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Reliability Theory and Safety in German Geotechnical Design

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ABSTRACT: In Germany the reliability theory using a probabilistic approach in geotechnical design was officially introduced as the basic concept for geotechnical design at the German National Geotechnical Conference in 1978 as it had also been adopted as the common safety concept for the future Eurocodes. In the following years numerous research studies were published on the application of the reliability theory in the various geotechnical verifications. In the end, however, it was only the selection of characteristic values of ground properties where the application of the reliability theory was implemented in Eurocode 7 "Geotechnical design - Part 1: General rules" and the German geotechnical design standards. The paper describes the history of the discussion in the German geotechnical community and the results of those discussions.

Keywords: reliability, safety, safety factors, geotechnical design, standards

1 INTRODUCTION

At the first international symposia on geotechnical safety and risk, which were held in Shanghai in 2007 and in Gifu, Japan, in 2009, colleagues from Asia mainly reported on their scientific studies on Reliability Based Design (RBD) and its application in practice. By contrast, a large number of European papers focused on presenting the Eurocodes for structural design, in particular Eurocode 7 "Geotechnical design", in which the probabilistic approach now only plays a subordinate role. When work on writing the Eurocodes began in the 1970s, the probabilistic approach was still one of the basic components of the safety philosophy of the Model Codes. So why had its application disappeared almost entirely from European design standards? This issue needed to be clarified before we could enter into productive scientific discussions with the proponents of RBD on the usefulness of a probabilistic approach in geotechnical design standards.

The review presented in this paper is limited to the debate in Germany although several Swiss and Austrian publications are also considered. It describes the discussions that took place up until 2010 and may therefore reflect an intermediate stage and the problems of yesteryear. Perhaps the 3rd International Symposium on Geotechnical Safety and Risk will provide new ideas that can contribute to advancing standardization in Germany and Europe.

2 THE HISTORY

2.1 *The German National Geotechnical Conference of 1978*

The traditional safety factor concept has the serious disadvantage that the actual variability of the soil strength is not directly taken into account, and consequently a particular conventional safety factor does not necessarily have the same meaning for all soils. Comparison of different designs with different soil types, or even different designs with the same soil type, is not easy. A probabilistic approach instead of the traditional global concept is therefore a fascinating vision for geotechnical engineers as it not only provides a rational basis for the quantification of geotechnical safety but also a meaningful and consistent basis for comparison (Lumb, 1970). By defining a probability of failure, direct comparison is possible while global safety factors are related to every single verification format that cannot be compared with each other.

The reliability theory had been adopted as the common safety concept for the future Eurocodes (Joint Committee on Structural Safety, 1976). As a consequence, a special committee was established in Germany which lay down the principles for the application of the reliability theory in future structural standards (Arbeitsausschuß "Sicherheit im Bauwesen" ("Safety in Structural Design" committee), 1981). For geotechnical design, the reliability theory using a probabilistic approach was officially introduced at the German National Geotechnical Conference in 1978. The concept was presented by G. Breitschaft (Breitschaft and Hanisch, 1978) who was president of the DIBt (Deutsches Institut für Bautechnik, an institute of the German Federal and *Laender* Governments for a uniform fulfilment of technical tasks in the field of public law) and later became chairman of the technical committee of CEN in charge of the structural Eurocodes (TC 250). The lecture intended to promote the ideas among German geotechnical engineers and to lay the basis for future standardization work in Europe and Germany.

Standards writers were fascinated by the reliability theory as it was a practice-related safety theory that promised to enable them

- to state the actions in a uniform way that was independent of the type of construction and construction materials and
- to specify the resistances of structures and members in a rational manner,
- thus permitting the introduction of a consistent safety level for different types of construction.

The application of the reliability theory is based on knowledge of the statistical data of those parameters that have a significant effect on safety (in geotechnical engineering, the shear parameters φ' and c' and the loads), i.e. the mean values, standard deviations and type of distribution as well as any distribution limits. The statistical distributions of the parameters are analysed by means of the statistical methods of the reliability theory in order to obtain a measure of the reliability of a structure. The result is based exclusively on verified technical data, is therefore rational and free from any subjective and qualitative experience. It is not intended to present the theoretical basis of the safety concept here but rather to draw attention to well-known papers and publications. For probability based design, the approximate method of Hasofer and Lind (1974), usually known as the "first order reliability method" (FORM), was favoured.

