has been analyzed to evaluate the effect of the Satz and protective basins in the slope on the behavior of falling rocks.

The Satz has a limited effect on smaller blocks (up to 3m diameter). The Satz will also have a

scattering effect and will serve as a base on which falling blocks will be chattered.
Protective basins have been analyzed to evaluate their effect on falling blocks. The calculations show that the basins are able to trap the smaller blocks (up to 3,5m diameter) but the larger blocks will pass the basins, the ulimate velocity will not be influenced by the basins. The maximum runout distance for single blocks as calculated by CRSP is approximately as far as the Li risk zone.

RECOMMENDATIONS

From the performed analyses can be concluded that future instabilities, leading to damage in the Rhine Valley, are likely. Following recommendations contain measures to minimize the chance of damage.

F Protective measures; Above all, safety measures must be implemented, such as the construction of protective basins along the slope including fences and/or nets and placing a protective dike at the foot of the slope as a second safety barrier.

F Stabilization of the block; Observations in the field lead to the conclusion that stabilization would be practically impossible.

F Quarrying; The block could be quarried to achieve an increase in factor of safety. However, this solution has the disadvantage that a lot of excavation is required in order to achieve a small increase in stability, furthermore problems arise concerning safety and logistics.

F Controlled blasting; The block could be blasted in such a way that a stable situation is left at the top of the Breiter Berg. Disadvantages are the danger of creating a potentially uncontrollable situation.

RECENT DEVELOPMENTS

In the end of 1996 the AGRG has visited the site with experts on blasting and rock mechanics from Germany, Austria, TU-Delft and local municipal representatives to assess the present situation of the block and to consider the possibilities of actually blasting the block. The revealed showed new cracks in the foot of the block which could imply tension built up. The situation has proven to be urgent and will have to be dealt with quickly according to the experts. As a result preparations are now being taken for closely monitoring the block and blasting in the near future.

REFERENCES

Davies, T.R.H., 1982, Speading of Rock Avalanche Debris by Mechanical Fluidisation, Rock Mechnics, No. 15, 9-24.

Li, T., 1983, A mathematical model for predicting the extend of a major rock fall, Zeitschrift fur Geomorphologie, Nr. 27, 473-482.

Scheidegger, A., 1973, On the prediction of reach and velocity of catastrophic lanbdslides, Rock Mechnics, No. 5, 321-236

Book Review

Handbook on liquefaction remediation of reclaimed Land

Port and Harbor Research Institute, Japan (1997), pp. 312, ISBN 90-5410-653-0. Price: 150 DM

INTRODUCTION

"*Loose sandy deposits sometimes change into a liquid state during earthquakes. This is called liquefaction and poses a serious problem in waterfront areas. When the sandy deposits liquefy, structures build on those deposits are seriously affected by loss of bearing capacity and settlement of the ground. Reliable remediation with respect to liquefaction is necessary in geotechnical practice.*"

As such starts the preface of this very useful collection of knowledge focussed on the liquefaction phenomena, assessment and remediation. Published in 1997 the book also reflects the very recent experience in liquefaction damage during the 1995 Kobe earthquake, after which over 90% of the harbor facilities was out of order and set back economical growth in the area for two years.

The 1995 Kobe earthquake proved that liquefaction is not that easily described in a generalized way, by empirical formula's. Soil types, used for back-fill and as rubble mount, that were not expected to liquefy did (weathered gravely materials). Re-evaluation of the liquefaction concept will hopefully prevent such disasters in the future.

CONTENTS

The book gives and overview of topics all related to liquefaction in general, i.e. liquefaction phenomenon, examples of damage, strategy for remediation, in-situ and laboratory tests for the assessment of liquefaction and the actual remediation of liquefiable soils.

Chapter one and two give an insight in the objective of the handbook as well as a clear view on the main principles of liquefaction; a nice introduction, even for non-specialists. A variation of (historical) damage resulting from liquefaction is listed, with a direct correlation between type of damage, cause of damage and structures involved.

Cases where more information is obtained about displacement and sub-soil are illustrated by sketches.

REMEDIATION STRATEGY

During development of a particular area, remediation strategy changes depending on scale and timing of remediation within the development program. Chapter three discussed the remediation and differentiates on scale between large and small scale remediation, i.e. per reclaimed area or structure. Whereas the timing is differentiated on before or after land reclamation and before or after construction of structures.

Apart from general guidelines, special structures like roadways and buried structures as well as bridges and bridge access are treated separately. As are connections between buildings and their surroundings, e.g. pipelines etc.

ASSESSMENT OF LIQUEFACTION

Chapter four shows a very straightforward approach in assessing liquefaction in service for remediation of liquefiable soils. Seismological and geotechnical studies result in an assessment, whereafter the construction and civil engineers determine whether damage to a structure will occur and be significant. If so remediation has to be carried out adapting either the subsoil, the structure (foundation design) or both.

A list of assessment methods is given, however the Japanese origin of this handbook shows through the fact that all in-situ methods are based on SPT-N values. Tables indicate the type and depth of soil investigation for liquefaction assessment, and pays attention to the different stages of the assessment (preliminary or final) and the importance of the structure. Similar, but more elaborated information in siting in earthquake areas can be found in Wang et al. (1994).