It does not need to be emphasized that the concept was expected to deliver new ideas for ways to optimize construction both technically and economically. Owing to these promising advantages, the probabilistic safety concept was welcomed, not only by those involved in developing European and German standards for structural engineering but also by well-known experts in the field (Joint Committee on Structural Safety, 1976, Arbeitsausschuß "Sicherheit im Bauwesen", 1981).

2.2 *The German National Geotechnical Conference of 1982*

In the following years numerous research studies on the application of the reliability theory were conducted and published for the various geotechnical verifications (e.g. Rackwitz, R. and Peintinger, B., 1981). Moreover, a revised guidance paper was drawn up by the "Safety in Structural Design" committee of DIN (NABau Arbeitsausschuß "Sicherheit im Bauwesen", 1981) which was intended to serve as a mandatory basis for all future structural design standards.

However, the subject of the probabilistic safety concept was not brought up again until a special session held during the National Geotechnical Conference in 1982. Pottharst (1982) presented his findings for the verification of the bearing capacity of shallow foundations. He evaluated a number of test results obtained with sand and demonstrated that the distribution of the single values of φ' could best be approximated by means of a logarithmic normal distribution with its lower boundary at 20°. In his model calculation, Pottharst also took into consideration that the standard deviation of the mean value of the angle of shearing resistance on the potential failure surface is lower than that of the single values obtained in the tests. He showed that it is possible to perform a verification of the bearing capacity of soil with partial safety factors derived on the basis of the statistical safety concept and to achieve a relatively consistent safety level. By contrast, verifications performed in accordance with DIN 4017, in which a global safety factor, η_p, of 2.0 is only applied to the loads, yield safety levels that are inconsistent and, above all, are also lower. In spite of this positive result for the probabilistic approach, Pottharst stressed the limitations of the method which he considered primarily to be the insufficient proof of the distribution of the distribution densities of very low and very high values and the fact that errors in planning and execution cannot be taken into account. Gässler (1982) applied the safety concept to anchored walls and nailed walls and arrived at a similar conclusion. He stressed that the new type of design did not involve more work for designers but that, on the other contrary, the use of diagrams and equations would simplify their work instead. Three other papers dealt with the problem of how to evaluate test results with regard to their spread and their correlations (Peintinger, 1982; von Soos, 1982) and how prior knowledge can be used (Rackwitz, 1982).

The most interesting part of the special session was a panel discussion. Most of the arguments for and against the probabilistic safety concept, which have been repeated over and over again in discussions since then, were put forward there. They were as follows:

- The probabilistic approach does not take account of human error in design and execution although it is the main cause of damage (Blaut, 1982).
- The possibilities of collecting statistical data on soil are severely limited in practice (Vollenweider, 1982).
- The differences between geotechnical engineering and other areas of structural engineering are not only the higher coefficients of variation in the former – soil cannot be produced with clearly defined characteristics according to a set formula – but also that the geotechnical engineer only ever sees a limited part of the structure he is designing (Vollenweider, 1982).
- Damage is usually due to risks which are connected with the soil but which go undetected (Smoltczyk, 1982).
- Distributions of geotechnical basic variables that have no upper or lower limit are unsuitable as it is not possible to measure very high and very low values, nor are such values considered likely to occur for mechanical reasons (Kramer, 1982).
- Soil excavations and tests of the mechanical properties of soil never provide enough data to enable a probability calculation to be performed (Lackner, 1982).

All in all, the most prominent German geotechnical engineers took rather a critical view of the probabilistic approach (in favour: 3; undecided: 5, against: 4). However, it was generally agreed that greater effort was required during soil investigations, there was a definite need for databases for information on soil to be set up and that more extensive checks and inspections of geotechnical engineering work were necessary.