In this chapter also the development of shear stresses in the soil and several assessment methods, i.e. Iwasaki, Ishihara, Seed and Idriss and Tsuchida, are discussed in detail.

REMEDIATION OF LIQUEFIABLE SOILS

The remediation methods discussed are mainly based on the following principles: (1) Soil improvement should result in prevention of liquefaction in the soil, and (2) structural improvement should minimize the damage to the structure, even when liquefaction occurs.

Soil improvement can focus on a number of soil properties/behavior: (1) Prevent collapse of the soil skeleton, and (2) speedy dissipation of excess pore water pressure. The *structural improvement* is done by paying attention to (1) reinforcement of the structure and maintenance of structural stability with strength and rigidity and/or (2) relief of external force by attaching flexible joints or modifying a structure.

In light of soil improvement standard methods like compaction, pore water dissipation, cementation and/or solidification, replacement, lowering groundwater table, shear strain restraint and preloading are discussed.

For each of the methods above practical limits for soil improvement are discussed and indicated.

CONCLUSIONS

The book is indeed a handbook for liquefaction remediation, which is in practice particularly interesting for SPT-N based empirical approaches in liquefaction assessment. In general the book gives a good overview on liquefaction in general and remediation methods available. For Europe the methods of assessing liquefaction potential and the in-situ limits for soil improvement can not be obtained from this book directly. However, using transformation graphs between SPT-N and CPT-q_c values by Robertson an indication of the related SPT-N values can be obtained.

REFERENCES

Wang, J.G.Z.Q. & K.T. Law (1994); Siting in Earthquake Zones; Balkma, Rotterdam, 115 pp.

Investment impulse knowledge infrastructure and engineering geology

R.D. Koster, ITC Delft, Kanaalweg 3, 2628 EB Delft & J.K. Haasnoot, TU Delft, Faculty of Applied Earth Sciences, Section Engineering Geology, PO Box 2628, 2600 GA Delft.

This paper gives an overview of the Investment Impulse Knowledge Infrastructure and Engineering Geology. Two of the three research areas of the Investment Impulse Knowledge Infrastructure program, which are co-ordinated in co-operation with the CUR, Centre for Civil Engineering Research, Codes and Specifications (Civieltechnisch Centrum Uitvoering Research en Regelgeving) in Gouda are discussed. The three research areas are:

- the impulse program: 'Underground Construction Knowledge Network' (COB);
- the investment program: 'Land Water Environment Information Technology' (LWI);
- the Dutch research program: 'biotechnological in-situ sanitation' (NOBIS).

Engineering geologists involved in the COB and the LWI projects explain how engineering geology contributes to the current strategic investments in research and development in the Netherlands

INVESTMENT IMPULSE KNOWLEDGE INFRASTRUCTURE

In 1990 the Dutch government has decided to invest Dfl. 5 billion to improve the Dutch infrastructure. Five percent of this investment, Dfl. 250 million, was allocated to be spend on the enhancement of the knowledge- and technological infrastructure. This part is generally referred to as the 'Investment Impulse Knowledge Infrastructure' (*Investerings-impuls Kennisinfrastructuur*). The ICES[1] advises the government on the implementation of the investment impulse. As a consequence, the funding of the investment impulse to improve the Dutch infrastructure is often referred to as 'ICES-funding'.

The main theme of the impulse is an investment aiming at sustainable development and management of knowledge which will strengthen the Dutch economy. A vital part of the investment impulse is the sustainable co-operation between research and educational organisations, and the Dutch trade and industry (public-private co-operation). The co-operation of the public and private sector should contribute to the strengthening of the national economic structure, and should last beyond the end of this governmental financial input (the year 1998).

The investment impulse comprises of several research programs also referred to as impulse or investment programs by different organisations. Projects, such as High Performance Computing and Networking (HPCN), transport technology, mainport Rotterdam, etc., are supported by the investment impulse knowledge infrastructure.

Three of such programs are being carried out in co-operation with CUR. In these programs engineering geology plays an important role. The programs are:

- Impulse Program Underground Construction Knowledge Network, co-ordinated and managed by the Centre for Underground Construction (*COB, Centrum Ondergronds Bouwen*).
- Investment Program Land Water Environment Information Technology, co-ordinated and managed by the LWI-foundation (*LWI, Land Water Milieu Informatietechnology*).
- Dutch Research Program Biotechnological In-situ Sanitation, co-ordinated and managed by the NOBIS-foundation (*NOBIS, Nederlands Onderzoeks-programma Biotechnologische In-situ Sanering*).

The COB and the LWI projects will be discussed in the following paragraphs. Their aims and their contents are given and the distinct links with engineering geology is explained. This last point is further elaborated by the authors of the different

[1] ICES *Interdepartementale Commissie Economische Structuurversterking* (Interdepartmental Committee on Economic Structure-strengthening).

Themes		Aim
I	Tunnel-boring in weak soils	Gain knowledge and experience concerning the application of the boring technique in the specific weak Dutch soil: gain insight in the boring process and the risks and effects of boring on the environment and the surroundings. gain experience on the application of boring techniques in weak soil. validation of the available methods for exploration, prediction and monitoring.
II	Exploration, prediction and monitoring	Controlling the risks of tunnel construction by the development of: reliable instruments for exploration, prediction and monitoring for bored tunnel construction in weak soil.
III	Economic tunnel construction	Optimisation and innovation of tunnel construction methods for weak soil in order to obtain an optimal price/quality ratio
IV	Construction, management and maintenance	Reach an optimal product for the user, the manager and the environment by: designing safe and sustainable tunnels that can be economically maintained. designing and constructing tunnels in such a way that they can be optimally integrated in town and country planning.
V	Use of underground space	Integration and extension of the knowledge in the field of underground construction, especially outside the specific infrastructural application.

***Table 1** Themes of the executive program of the COB.*

sections who are engineering geologists active in projects of the different programs.

IMPULSE PROGRAM UNDERGROUND CONSTRUCTION KNOWLEDGE NETWORK

Underground construction has been adopted much earlier abroad then in the Netherlands. Obviously, the Dutch geo-environment is part of this slow start; a flat country, with weak soils and a high ground water level does not invite to intensive use of the subsurface.

The Dutch can rank themselves amongst the worlds experts in soil mechanics, foundation engineering and dredging. Despite the expertise in immersed tunnel techniques, the present knowledge and know-how is as yet not that sufficient to be able to assess all the consequences of underground construction, especially knowledge in the new field of bored tunnelling. But the ingredients to become experts in soft soil underground construction are prominently present.

The Dutch government has acknowledged this excellent basis to obtain new, 'high-quality' knowledge by a strategic investment of Dfl. 40 million in the Impulse Program Underground Construction Knowledge Network. The impulse program is co-ordinated and managed by the Centre for Underground Construction (*Centrum Ondergronds Bouwen, COB* in Dutch).

Objectives of the COB

The objectives of the impulse program underground construction knowledge network comprise:

- Establishing a knowledge centre for the co-ordination and initiation of research and development in the use of underground space. Within this centre all parties, both public and private, will co-operate to find possible innovations and improvements in the use of underground space. The combination of theory and practice aims at the development of successful products and practical applications.
- A short term executive program (5 years) and a long term executive program (5 to 20 years). Their aims are listed in table 1.
- The chair underground construction technology at Delft University of Technology closely associated with the activities of the knowledge centre. This chair is occupied by Prof. ir. E. Horvat. Prof. Horvat could be considered as an engineering geologist *avant la lettre*, being a mining engineer who has been engaged with geotechnics throughout his career.

COB and Engineering Geology

Engineering geologists establish and translate the physical conditions of the geo-environment for (civil) engineering purposes. This knowledge is considered essential in underground construction.

The emphasis of the executive program of the *COB* is on shield tunnelling. Shield tunnelling is a civil engineering activity which intensely interacts with the surrounding geo-environment. Nearly every operation in shield tunnelling depends on the surrounding physical conditions. Excavation and transportation processes, bore-front stability, jacking forces, settlement, etc. are determined by the geo-environment in which the tunnel is constructed. (further reading Van Lange , 1996).

Theme I of table 1 is fully focused on gaining expertise in shield tunnelling in soft soils. This becomes most prominently clear in the two pilot projects monitored by the COB, the second Heinenoord tunnel and the Botlek railway tunnel (see also Maurenbrecher, 1996). An extensive geotechnical monitoring scheme accompanies these projects. Research within this theme focuses on understanding the different parts of the tunnel boring process, with the aim to control, minimise or avoid settlement (for an overview Bakker, 1997). Besides these geotechnically oriented subjects shield tunnelling research also includes excavated soil transportation problems, soil conditioning problems (foam application), cutting of soil, etc.

Theme II (table 1) appeals to the site investigation spirit of the engineering geologist, with probing ahead from the tunnel boring machine as its *piece de resistance*. This concept offers many challenges because the information obtained by this tool needs to be translated in tunnelling process parameters within a few minutes, if not real time. The additional information gained by probing ahead, could enhance the accuracy of geotechnical units in the tunnel trajectory and may possibly change the strategy of site investigation. At this moment tests are prepared to perform horizontal cone penetration tests, with the intention to apply this tool in a tunnel boring machine.

Although much attention is being paid to the large diameter bored tunnels, a lot of research is carried out on trenchless technology. Especially horizontal directional drilling techniques (HDD) are under thorough study. A test on a 1:1 scale is performed at Delft Hydraulics to observe the tunnelling process (Mastbergen 1997). This included the flow processes of the bentonite suspension, hydraulic excavation, the plastering-function of the bentonite and the pressures involved related to possible blow-outs.

Theme V, "use of the underground space", focuses on administrative and planning aspects of the use of underground space. This research includes amongst others the storage of nuclear and hazardous waste in the subsurface. In the past engineering geologists have been involved with this delicate subject. It is therefor not surprising that a Ph.D. student at the faculty of Applied Earth Sciences is extending this work.

Final Remarks

The shortage of surface space in the Netherlands demands for innovative solutions in order to continue the economic development in parallelism with a high quality living environment (figure 1). Effective use of the underground seems a logical approach to tackle this problem. This demands high quality solutions, both in engineering as well as in policy making and urban planning. The role of the engineering geologist as translator of the physical conditions of the geo-environment for (civil) engineering purposes is in this interdisciplinary impulse program an obvious one.