2.3 *Research and discussions in the following years*

In the following years the probabilistic approach was a research topic at nearly all university geotechnical engineering departments in Germany and nearly all analyses in geotechnical design were examined to establish whether they were suited to application of the probabilistic approach. Eder recalculated the failure of a rock slope (Eder, 1983), Heibaum examined the stability of anchored retaining walls at deep slip surfaces (Heibaum, 1987), Genske and Walz (Genske and Walz, 1987) as well as Smoltczyk and Schad (Smoltczyk and Schad, 1990) considered the application of the probabilistic safety philosophy to calculations of the bearing capacity of soil, Reitmeier researched the possibility of applying a stochastic approach to quantifying differential settlements (Reitmeier, 1989) while Hanisch and Struck applied the method to evaluate pile loading tests (Hanisch and Struck, 1992).

In addition, there were a number of publications dealing with the evaluation of soil investigations in terms of how the results could be used in connection with the probabilistic approach (Hanisch and Struck, 1985, Soos, 1990, and Alber, 1992) as well as papers in which the new concept was clearly set out and explained to colleagues in the field with the intention of promoting it (Gudehus, 1987 and Franke, 1990).

Even though the future direction of standardization work in geotechnical engineering seemed to have been firmly established by a decision of the steering committee of the national committees in charge of drafting geotechnical engineering standards in 1982, the “Principles for the specification of safety requirements for structures” (Arbeitsausschuß “ Sicherheit im Bauwesen”, 1981) were repeatedly the subject of fundamental criticisms in the years that followed. Thus Franke (Franke, 1984) demonstrated the problems that occur when the probabilistic safety concept is applied to piles, commenting scathingly that the possibility (of applying the probabilistic approach) was viewed most optimistically by those colleagues who were least involved in conducting soil and rock investigations and describing soil and rock on a daily basis in practice. He went on to say that, in his view, the observation method was a far superior aid even though it is not mentioned in the “Principles for the specification of safety requirements for structures”.

Furthermore, it was also shown that, for a constant safety level, the partial factors depend on the magnitude and number of parameters involved and in particular on the coefficient of variation (Heibaum, 1987). However, it is seldom possible to obtain more than only a rough estimate of the coefficient of variation of geotechnical parameters.

Fundamental criticism of the new safety concept was voiced above all by Swiss colleagues. After analysing 800 cases of structural damage that had been described by means of the same criteria and evaluated in different ways, Matousek and Schneider concluded that random deviations of the material properties, the resistances of structures or the loads on structures from the expected values are evidently well covered by the conventional safety concept and by specifying the appropriate safety factors in the structural calculations. The vast majority of cases of damage occur during execution. Matousek and Schneider went on to state that while every care is taken to consider the use of structures at the design stage the construction conditions are often viewed as of secondary importance although they require greater attention (Matousek and Schneider, 1976). Schneider considered the probability of serious errors generally to be far greater (ten- to a hundredfold) than the theoretical probabilities of failure (Schneider, 1994). Vollenweider expressed similar doubts about the safety goal of a very low probability of failure for which only values with a low probability of occurrence are relevant. He questioned whether the statistical data for this range of values, if available at all, was sound and whether the correct distribution laws were applied. Vollenweider spoke out in favour of applying the hazard scenario approach instead to enable the risk potential to be managed more reliably (Vollenweider, 1983 and 1988).

Summing up the scientific studies and the attendant debate up until around 1990 it can be seen that the probabilistic approach in geotechnical engineering yielded a great number of interesting scientific research results and findings in Germany but that it was not yet possible to develop a convincing standardization concept for application in everyday practice. Although the partial safety concept had won through, the probabilistic approach no longer had any part to play during discussions between standards writers on the issue of which parameters partial safety factors should be applied to and what the values of those factors should be. There were only a few isolated voices who continued to advocate taking the probabilistic approach into account in geotechnical engineering standards (Hanisch, 1998).