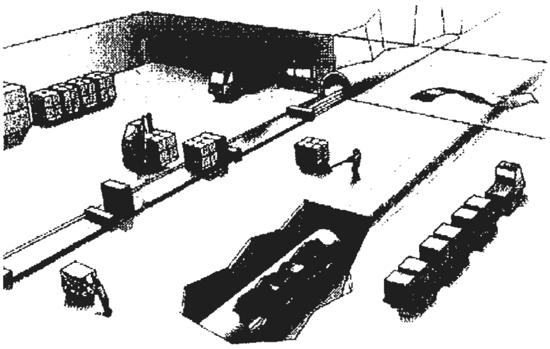

Figure 1 *UTP, Unit Transport per Pipeline is an example of innovative and effective use of underground construction. It requires a multi-disciplinary approach of innovative civil engineering and effective transportation systems.*

More information on the COB program can be obtained from the CUR/COB secretariat (0182-539600) or on the Internet:
http://www.bouwweb.nl/CUR/cob.html.

References

Bakker, K.J., 1997, Boortunnels in Nederland, "stand van zaken met betrekking tot de geotechniek rond de Tweede Heinenoordtunnel". *Geotechniek, jaargang 1, nr 1, jani/mrt 97*, 4-11.

Van Lange, M.W.P., 1996, Geotechnical aspects in soft soil shield tunnelling. *Ingeokring Newsletter No.3 Spring 1996*, 35-40.

Mastbergen, D.R., 1997, BTL-Proeven Directional Drilling in Baggergoot WL. COB Nieuws, nr 9.

Maurenbrecher, P.M., 1996, Visit to the first bored tunnel in the Netherlands: the second Heinenoord tunnel *Ingeokring Newsletter No.4 Autumn 1996*. pp.7-16.

LAND WATER ENVIRONMENT INFORMATION TECHNOLOGY (LWI)

General introduction

The conflict of interest between the demands of environment, economy, space and population density is increasing, especially in the highly populated coastal and delta regions like the Netherlands. National and local authorities are therefor looking for instruments which can assist the balanced development and sustainable management of these areas. The new field of information technology may provide these instruments. This awareness has led to the growth of a need to combine knowledge from the fields of civil engineering, environmental studies, land and town planning and information technology which has resulted in the erection of the LWI-program.

For all projects within the LWI-program, the emphasis is placed on the opportunities that Information Technology can provide to manage the complex nature of the interests to be considered and of the disciplines involved in large scale infrastructural workings. Unsupported technical solutions are no longer acceptable; it is necessary to involve other disciplines, such as economy, ecology and sociology, in the decision process. It also must be made clear how decisions come to be taken. This means that the evaluations have to be inter-communicable and, of course, that in decision making process the various opinions are sounded at an early stage of the project.

Objectives of LWI

The objectives of the LWI-program comprise:
The development of insight and instruments through the combination of knowledge and skills in the broad working domains of civil engineering, environmental studies and information technology, aimed towards the sustainable development and management of infrastructure which will strengthen the competitive power of the Dutch industry in the national and international markets.

The emphasis of the LWI-program is placed upon the involvement of clients and the end users in programming, steering and co-financing the developments. The products developed by the LWI range from research versions to dedicated versions for specific practical applications.

LWI-framework

Within the framework of the LWI, there are four Project groups associated with the following themes:

- Estuaries and Coasts;
- Rivers and water management;
- Mainports: sustainable construction and management of urban, port and industrial areas;
- Large Scale Line Infrastructure.

In 1996 a separate group was founded which provides instruments to evaluate possibilities for the development of the West of the Netherlands. The project groups are supported by the Information Technology Productgroup.

The participants in the LWI-foundation are the Ministry of Transport, Public works and Water Management *(Ministerie van Verkeer en Waterstaat)*, engineering consultancies, information technology companies, research institutes, universities and other companies.

Projects in the LWI-program

The project group estuaries and coasts focuses on the broad field of integrated water and coastal zone management. Because Decision Support Systems play a role in every part of water management and water policy, the research on these systems are considered of major importance. Research on the innovation of dredging methods, a 'wadden measuring system' using remote sensed data, the exploration of the morphological and ecological effects of navigation channel deepening in the Westerschelde are also parts of the program.

The managers of rivers are increasingly confronted with the need to consider the different interests when accommodating social and economic questions which relate to the various functions of the river. All these aspects demand integrated solutions with regard to 'The River System'. In this project the research is mainly focused on the establishment of a Decision Support System for river system management.

The third project group, mainports, mainly focuses on the port area of Rotterdam and its surrounding urban and industrial areas. In this zone there is a great discrepancy between space available and the space that is required. Research is performed to the development of new high quality tools in order to consider the effects of changes to the physical infrastructure in relation to the surrounding areas. These tools are to provide information to all parties involved and assist decisions making.