Although the probabilistic approach was finally abandoned in German geotechnical design standards the subject continued to be attractive in scientific research. Thus Hartmann and Nawari attempted to discover new ways of evaluating uncertainty and risk with the aid of fuzzy logic and the fuzzy set theory (Hartmann and Nawari, 1996), Pöttler et. al. examined the application of the probabilistic approach to tunnel construction (Pöttler et. al., 2001), Ziegler considered the possibilities of risk simulation calculations (Ziegler, 2002), Katzenbach and Moormann used the data collected for Frankfurt clay over many decades to examine the structural performance of piled raft foundations (Katzenbach and Moormann, 2003), Stahlmann et. al. employed probabilistic methods to simulate the inhomogeneities in the soil properties of a railway embankment (Stahlmann et. al., 2007) and Russelli compared various probabilistic methods as applied to investigations of the bearing capacity of soil, demonstrating the great influence of the combination of friction and cohesion (Russelli, 2008). So far, none of these studies has been taken into account in standards or recommendations.

2.4 *Eurocode 7*

Work on the Model Code for Eurocode 7 "Geotechnical design" started in 1981 and was headed by Krebs Ovesen (Orr, 2007) who chaired the committee in charge of the work for 18 years. One of the fundamental ideas was that the Eurocode should only contain qualifying rules, in other words, should require the bearing capacity to be verified but would not specify which method of calculation should be used. Naturally, this improved the likelihood of reaching a consensus on the rules. There were intense discussions on the applicability of the statistical safety concept in the European committee as the original enthusiasm for the probabilistic approach had vanished. It was agreed that, should the probabilistic safety concept be introduced in geotechnical engineering, a great number of difficulties would still need to be overcome and that the partial factors would initially have to be based on experience but would have to be confirmed by probabilistic analyses at a later date (Sadgorski, 1983). The drafts of the Eurocode differentiated between the core text and supplementary comments. Initially there was no intention of specifying numerical values for either the loads or the partial factors in the core text of the Eurocode (Sadgorski, 1983); the values were to be set in National Annexes instead.

In 1987 the "Draft Model for Eurocode 7 – Common unified rules for Geotechnics, Design" was published (Representatives of the Geotechnical Societies within the European Countries, 1987) as a report prepared for the European Communities. The annex of the draft model specified partial factors after all. Reference was made to the relevant loading codes for structures above ground level for variable actions while a partial factor, γ_g, of 1.0 was specified for permanent actions from the structure, ground and groundwater. The following partial factors were given for geotechnical parameters: $\gamma_\varphi = 1.2$ on the tangent of angle of internal friction, $\gamma_{c1} = 1.8$ on the cohesion when verifying the load-bearing capacity of foundations and γ_{c2} on the cohesion when verifying the stability and earth pressure. Moreover, partial factors were stated for the load bearing resistance of piles and anchors and for structures under construction.

In 1989 “Eurocode 7 Geotechnics” was published as a Preliminary Draft for the European Communities on the basis of the December 1987 version of the Model Code produced by the ISSMFE (EC 7 Drafting Panel, 1989). A chapter 7 for piles and a chapter 8 for retaining structures had not yet been prepared. This version now gave numerical values for partial factors in the core text and it was emphasized in the preface that “they represented the best estimate of the drafting panel. In geotechnical engineering limited experience has been gained until now on a European basis on the use of limit state design and partial safety factors. Consequently there is a strong need for calibration of all safety elements introduced into the draft before it is issued for use”. In Chapter 2 “Basis of Design” it was stated as a fundamental requirement that: “(1) A structure shall be designed and constructed in such a way that: - with acceptable probability, it will remain fit for the use …., and – with appropriate degrees of reliability, it will sustain all actions ....”. However, neither principles nor application rules were given for the derivation of partial factors on actions and ground parameters by means of reliability theory.

A first complete version of Eurocode 7 was published in 1994 as prestandard ENV 1997-1:1994 “Geotechnical design - Part 1 General rules”. For the verification of ultimate limit states in the ground two combinations of partial factors had to be investigated: Case B and Case C. Case B aimed to provide safe design against unfavourable deviations of the actions from their characteristic values. Thus, in Case B, partial factors greater than 1.0 were applied to the permanent and variable actions from the structure and the ground, the factors being the same as those used in other fields of structural engineering. By contrast, the calculations of the ground resistance were performed with characteristic values, i.e. the partial factors for the shear parameters, γ_φ, γ_c and γ_{cu}, were all set at 1.00. Case C in the prestandard aimed to provide safe design against unfavourable deviations of the ground strength properties from their characteristic values and against uncertainties in the calculation model. It was assumed that the permanent actions corresponded to their expected values and the variable actions deviated only slightly from their characteristic values. Thus, the partial factors for the characteristic values of the ground strength parameters were $\gamma_\varphi= \gamma_c= \gamma_{cu}= 1.25$ while the characteristic values of the permanent actions from the structure (with γ_G set at 1.00) were used in the verification.

This concept for the verification of two cases, A and B, was strongly opposed in Germany. The philosophy for Cases B and C was not convincing because it could not guarantee a sufficient safety level for the combination or superposition of the uncertainties of the material properties (soil and other material) and the actions. Furthermore, there were strong objections to the mandatory application of partial factors to the ground strength properties φ', c' and c_u in order to determine the design values of the resistances of the soil. Although this corresponded to German practice for the verification of slope stability, in which the Fellenius method was applied, it was not the case for the verification of the design of shallow foundations and retaining walls. The application of partial factors to the ground strength properties would have resulted in some cases in larger dimensions and in others in smaller dimensions than would have been obtained if the former global safety concept had been applied (Weißenbach, 1991). Moreover, with factored shear strength parameters, the relevant verification would be based on non-reliable failure geometries in the ground. A more detailed critical review and a proposal for an improvement of the prestandard of EC 7 can be found in Schuppener et. al. (1998) and Weißenbach (1998).

These fundamental criticisms were shared by many other European countries. As a compromise, the final version of EC 7 of 2004 (CEN 2004) gives three design approaches (DA) as options. Each Member States has to establish in its National Annex to EC 7 which of the three DA is mandatory for which limit state verification. Among these three approaches, only DA2 without factored shear strength parameters of the ground avoids the above-mentioned drawbacks.

2.5 *DIN 1054 “Safety in Earthworks and Foundation Engineering”*

The steering committee of the national committees in charge of drafting geotechnical engineering standards decided in 1982 to gradually incorporate the new safety concept into the standards for that field (Gudehus, 1987). It was even decided to prepare a Guidance Paper on Reliability in Geotechnical Design. A new standardizing committee “Safety in Earthworks and Foundation Engineering” was established. Its aim was to act as a mirror committee for the European subcommittee drafting Eurocode 7 “Geotechnical Design” (EC 7) and revise the German standard DIN 1054 with the new title “Safety in Earthworks and Foundation Engineering” to make it compatible with the principles and application rules of the future Eurocode 7.

The first draft of the revised DIN 1054 “Safety in Earthworks and Foundation Engineering” (Deutsche Gesellschaft für Erd- und Grundbau, 1990) was circulated as a draft for discussion at the German National Geotechnical Conference. It was stated in the foreword that: “In spite of a great deal of research work it has not been possible to find an indisputable scientific basis for specifying even a few of the partial factors. Although adapting the specifications to take account of tried-and-tested methods of verifying safety was seen as a way around the problem, it constituted a deviation from the aim of the ‘Principles for the establishment of safety requirements for structures’”. As in the 1989 version of the Eurocode, the design values of the actions and resistances of the soil were determined by applying partial factors to the geotechnical parameters, i.e. $\gamma_\varphi = \gamma_\delta = 1.20$ for friction and wall friction and $\gamma_c = 1.70$ for cohesion. Depending on the load case and application, the factors had to be increased or reduced by γ^μ, with $0,5 \geq \mu \leq 1,4$.