The objective of the Project Group Large Scale Line Infrastructures is to develop an integrated system for project development and for its control by the management divisions of large scale line infrastructure projects. Line infrastructures include roads, railways, canals and pipelines. The areas of research interest of the project group include all phases of line infrastructure projects. The intention of the project group is to illustrate the process for each phase, to indicate possible improvements and, where possible, to work out, introduce and evaluate these improvements. The analyses must converge to form a coherent set of know-how and tools which the project group terms 'common system'. The project group focuses on two pilot projects; Pilot HSL (High Speed Train Link) and Pilot Project Highway-15 (RW-15).

The product group of the LWI-program supports the four project groups. The task lies in standardisation, searching for the possibilities of generic product development and the use of recent innovative developments in the fields of GIS, DIS and internet.

LWI and Engineering Geology

Engineering geology is an interdisciplinary science that combines the fields of geology and civil engineering and is in contact with the fields of ecology, geography, mining, computer science, and management. The majority of the topics the engineering geologists addresses are practical problems of importance for the Dutch society and their economy and overseas engagement of Dutch industries.

An engineering geologist possesses a variety of skills. Mapping is the first stage of problem identification in any engineering project and one of the skills of an engineering geologist. Mapping establishes the basis of feasibility analyses and provides a tool to localise all kinds of features.

Today sophisticated tools such as remote sensing techniques and shallow geophysics are used in the field of mapping. The obtained information can be stored, processed, and analysed with 2D and 3D Geo-Information Systems (GIS), expert systems and geostatistical techniques which are also within the expertise of an engineering geologist. In the field of geomechanics the engineering geologists applies new computer techniques which are increasingly used in numerical modelling of the behaviour of ground- and groundwater for civil engineering projects. These skills and the expertise of environmental engineering, comprising the remediation of derelict contaminated sites, finalises the abilities of an engineering geologist.

Looking at the kind of projects and the objective of the LWI-program, one can conclude that the all the different skills of an engineering geologist can contribution to various parts of the projects of the LWI-program. A specific role of an engineering geologist within these projects can not be appointed. His or her role can range from acting as an expert in subjects like remote sensing, GIS or ground modelling to project management in general. The role of an engineering geologist is above all also an obvious one.

More information on the LWI-program can be obtained at the CUR/LWI secretariat (0182-540670) or from the LWI homepage on the Internet:
http://www.lwi.nl

References

LWI homepage
Engineering Geology homepage

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.

INVESTIGATING FAULT SLIP IN A MODEL OF AN UNDERGROUND GAS STORAGE FACILITY

To be published in the proceedings of the ISRM Symposium NY Rocks'97, June 29- July 2, 1997, New York.

In the Netherlands, gas storage facilities are being created in three gas fields. These gas fields, however, are located in areas where earthquakes with small magnitudes ($M_l \leq 3.2$) are frequently induced by hydrocarbon recovery. It is indicated in previous studies that compaction of a reservoir causes stresses to accumulate on faults, which may be released seismically. Although little is known about earthquakes associated with underground gas storage, it is anticipated that the stress changes occurring due to pore pressure fluctuations may result in small seismic events. The paper deals with an investigation of the relationship between pore pressure variations and fault movement when a gas reservoir is used for storing natural gas after partial depletion has taken place, which is carried out by numerically modelling a gas reservoir and simulating its depletion and subsequent cyclical loading. The approach taken is that of datalimited modelling, which emphasises increasing the understanding of the mechanisms rather than making absolute predictions. A generic model of a gas-filled reservoir is constructed, the input parameters of which are obtained from previous studies and from making reasonable assumptions. The tilted reservoir is divided by three normal faults and covered by a thick salt layer, while the stresses acting on the model are assumed to be induced by gravity only.

In order to assess the amount of fault movement, the two-dimensional finite difference program FLAC is used for modelling the reservoir. An additional iterative program is created for estimating pressure variations and for establishing well rates for real gas flow. A primary depletion phase is carried out which is followed by six consecutive storage cycles. Gas is injected during the summer for seven months and extracted in the winter for one month. The accompanying maximum pressure fluctuation and the maximum well rates are kept within the limits which are proposed for the storage fields. Maximum pore pressures are kept below the initial reservoir pressure.

The results from the numerical modelling of a gas reservoir are twofold:

- While the gas field is depleted, slip occurs on normal faults due to compaction of the reservoir.
- No significant additional amounts of slip are observed when the reservoir is subjected to alternating injection / extraction periods.

The scope of the paper is limited to investigating fault slip in or near the reservoir. The possibility of microseismic events occurring because of high well rates and local pressure differences in the reservoir cannot be excluded. The influence of time-dependent effects, like the relaxation of built-up stresses, has not been assessed in the model. Although the results are only applicable to a storage facility which is very similar to the model with respect to layout and tectonic setting, this investigation indicates that problems related to seismicity are expected to be limited, even when the storage facility is located in regions where induced events occur.

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CHARACTERIZATION OF THE GEOTECHNICAL PROPERTIES OF ROCK MATERIAL FOR CONSTRUCTION PURPOSES

To be published in the proceedings of the ISRM Symposium NY Rocks'97, June 29- July 2, 1997, New York.

The study on which the article is based was undertaken in a sandstone quarry found in Rieudotte, central part of Belgium. The main objectives were: to study the variations of the rock material properties in a quarry, to establish a link between the variations and the sampling intervals, and to assess the usefulness of geostatistical methods for quarry and other in situ sampling optimization with regard to the quarrying for construction materials and aggregates.