Weißenbach demonstrated in his study (Weißenbach, 1991) that, for retaining walls, there are numerous cases in which greater dimensions are required given the above conditions but that there are also instances in which smaller dimensions are obtained than with the former global safety concept. The reason for this is that it is not possible to maintain a constant safety level if a partial factor is applied to the coefficient of friction, tan φ. For example, there is a lower reduction in the coefficient of active earth pressure for small angles of shearing resistance than for large ones. Moreover, the introduction of a partial factor, γ_φ , on the angle of shearing resistance means that the failure pattern geometry is no longer realistic so that loads that were previously outside the soil mass under consideration are now inside it, with the result that different loads are determined than previously. In addition, it is not possible to determine an earth pressure load for slopes inclined at angles between $\beta = \varphi'_d$ and $\beta = \varphi'_k$. In order to eliminate such inconsistencies, Weißenbach proposed determining the characteristic actions and resistances from the characteristic values of the soil parameters first and then applying the partial factors to the resultant values. The values of the partial factors would then have to be specified in such a way that the former safety level was maintained. A further advantage of this method was that it enabled not only the ultimate limit state but also the serviceability limit state to be verified using the characteristic values (Weißenbach’s concept).

The following version of DIN 1054-100 (1996) thus included partial factors on the characteristic forces for both the actions and resistances of the soil in analyses of the stability of retaining walls, shallow foundations, piles and anchors (Load and Resistance Factor Approach). Partial factors were only applied to the shear strength of the soil in the analysis of the stability of slopes (Material Factor Approach).

The idea behind revising DIN 1054 at the same time as Eurocode 7 was being drafted was to familiarize German geotechnical engineers with the new design concepts as early as possible and to enable them to make technically sound contributions to the discussions held during the process of writing the Eurocode. In doing so, it was quite clear that it would no longer be possible for Eurocode 7 and DIN 1054 to apply side-by-side in future. The current version of DIN 1054 (2010) therefore only contains specifically German rules, which are not given in Eurocode 7 (CEN, 2004). The title of the DIN standard has been amended accordingly to “Subsoil – Verification of safety of earthworks and foundations – Supplementary rules to DIN EN 1997-1”.

3 CONCLUSIONS

3.1 *Reliability theory*

The objectives of the new probabilistic safety concept covering all areas of structural design in Europe were essentially as explained below:

1. The concept aimed primarily at achieving a consistent probability of failure for all structural members by means of a probabilistic safety concept in which designs are based on a known stochastic distribution of the magnitudes of the actions and the mechanical properties of construction materials. It was clear from the outset that a comprehensive “level II” probabilistic verification would only be feasible in exceptional cases, on account of the great deal of time and effort required, and in fundamental design analyses. Therefore, for the day-to-day work of structural engineers, it was planned to use “level I” design methods employing partial safety factors with values derived from comprehensive probabilistic analyses of each limit state.

2. For the application of the concept in practice and its implementation in European design standards it was also desirable for the same numerical values of the partial factors on the actions to be used in all fields of structural design. It was intended for the partial factors for the resistances of the various materials to be derived from the stochastic distribution of the mechanical properties.

3. Moreover, designs based on the new safety concept should only be permitted to result in greater dimensions than those achieved with the global safety concept of previous standards in well-founded exceptional cases. Any appreciable reduction in the safety level compared with the previous one would have met with objections by the building inspectorates.

The discussion very soon revealed that it would not be possible for all three of those demands to be incorporated into a geotechnical design concept suitable for inclusion in standards. The greatest problems lay in the consistent implementation of the probabilistic approach. The studies and discussions conducted by the standards committees over the years showed that the data required for a sufficiently reliable statistical description of the soil parameters in practice was only available in exceptional cases and that, even then, it was not always possible to achieve a sufficiently consistent safety level for the ground strength properties. The probabilistic approach was therefore no longer taken as a basis for specifying partial factors for geotechnical engineering in national and European standardization work. The original probabilistic approach has only been retained in EC 7 for the purpose of specifying the characteristic values of the ground properties (CEN, 2004) and as informative Annex C in "Eurocode - Basis of structural design" (CEN, 2002). The probabilistic approach may have been a psychological aid and provided the initial spark for the work of harmonizing the numerous national concepts during the drafting of the European construction standards but it became clear during the discussions that it was not a suitable means of describing the safety and reliability of structures in standards. In ISO 2394 (1998) "General principles on reliability for structures", however, the principles of probability-based design are still covered in the core text and in an informative annex.