The field measurements were undertaken using an equotip hardness tester along a selected section of the quarry. Typical samples were also taken for laboratory analysis. Using the laboratory results, correlations between the equotip values and some rock material parameters such as the unconfined compressive strength, tangential modulus of elasticity, density, water absorption and accessible porosity were obtained. The variations in these correlated properties was then assessed using equotip measurements.

The equotip measurements were analyzed using different measures of spatial continuity. The variogram models to describe the spatial continuity and for estimation purposes were developed. The semivariograms revealed that the variation in the quarry is anisotropic with very high variability in the vertical as compared with the horizontal direction. Based on this analysis, the shale is found to be more variable than the sandstone. An estimation at an unsampled locations was performed using block kriging. Reliable estimates were obtained leading to the characterization of the site into different geotechnical units. The error associated with estimates was assessed and found to be within tolerable limits. The error analysis provided a good indication of the variability and sampling reliability. For future sampling in this quarry, optimum sampling intervals of 4.0 m by 0.3 m in the directions of maximum and minimum continuity respectively, were determined. Furthermore, a methodology for in situ sampling optimization has been proposed. This methodology makes it possible to drastically reduce the amount of sampling necessary in quarry exploration and exploitation. The proposed methodology is also applicable in other fields besides rock characterization for construction material purposes.

It is concluded that geostatistical methods are useful for quarry and other in situ sampling optimization. However, it is noted that the success of their applications rest on the deployment of a correct methodology in data acquisition, analysis and interpretation.

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INFLUENCE OF THE PASSAGE THROUGH ASPHALT INSTALLATIONS ON THE MIX PROPERTIES

To be published in the proceedings of the Int. RILEM symposium MTBM 97, Lyon, May 14-16, 1997.

During the production of asphalt mixes the constituents pass through the asphalt installation, exposing them to heat and mechanical loading. This can influence the properties of the constituents, and thereby the total asphalt mix. In this article we will discuss the possible influences. The focus is on the aggregates, as in practice differences in aggregate properties are far more important with respect to the overall quality of the asphalt mix than differences in bitumen properties. Therefore, a thourough knowledge and understanding of the properties of the aggregates is vital for a proper functional evaluation of asphalt concrete mixes.

Three different types of asphalt installations are involved in the research: one installation with a batch mixer with the heating flame in the drying drum directed towards the entrance of the aggregate, and two drum mixers, one with the heating flame directed towards the entrance and one with the flame towards the exit of the aggregates. Various aggregates that are presently used in asphalt mixes in the Netherlands have been investigated both before and after passage through the asphalt installations (without adding the bitumen). The research involved crushing tests and Micro Deval Abrasion tests, with an additional sieve analysis of the remains after each tests. Furthermore, a petrographic examination of the aggregates has been carried out.

after a discussion of the possible effects of heating, drying, and mechanical transport on the aggregates, it will be shown that passage through the installation generally results in a better performance of the aggregates in the performed tests. This is attributed to the fact that loading during passage causes the weakest aggregates and parts of aggregates to be damaged during their passage. This changes the aggregate strength and the size distribution of the particles during production.

he results of these investigations can be used to determine if a heat resistance standard is necessary and, if so, what such a standard should comprise. At present the CEN is considering such a standard.

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[2]Ministry of Transport and Public Works/Road and Hydraulic Engineering Division, P.O. Box 5044, 2600 GA Delft, The Netherlands.

FORECASTING OF ROCK TRENCHER PERFORMANCE USING A FUZZY LOGIC APPROACH

To be published in the proceedings of the ISRM Symposium NY Rocks'97, June 29- July 2, 1997, New York.

Prediction of the performance of rock excavation machines is often hampered by inaccurate knowledge and variability of the properties of the rock mass. To improve this situation, the performance of rock cutting trenchers was monitored. Data on the production and tool consumption was assembled and compared with the rock characteristics obtained from studying the trench geology and performing rock engineering tests on samples. The goal of the research was to find better methods to handle the rock data assembled, in order to come to more reliable predictions.

Performance of one type of trencher, the Vermeer T-850, was monitored on more than 16 sites. Machine advance rate, the rock excavation rate, the wear of the bits and breakage of bits was recorded. The trench dimensions and the excavated rock volume were established. The nature of the rock (mineralogy, grain size) and the engineering properties, such as rock strength (UCS, E modulus), the joint density and the block size were determined.

Examination of the data led to an improved understanding of the rock related factors involved in production and tool consumption in qualitative terms. Not enough data was available to perform reliable statistical correlation studies. Describing the rock mass characteristics using the RMR, Q-system or similar classification methods proved too crude. Therefore use was made of a Fuzzy Expert System to construct models that predict production and tool consumption. The uncertainty of the parameters used was defined by fuzzy membership functions and rule bases were made, based on numerical data, but also on expert opinion. Sets of rules for tool consumption (wear and breakage), bit wear only, and production rate are presented. The results are promising and the models are in the verification stage at present.

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News and announcements

GEO-ENGINEERING OF HAZARDOUS AND RADIOACTIVE WASTE DISPOSAL
3rd European engineering geology conference and 33rd engineering group annual conference.
Newcastle upon Tyne, England, September 10-14, 1997

Organised by the Geological Society Engineering group and the University of Newcastle upon Tyne.

Themes: Site selection and evaluation methodology for hazardous and radioactive waste disposal, site identification and selection, site preparation techniques and geo-engineering, site investigation methods and technology, case histories and lessons for the future, remedial methods and engineering, the role of geoscience in national waste disposal policy and planning, radioactive waste disposal research and development, geoscience research and investigation programmes, site investigation techniques and technology, radioactive waste disposal planning, policy and the earth sciences, site performance and safety case evaluation.

Correspondence: George M Reeves, EEG '97, Geological Society Engineering Group, Geotechnical Group, Drummond Building, Dept of Civil Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, England. tel: 0191 2227121 Fax: 0191 2226613.

7TH INTERNATIONAL CONFERENCE UNDERGROUND SPACE: INDOOR CITIES OF TOMORROW
Montreal, Canada, September 29 - October 3, 1997

Organised by the University of Montreal and the city of Montreal.

Themes: underground planning: challenges and issues, underground architecture, engineering and technological innovation, aspects of durability and viability, integration of the arts, archeological heritage, orientation and safety in enclosed environments, environmental dimensions, integration of surrounding context, tourist attractions, aspects of urban analysis, subsoil rights, economic potential of subsoil, segregation of transportation modes.

Correspondence: 7th International Conference Underground Space: Indoor Cities of Tomorrow, Organizing Committee, 303, Notre-Dame St. E., 5th floor, Montreal (Quebec), Canada H2Y 3Y8.

SARDINIA '97
6th International Landfill Symposium.
S. Margherita di Pula (Cagliari), Sardinia, Italy, October 13-17, 1997

Organised by the University of Cagliari, Technical University of Denmark, Technical University of Hamburg-Harburg, CISA - Environmental Sanitary Centre, Cagliari.

Themes: waste management and landfilling strategies, waste characterisation, waste pre-treatment, processes and emissions, design & construction, operational problems, special waste landfilling, administrative and financial aspects, environmental law and landfill regulations, aftercare, technology advances & developments, public concern, quality and risk assessment, economical aspects, old landfill, barrier performance, environmental impacts and monitoring, case studies, experiences and future perspective, education.

Correspondence: Ms. Anne Farmer, CISA - Environmental Sanitary Centre, Via Marengo 34, 09123 Cagliari, Italy. tel: +39 70 271652, fax: +39 70 271371, e-mail: cossur@vaxca3.unica.it

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4TH INTERNATIONAL CONFERENCE ON CASE HISTORIES IN THE GEOTECHNICAL ENGINEERING
St Louis, USA, March 09-12, 1998

Organised by the Univ. of Missouri-Rolla

Themes: case histories of foundations, case histories of slopes, dams, and embankments, case histories of the geotechnical earthquake engineering, case histories of retaining structures and deep excavations, case histories of the geological, rock, and mining engineering, including underground structures and excavations, case histories of a soil improvement, grouting, geosynthetics, dynamic compaction, vibroflotation, blasting, and other methods, including geo economics, case histories of the forensic engineering: "where things went wrong", case histories of new solutions to traditional geotechnical problems, case histories of the geotechnical and hydrological management and remediation of solid, hazardous, and low-level radioactive wastes, including liner cover systems, case histories of the non-destructive evaluation of drilled shafts, auger cast piles, and driven piles, geotechnical engineering in the 21st century.

Correspondence: Prof. Dr Shamsher Prakash, Conference Chairman, 308 Civil Engineering, Univ. of Missouri-Rolla, Rolla, MO 65409-0030, USA, 3414729(fax);
Email: prakash@novell.civil.umr.edu. Mr Buddy Poe, Conference Co-Ordinator, 103 ME Annex, Univ. of Missouri-Rolla, Rolla, MO 65409-1560, USA. TLP: 1-573-3416061 or 3414992(fax); EM: buddyp@shuttle.cc.umr.edu.

MJFR-3
3rd international conference on mechanics of jointed and faulted rock: 3D-Modelling, time dependence and complex interaction
Vienna, Austria, April 6-9, 1998

Organised by the Institute of Mechanics, Technical University Vienna

Themes: geology and structural geology, dynamics of jointed and faulted rock, physical modelling and testing, constitutive modelling, numerical modelling, seismicity and tectonics, instrumentation, hydraulics, applications.

Correspondence: Dr. H.P. Rossmanith, Institute of Mechanics, Technical University Vienna, Wiedner Hauptstr. 8-10/325, A-1040 Vienna, Austria, tel: 43-1-588015514, fax: 43-1-5875863.

NARMS '98
3rd N American Rock Mechanics Symposium
Cancun (Quintana Roo), Mexico, June 03-05, 1998

Organised by the SMMR.

Topics: rock mechanics testing, mechanical breakage of rocks, petroleum rock mechanics, research and development, under-ground excavation, application of geo-physical techniques, environmental geotechn-ology, state of stress, rock mechanics teaching, forensic and pathology in rock mechanics, dams and hydro projects, mine design, and ground control, storage and disposal, fracture and discontinuity, instrumen-tation, rheology, rock slope stability, numerical modelling, tunnelling, seepage and grouting, ground support, boring technology, rock blasting, foundations, case histories, block theory.