3.2 *Partial factors*

Germany has a tradition of standards for geotechnical engineering that dates back more than 70 years. The first edition of DIN 1054, entitled *Guidelines for the permissible loads on ground in building construction,* was published in 1934. Since then, geotechnical standards have continuously been optimized and have reached an outstanding quality. The safety level of the former global safety concept proved successful and the specified safety factors made safe and economic geotechnical designs possible. The Advisory Board of the Standards Committee for Building and Civil Engineering of the German Standards Institute, DIN, therefore decided in 1998 that any increase in cost as a result of new standards had to be justified. As the existing standards were well tried and tested, it was decided that the safety level of the former global safety concept should be maintained when the geotechnical standards were adapted to accommodate the partial safety factor concept of the Eurocodes. This meant that the design approaches and the partial factors had to be selected in such a way that a foundation designed according to EC 7 would have roughly the same dimensions as a design in accordance with the previous standards. This was a prerequisite as serious problems regarding the acceptability of the Eurocodes would otherwise have arisen. For example, a structure undergoing modification might need strengthening or even underpinning according to the new safety concept, although this may not have been necessary under the previous one. As reliability theory was not considered to provide partial factors for ground resistance and ground properties, maintaining the safety level of the former global safety concept was also a necessary assumption for the determination of the partial factors for geotechnical actions and resistances. In order to maintain that safety level in the concept of partial factors the equation $\gamma_R \cdot \gamma_{G/Q} \approx \eta_{global}$ must be fulfilled, where γ_R is the partial factor for the resistance of the ground, $\gamma_{G/Q}$ is a weighted mean partial factor for the effects of permanent and variable actions and η_{global} is the global safety factor used hitherto. The values recommended in Annex A of "Eurocode - Basis of structural design" (CEN, 2002), which are $\gamma_G = 1.35$ and $\gamma_Q = 1.50$ for the permanent and variable effects of actions respectively, were adopted in EC 7 and in German geotechnical design standards as they had been in the other fields of structural engineering. As the permanent actions are generally greater than the variable actions in geotechnical engineering, a weighted mean value, $\gamma_{G/Q}$, of 1.40 was used to calculate the partial factor for the ground resistance, γ_R, for the various verifications. Thus the following partial factor, γ_R, for the resistance is obtained from $\gamma_R \approx \eta_{global} / \gamma_{G/Q}$. For the ground bearing resistance, where a global safety factor η_{global}, of 2.00, was used in Germany we then arrive at a partial factor of $\gamma_{R,v} = 2.00/1.40 \approx 1.40$. The partial factors for the ground resistance in each limit state were determined in this way.

The numerical values of the partial factors for actions have been specified by structural engineers and it is therefore certainly debatable whether they provide a realistic description of the uncertainties in geotechnical engineering. Yet SC 7 and the national German standards committee for geotechnical engineering considered it more important for common partial factors to be used in all fields of civil engineering in future than for specific partial factors to be laid down for geotechnical design, especially as selecting the values would also have given rise to endless discussions.

However, several problems arose in geotechnical engineering. As is generally known, the global safety factors for geotechnical engineering differ from those used in the design of concrete, masonry and steel structures, some of the factors being lower (safety against sliding and overall slope stability) while others are higher (bearing capacity of the soil). If the partial factors for unfavourable permanent actions, γ_G = 1.35, and variable actions, γ_Q = 1.50, which were originally set for the design of concrete, masonry and steel structures, are applied to verifications of the safety against sliding, for which high variable horizontal loads frequently need to be analysed, most of the safety on the loads is already utilized if the mean partial factor γ_{G+Q} is greater than 1.40. A partial factor on the resistances, e.g. on the shear parameters, would result in greater dimensions for foundations than previously when the design was performed with a global safety factor, η, of 1.50. For the verification of the safety against sliding, a partial factor, γ_{Sl}, of 1.10 has therefore been applied to the resistances (base friction and the passive earth pressure in front of foundations, as appropriate) instead of the shear parameters and it has been taken into account that greater dimensions will be required for foundations than in the past if high levels of variable actions are expected to occur.