Correspondence: Sociedad Mexicana de Mecánica de Rocas, Camino a Santa Teresa No. 187, Col. Bosques del Pedregal, MEX-14020 México, D.F., MEXICO. phone: 52-5-5282089(also fax); EM: asg_smmr@intmex.com.

1ST INTERNATIONAL CONFERENCE ON SITE CHARACTERISATION
Atlanta GA USA, June, 1998

Topics: Planning, drilling, sampling, in-situ testing, and geophysical testing for the site characterisation.

Correspondence:Prof. P.K. Robertson, Dept of Civil Engineering, Univ. of Alberta, Alb., Canada. TLP: 1-403-4928198(fax). 1998

EUROCK '98
Trondheim Norway, August 1998,

Organized by the ISRM NG NORWAY and the Society of Petroleum Engineers (SPE).

Themes: Rock mechanics in the petroleum engineering. topics: rock properties and rock behaviour, rock stresses, rock mechanics and geophysics in the exploration, drilling and borehole stability, rock mechanics in the well technology, compressible reservoirs, compaction, and surface subsidence, disposal and environmental applications

Correspondence: Prof. Rune M. Holt, Dept of Petroleum Technology and Applied Geophysics, NTH, N-7034 Trondheim, NORWAY. TLP: 47-73-591187, 594982, 591102(fax), or 944472(fax); EM: rune.holt@iku.sintef.no.

8th International Congress of the IAEG
Vancouver BC, CANADA, September 1998

Organised by The Canadian Geotechnical Society/La Société Canadienne de Géotechnique.

Topics: New developments in site investigations, engineering geology and natural hazards, engineering geology and the environment, construction materials, case histories and new developments in surface workings, case histories and new developments in underground excavations , coastal and offshore engineering. The 1998 IAEG Executive Committee, Council, Commission, and General Assembly Meetings will be held in conjunction with this Congress. Abstracts: 01/11/1997; Papers: 15/03/1998.

Correspondence: Ms Kim Meidal, Secretariat, 8th Congress IAEG, c/o BC Hydro, 6911 Southpoint Drive, Burnaby, BC V3N 4X8, CANADA. Phone 604-5282421 or 5282558(fax); email: kim.meidal@bchydro.bc.ca.

IS-TOKYO 98
International Conference on Centrifuge 98

Themes: Development in the centrifuge modelling, equipment, and instrumentation; testing manuals; relations between the centrifuge modelling and numerical methods; centrifuge modelling for natural and man-made hazards reductions; application of the centrifuge modelling to practical problems. Abstracts: 30/06/1997; Papers: 30/11/1997.

Correspondence: Secretariat of Centrifuge 98, Dr Jiro Takemura, Dept of Civil Engineering, Tokyo Inst. of Technology, 2-12-1, O-Okayam, Meguro, J-152 Tokyo, JAPAN. TLP: 81-3-37290728(fax); EM: cen-98@cv.titech.ac.jp.

WORLD TUNNEL CONGRESS '98
Tunnels and Metropolises 24th ITA Annual Meeting
Sao Paulo, Brazil, April 25-30, 1998

Organised by the Brazilian tunnelling committee (CBT), the Brazilian society for soil mechanics (ABMS) and the international tunnelling association (ITA).

Themes: Planning and project management, design criteria, geotechnical and structural aspects, infiltration, maintenance and rehabilitation, mechanized tunnelling, urban constraints on underground works.

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The Netherlands Students Award for Engineering Geology

The Ingenieursgeologische Kring, the Netherlands National Group of the International Association of Engineering Geology (IAEG) has established a prize for the best ir., drs. or MSc thesis in the field of Engineering Geology submitted to a Netherlands institute of higher education. The prize consists of a sum of NLG 1,000 and a certificate, to be handed out at the annual meeting of the Ingeokring in the spring of 1998. The thesis must be a contribution to the application of earth scientific knowledge to the solution of problems in civil engineering, mining engineering or environmental engineering.

We invite the submission of theses produced in the academic year September 1996 - August 1997

Individuals can send in their own thesis or the thesis of others. Membership of the Ingenieursgeologische Kring is not required. Three complete copies of the thesis (including figures, photographs, annexes) have to be submitted by December 15, 1997 to the secretary of the Ingeokring. The committee which will select the best thesis is composed as follows:

* Drs. H.R.G.K. Hack (chairman Ingeokring)
* Prof. Dr. D.D. Genske (TU Delft, chair Engineering Geology)
* Dr. J. Rupke (University of Amsterdam, Dept. of Physical Geography)
* Ir. A.H. Nooy van der Kolff (Boskalis Westminster BV)
* Ir. C.M. Breukink (IWACO)

Criteria used for the selection will be:

* Relevance for earth sciences and engineering
* Scientific quality
* Originality of approach
* Quality of presentation

The Award is sponsored by:

* Ingenieursgeologische Kring
* Boskalis Westminster BV
* Fugro Engineers BV
* Ballast Nedam Engineers BV
* IWACO
* Rijks Geologische Dienst
* Geocom Consultants

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.