The verification of overall slope stability, for which a global safety, η, of 1.40 used to be required, is even more difficult. If, in this case, the partial factor γ_Q = 1.50 were applied to variable actions and γ_G = 1.50 to the loads from the self-weight of the ground, a partial factor, γ, greater than 1.0 on the shear parameters or the resistances of the ground would result in a considerably less economic design than was previously the case. It is for this reason that the partial factors γ_G = 1.0 for the permanent actions, γ_Q = 1.30 for the variable actions and, for the resistances, $\gamma_\varphi = \gamma_c = \gamma_{cu}$=1.25 for the shear parameters were recommended for the verification of overall slope stability in Eurocode 7.

3.3 *Critical remarks on the safety concept of the Eurocodes and Eurocode 7*

The introduction of the partial safety concept provided a common format for analyses in structural design for different types of construction and construction materials. However, a common safety level, in terms of a common probability of failure, has not been achieved, even if very similar partial factors have been introduced for the actions in all areas of structural design. As explained above, these partial factors have also been adopted in geotechnical engineering, with no attempt being made to develop separate partial factors for geotechnical actions. Thus they are not – as was originally planned – a measure of the reliability with which the magnitude of geotechnical actions can be determined. The same applies to the partial factors for the resistances as they were derived on the basis of the condition that approximately the same dimensions for foundations should be obtained for designs in accordance with the partial safety concept as for those performed with the former global safety concept. Thus, in actual fact, the partial safety concept is also a global safety concept. The incorporation of the new concept into all German geotechnical engineering standards and recommendations has meant that these have been harmonized and thus become more user-friendly. Any technical progress was only an indirect consequence owing to the fact that the German standards and recommendations were, of course, brought up to date and improved as they were being revised to include the partial safety concept.

Eurocodes do not take account of human error, nor are such errors mentioned in the definitions of the partial factors. Instead, all Eurocodes have a list of assumptions which define and make sure that everything is planned, executed, supervised and maintained according to the plans by personnel having the appropriate skill and experience. Although human error was never explicitly referred to in the standards based on the global safety concept it was implicitly assumed that it was covered, at least to a certain extent, by the safety factors. The objective was always to achieve a robust yet economic design that would not fail just because of a few minor errors. The adoption of the safety level of the previous standards has thus meant that “minor” human errors are now included in the partial factors.

4 SUMMARY AND OUTLOOK

The attempt to introduce a probabilistic approach into geotechnical design standards has failed as, in practice, the data required for a sufficiently reliable statistical description of the ground strength properties is only available in certain exceptional cases and, even then, the design calculations required are so time-consuming that they are not (yet) suitable for inclusion in standards. The approach has therefore only been retained for the specification of the characteristic values of the ground strength properties in

EC 7 and as the informative Annex C “Basis for partial factor design and reliability analyses” in “Eurocode - Basis of structural design”. The introduction of the ψ-factors to take account of variable actions that occur simultaneously can also be viewed as a pragmatic application of the probabilistic approach.

Reliability Based Design lacks a way of taking account of human error. The Eurocodes do not take account of human error either. However, the latter is covered, at least to a certain extent, by calibrating the partial factors to comply with the level of the former tried-and-tested global safety concept.

There is general agreement amongst experts that human error presents the greatest risk in building and civil engineering as a whole and that reducing it would be the most effective way of improving safety in this field. The authors therefore believe that, in future, the incorporation of the hazard scenario approach (Vollenweider, 1983, SIA 260:2003 and SIA 267:2003) or risk simulation calculations (Ziegler, 2002) into geotechnical engineering standards would be more appropriate, especially as the theories behind them are closer to engineering practice. However, in this context, the supervision of the execution of structures by building inspectorates or test engineers is particularly important. Unfortunately, the opposite path has been taken by the political powers that be and evidence of its adverse effects can already be seen.

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